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PBRG Sub-project Completion Report on
Improvement of Soil Health and Crop Productivity of
Major Problem Soils of Bangladesh Through Organic Amendments

Sub-Project ID: 135

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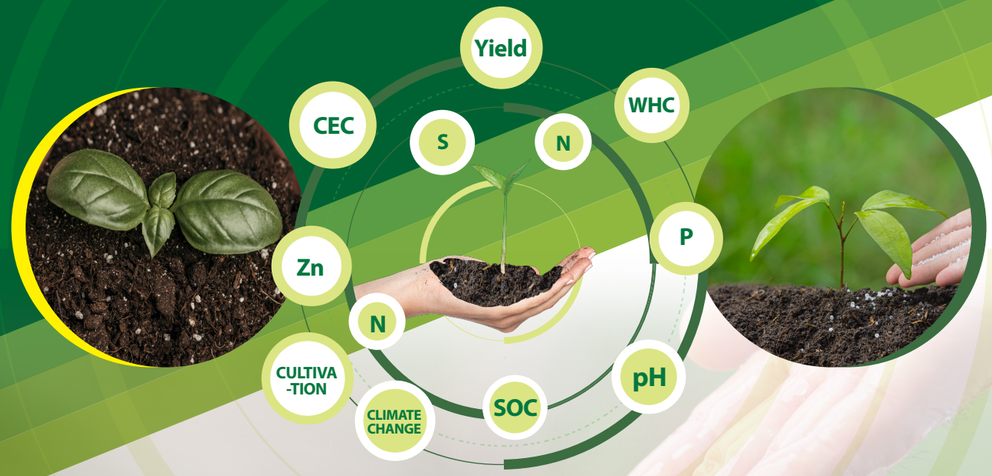
PROGRAM BASED RESEARCH GRANT (PBRG)

Sub-project Completion Report

on

IMPROVEMENT OF SOIL HEALTH AND CROP PRODUCTIVITY OF MAJOR PROBLEM SOILS OF BANGLADESH THROUGH ORGANIC AMENDMENTS



Sub-project Duration

March 2018 to February 2022

Coordinating Organization

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Bangladesh Agricultural Research Council

Project Implementation Unit

National Agricultural Technology Program-Phase II Project

Bangladesh Agricultural Research Council

Farmgate, Dhaka-1215

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IMPLEMENTING ORGANIZATION

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Soil Science Division
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Soil Science Division
Bangladesh Institute of Nuclear Agriculture (BINA)

Soil Science Division
Bangladesh Agricultural University (BAU)

Soil Science Division
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Abbreviation and Acronyms

Sl. No.	Abbreviation and Acronyms	Full meaning
1.	%	Percentage
2.	AEZ	Agro-Ecological Zone
3.	AIS	Agriculture Information Service
4.	ANOVA	Analysis of Variance
5.	AFS	Ammonium Ferrous Sulphate
6.	AC	Active carbon
7.	As	Arsenic
8.	BBS	Bangladesh Bureau of Statistics
9.	B	Bacillus
10.	BR	Basal respiration
11.	BC	Biochar
12.	BARC	Bangladesh Agricultural Research Council
13.	BARI	Bangladesh Agricultural Research Institute
14.	BINA	Bangladesh Institute of Nuclear Agriculture
15.	BD	Bulk Density
16.	Co-PI	Co-Principal Investigator
17.	C	Carbon
18.	°C	Celsius or Centigrade temperature
19.	c mol kg^{-1}	Centimole per kilogram
20.	CO_2	Carbon Dioxide
21.	CliAC	Carbon liability index for active carbon
22.	CliMBC	Carbon liability index for microbial biomass carbon
23.	CliPOC	Carbon liability index for particulate organic carbon
24.	CMI	Carbon management index
25.	C stock	Carbon stock
26.	Cfu	Colony forming unit
27.	CFU/g	Colony-forming units per gram
28.	Cr	Chromium
29.	Cu	Copper
30.	Ca	Calcium
31.	Cd	Cadmium
32.	CD	Cowdung
33.	CDS	Cowdung Slurry
34.	CEC	Cation Exchange Capacity
35.	cmol/kg	Centimoles per Kilogram
36.	CSW	Continuous Standing Water
37.	CV	Coefficient of Variation
38.	C:N	Carbon to Nitrogen Ratio
39.	DAI	Days After Incubation
40.	DAT	Days After Transplanting
41.	DTPA	Diethylenetriamine Pentaacetate
42.	dw	Dry weight
43.	FAO	Food and Agriculture Organization
44.	FC	Field Capacity
45.	Fe	Ferrous
46.	FRG	Fertilizer Recommendation Guide
47.	GHG	Greenhouse Gas
48.	GoB	Government of Bangladesh
49.	g/cm3	Gram Per Cubic Centimeter
50.	GPS	Global Positioning System
51.	g	Gram
52.	ha	Hectare

Sl. No.	Abbreviation and Acronyms	Full meaning
53.	HRC	Horticulture Research Center
54.	IM	Irrigation Management
55.	IFAD	International Food and Agriculture Organization
56.	IPNS	Integrated Plant Nutrition System
57.	IS	Islampur
58.	K	Potassium
59.	K	Rate constant
60.	Kg ha^{-1}	Kilogram per hectare
61.	KCl	Potassium Chloride
62.	kg	Kilo Gram
63.	k	C degradation constant
64.	l	Litter
65.	LS	Level of significance
66.	LSD	Least significant different
67.	MD	Modhupur
68.	M	Molar
69.	MBCR	Marginal Benefit Cost Ratio
70.	MBC	Microbial biomass carbon
71.	Mg	Magnesium
72.	Mn	Manganese
73.	mg/kg	Milligram per Kilogram
74.	mg kg^{-1}	Milligram per kilogram
75.	meq	Mili Equivalent
76.	MBN	Microbial biomass nitrogen
77.	meq/100 g	Milliequivalents per 100 grams of soil
78.	MOF	Mazim Organic Fertilizer
79.	MoP	Muriate of potash
80.	MT	Metric Ton
81.	n	number
82.	NATP	National Agricultural Technology Program
83.	NFB	Free living N_2 fixing bacteria
84.	NS	Non-Significant
85.	N	Nitrogen,
86.	N_t	Net nitrogen mineralized at time t
87.	N_o	Mineralization potential
88.	Na	Natrium (Sodium)
89.	NH_4-N	Ammonium Nitrogen
90.	Ni	Nickel
91.	NO_3-N	Nitrate Nitrogen
92.	OC	Organic Carbon
93.	OM	Organic Matter
94.	OF	Organic Fertilizer
95.	PP	Project Proposal
96.	PIU	Project Implementation Unit
97.	PBRG	Program Based Research Grant
98.	PCR	Project Completion Report
99.	PI	Principal Investigator
100.	PM	Poultry Manure
101.	POM	Particulate organic matter
102.	PMC	Potentially mineralizable carbon
103.	P	Phosphorus
104.	pp	Procurement plan
105.	PAA	Phenyl Anthranilic Acid

Sl. No.	Abbreviation and Acronyms	Full meaning
106.	Pb	Lead
107.	ppm	Parts per million
108.	POC	Particulate organic carbon
109.	POXC	Permanganate oxidizable carbon
110.	PSB	Phosphate Solubilizing Bacteria
111.	PMB	Poultry Manure Biochar
112.	qCO2	Soil microbial metabolic quotient
113.	RCF	Recommended Chemical Fertilizer
114.	RCBD	Randomized Complete Block Design
115.	RH	Rice Husk
116.	RHB	Rice husk biochar
117.	RF	Recommended Fertilizer
118.	RHB	Rice Husk Biochar
119.	S	Sulphur
120.	SE	Standard error of means
121.	SOC	Soil Organic Carbon
122.	t	Metric ton
123.	Tk.	Taka
124.	t/ha	Ton per Hectare
125.	T. Aman rice	Transplanted aman rice
126.	TOC	Total organic carbon
127.	TSP	Triple Super Phosphate
128.	TC	Tricocompost
129.	TN	Total nitrogen
130.	USA	United States of America
131.	USDA	United States Department of Agriculture
132.	VC	Vermicompost
133.	WB	World Bank
134.	w/v	Weight by Volume
135.	wt.	Weight
136.	Zn	Zinc
137.	µ	Micron
138.	µg	Micro Gram
139.	Available P	Available phosphorus
140.	Available K	Available potassium
141.	Available S	Available sulphur

Table of Contents

Sl. No.		Subject	Page No.
	Executive Summary		xxii
A.	**Sub-project Description**		01
	1.	Title of the PBRG sub-project	01
	2.	Implementing organization	01
	3.	Name and full address of Coordinator, PI/Co-PI	01
	4.	Sub-project budget	03
	5.	Duration of the sub-project	03
	6.	Background of the sub-project	03
	7.	Sub-project general objective	04
	8.	Specific objectives for each component	04
	9.	Implementing location	05
	10.	Methodology	05
	11.	Results and discussion	30
	12.	Research highlight/findings	299
B.	**Implementation Status**		311
	1.	Procurement	311
	2.	Establishment/renovation facilities	313
	3.	Training/study tour/ seminar/workshop/conference organized	313
C.	**Financial and physical progress**		314
D.	**Achievement of Sub-project by objectives**		316
E.	**Information/Knowledge generated/Policy generated**		326
F.	**Materials Development/Publication made under the Sub-project**		332
G.	**Description of generated Technology/Knowledge/Policy**		335
	i.	Technology Fact Sheet	335
	ii.	Effectiveness in policy support	352
H.	**Technology/Knowledge generation/Policy Support**		352
I.	**Information regarding Desk and Field Monitoring**		354
J.	**Sub-project auditing**		358
K.	**Lessons Learned**		359
L.	**Challenges**		360
M.	**Suggestions for Future Planning**		360
N.	**References**		362

List of Tables

Table No.	Description	Page No.
1.	Methods of soil samples analysis	7
2.	Location of collected soil samples for bench mark survey from Sripur and Gazipur after harvest of T. Aman rice during 2018	8
3.	Treatment description of field experiments at Sripur and Gazipur conducted during study period	12
4.	General soil information of sampling sites	15
5.	Bio-physico-chemical properties of the tested soil	19
6.	Nutrient status of different organic amendments	19
7.	Chemical properties of different organic amendments	27
8.	Banchmark survey of soil physical properties of Belabo upazilla (n-81)- [T. 8a] Banchmark survey of soil Chemical properties of Belabo upazilla (n-81)- [T-8b]	31 32
9.	Banchmark survey of soil physical properties of Godaghari upazila (n-81)- [T-9a] Banchmark survey of soil chemical properties of Godaghari upazila (n-81)- [T-9b]	32 32
10.	Banchmark survey of soil physical properties of Dumuria upazilla (n-126)- [T-10a] Banchmark survey of soil chemical properties of Dumuria upazilla (n-126)- [T-10b]	33 33
11.	Chemical compositions of the biochar samples produced from the straws of maize, wheat, groundnut, chickpea, mustard, rice straw, rice husk, poultry manure and saw dust	34
12.	Chemical compositions of studied soil	34
13.	Chemical compositions of organic materials	34
14.	Soil chemical properties after end of incubation	41
15.	Soil chemical properties after end of incubation under standing water condition	42
16.	Soil Chemical properties after end of incubation	46
17.	Soil Chemical properties after end of incubation under standing water condition	47
18.	Analytical data of the experimental soils of Belabo (Initial soil)	51
19.	Effects of different organic amendment on yield and yield contributing characters of cauliflower at Belabo during 2018-19, 2019-20 & 2020-21	52
20.	Effects of different organic amendment on yield and yield contributing characters of okra at Belabo during 2019, 2020 & 2021	54
21.	Effects of different organic amendment on yield and yield contributing characters of Indian spinach at Belabo during 2019, 2020 & 2021	56
22.	Average yield, cauliflower equivalent yield and total cauliflower (system) yield (t $ha^{-1}yr^{-1}$) of Cauliflower- Okra-Indian spinach	57
23.	Initial soil status of the experimental soils of Godaghari.	58
24.	Effects of different organic amendment on yield and yield contributing characters of mustard at Godaghari during 2018-19, 2019-20 & 2020-21	61
25.	Effects of different organic amendment on yield and yield contributing characters of boro at Godaghari during 2019, 2020 & 2021	63
26.	Effects of different organic amendment on yield and yield contributing characters of T. Aman at Godaghari during 2019, 2020 & 2021	65
27.	Average yield, rice equivalent yield and total rice (system) yield (t $ha^{-1}yr^{-1}$) of Mustard- Boro-T. Aman	66
28.	Analytical data of the experimental soils of Dumuria (Initial soil)	70
29.	Effects of different organic amendment on yield and yield contributing characters of sweet gourd at Dumuria during 2019, 2020 & 2021	71
30.	Effects of different organic amendment on yield and yield contributing characters of T. Aman at Godaghari during 2019, 2020 & 2021	72
31.	Average yield, rice equivalent yield and total rice (system) yield (t $ha^{-1}yr^{-1}$) of Mustard- Boro-T. Aman	74
32.	Chemical properties of the rice soils of Sripur and Gazipur Industrially polluted area	79
33.	Effect of different organic amendment on NO_3-N mineralization in the industrial effluent polluted and un-polluted soil	85

Table No.	Description	Page No.
34.	Chemical composition of organic materials used in the study during 2018-2020	98
35.	Nutrient concentration of water of the nearest irrigation channel of sampling areas	100
36.	Initial soil properties of experimental field at Sripur site 1. Field nearby (5 m) to the polluted irrigation channel	103
37.	Initial soil properties of experimental field at Sripur, Site 2. Field nearby 10 m to the polluted irrigation channel but 500 m far from polluted source	103
38.	Initial soil properties of experimental field at Sripur, site 3: Field 500 m far from irrigation channel and crop irrigated by underground water	104
39.	Effect of organic amendments and chemical fertilizer on the grain and straw yield of BRRI dhan29 at Sripur (site-1, site-2, site-3)	105
40.	Effect of chemical fertilizer and biochar application on grain and straw yield of Hira (Hybrid) at Sripur (site-4)	105
41.	Application of organic amendments and chemical fertilizer on grain and straw nutrient uptakes. Site 1: Nearby (5 m) to the polluted irrigation channel	106
42.	Application of organic amendments and chemical fertilizer on grain and straw nutrient uptakes, site 2: field nearby 10 m to the polluted irrigation channel but 500 m far from polluted source	106
43.	Application of organic amendments and chemical fertilizer on grain and straw nutrient uptakes, field 500 m far from irrigation channel and crop irrigated by underground water	107
44.	Yield and yield attributes of BRRI dhan 49 in T. Aman 2019 at Sripur	108
45.	Effect of different organic amendments and chemical fertilizer on plant growth and yield of BRRI dhan89 in the industrial polluted soil of Sripur.	109
46.	Effect of different organic amendments and chemical fertilizer on nutrient uptake of BRRI dhan89 in the industrial polluted soil of Sripur during Boro 2019-2020	110
47.	Initial soil properties of experimental field at Mirzapur. Site 1: about 200 m far from polluted irrigation channel	111
48.	Initial soil properties of experimental field at Mirzapur. Site 2: about 400 m far from polluted irrigation channel	111
49.	Effect of organic amendments and chemical fertilizer on grain and straw yield of BRRI dhan29 at Mirzapur during Boro 2018-2019	112
50.	Effect of organic amendments and chemical fertilizer on nutrient uptake of BRRI dhan29 in Mirzapur, Boro 2018-19. Site 1: 200 m far from polluted irrigation channel	114
51.	Effect of organic amendments and chemical fertilizer on nutrient uptake of BRRI dhan29 in Mirzapur, Boro 2018-19. Site 2: 400 m far from polluted irrigation channel	114
52.	Effect of different organic amendments and chemical fertilizer on plant growth and yield of BRRI dhan74 in the polluted area of PurboDuguri, Mirzapur	116
53.	Effect of organic amendments and chemical fertilizer application on nutrient uptakes in the grain and straw of BRRI dhan74 at Mirzapur during Boro 2019-20	117
54.	Initial soil properties of experimental field at Pirojali, Site 1: field experiment located 5 m nearby from the polluted irrigation channel	119
55.	Initial soil properties of the experimental field at Pirojali, Site 2: field experiment located 10 m far from the polluted irrigation channel but 500 m far from polluted source	119
56.	Effect of organic sources and chemical fertilizer on grain and straw yield of BRRI dhan29 at Pirojali during Boro 2018-2019	120
57.	Nutrient uptake due to application of different organic sources and chemical fertilizer in BRRI dhan29 at Pirujali (Site 1) during Boro 2018-2019	122
58.	Nutrient uptake due to application of different organic sources and chemical fertilizer in BRRI dhan29 at Pirujali (Site 2) during Boro 2018-2019	122
59.	Effect of different organic amendments and chemical fertilizer on plant growth and yield of BRRI dhan28 in the polluted soil of Pirujali, Mirzapur.	123
60.	Nutrient uptake due to application of different organic sources and chemical	124

Table No.	Description	Page No.
	fertilizer in BRRI dhan28 at Pirujali during Boro 2019-2020	
61.	Physical characterizations and geographical positions of soils at drought prone areas of Bangladesh	127
62.	Physical characterizations and geographical positions of soils at drought prone areas of Bangladesh	128
63.	Effect of water levels, organic amendments and their interaction on Fe, Cu, Mn, Zn, Na and Ca content in soil	149
64.	Effect of chemical and its combination with organic fertilizers on yield and yield attributing characters of Boro rice 2018	151
65.	Effect of chemical and it's combination with organic fertilizers on yield and yield attributing characters of rice in Aman 2019	151
66.	Effect of chemical and it's combination with organic fertilizers on yield and yield attributing characters of mustard in Aman 2020	151
67.	Effect of chemical and poultry manure on yield and yield attributing characters of Boro rice 2018	155
68.	Effect of chemical and poultry manure on yield and yield attributing characters of Aman rice 2019	156
69.	Effect of chemical and poultry manure on yield and yield attributing characters of mustard 2020	156
70.	Effect of chemical and poultry manure on yield and yield attributing characters of lentil 2020	156
71.	Effect of chemical and poultry manure on yield and yield attributing characters of wheat 2020	156
72.	Initial physico-chemical properties of soils at Madhupur and Islampur sites	158
73.	Initial physico-chemical properties of soil at Madhupur and Islampur site	158
74.	Initial macro and micro nutrient contents of soils at Madhupur and Islampur sites	158
75.	Particle size distribution of poultry manure biochar	161
76.	Particle Size Distribution of Rice Husk Biochar	160
77.	Physico-chemical properties of biochars along with other organic amendments used for crop production	161
78.	Effect of different treatments on yield and system productivity of Mustard–Boro–T. Aman cropping pattern	162
79.	Effects of organic amendments on nitrogen uptake and NUE at Madhupur site; mean ± SE (n=4)	165
80.	Effects of different treatments on SOC, POC, POXC and bulk density at Madhupur and Islampur sites at a depth of 0-15cm	167
81.	Effects of different treatments on carbon lability and management indices of active and microbial biomass at Madhupur and Islampur sites at a depth of 0-15 cm	168
82.	Effects of different treatments on total organic carbon, particulate organic matter, particulate organic carbon, permanganate oxidizable carbon, microbial biomass carbon stocks at Madhupur and Islampur sites at a depth of 0-15 cm	169
83.	Effects of different treatments on microbial population at Madhupur and Islampur sites at a depth of 0-15 cm	169
84.	Effects of organic amendments on soil aggregate properties (Madhupur Soil); mean ± SE (n=4)	170
85.	Physicochemical properties of soils amended with different organic sources for two consecutive years under mustard – Boro – T. Aman pattern; mean±SE (n=4)	171
86.	Physicochemical properties of soils amended with different organic sources for two consecutive years under mustard – Boro – T. Aman pattern; mean±SE (n=4)	171
87.	Effect of organic amendments on trace element contents in soil	173
88.	Effect of different treatments on yield and system productivity of Maize-Jute-T. Aman cropping pattern	175
89.	Effects of organic amendments on N uptake and NUE at Islampur site; mean± SE (n=4)	176

Table No.	Description	Page No.
90.	Effects of different treatments on SOC, POC, POXC and bulk density at Madhupur and Islampur sites at a depth of 0-15cm	178
91.	Effects of different treatments on carbon lability and management indices of active and microbial biomass at Madhupur and Islampur sites at a depth of 0-15 cm	179
92.	Effects of different treatments on total organic carbon, particulate organic matter, particulate organic carbon, permanganate oxidizable carbon, microbial biomass carbon stocks at Madhupur and Islampur sites at a depth of 0-15 cm	179
93.	Effects of different treatments on microbial population at Madhupur and Islampur sites at a depth of 0-15 cm	180
94.	Effects of organic amendments on soil aggregate properties; mean±SE (n=4)	181
95.	Effects of organic amendments on physico-chemical properties; mean±SE (n=4)	182
96.	Physicochemical properties of soils amended with different organic sources for two consecutive years under mustard – Boro – T. Aman pattern; mean±SE (n=4)	182
97.	Effect of organic amendments on trace element contents in soil	183
98.	Carbon mineralization rate kinetics under different organic amendments at acid soil site	187
99.	Carbon mineralization rate kinetics under different organic amendments at char land site	188
100.	Depth-wise soil chemical properties of the upper ridge of Dekharhaor site Sunamgonj	198
101.	Depth-wise soil chemical properties of the middle ridge of Dekharhaor site Sunamgonj	200
102.	Depth-wise soil chemical properties of the lower ridge of Dekharhaor site Sunamgonj	202
103.	Effects of topography and depth on soil properties	205
104.	Effects of topography and depths on basic cations	206
105.	Average values of bio-physicochemical properties of initial soil samples in arsenic contaminated area of Faridpur sadar	207
106.	Effect of different organic matters on post-harvest soil pH content in arsenic contaminated area of Faridpur sadar	208
107.	Effect of different organic matters on post-harvest soil total N (%) content in arsenic contaminated area of Faridpur sadar	208
108.	Effect of different organic matters on post-harvest soil OC (%) content in arsenic contaminated area of Faridpur sadar	209
109.	Effect of different organic matters on post-harvest soil available P (mg/kg) content in arsenic contaminated area of Faridpur sadar	209
110.	Effect of different organic matters on post-harvest soil available S (mg/kg) content in arsenic contaminated area of Faridpur sadar	210
111.	Effect of different organic matters on post-harvest soil exchangeable K (cmol/kg) content in arsenic contaminated area of Faridpur sadar	210
112.	Effect of different organic matters on post-harvest soil Zn (mg/kg) content in arsenic contaminated area of Faridpur sadar	211
113.	Effect of different organic matters on post-harvest soil CEC (cmol/kg) in arsenic contaminated area of Faridpur sadar	211
114.	Effect of different organic matters on post-harvest soil NH_4-N (mg/kg) content in arsenic contaminated area of Faridpur sadar	212
115.	Effect of different organic matters on post-harvest soil NO_3-N (mg/kg) content in arsenic contaminated area of Faridpur sadar	212
116.	Effect of different organic matters on post-harvest soil bulk density (g/cm^3) in arsenic contaminated area of Faridpur sadar	213
117.	Effect of different organic matters on post-harvest soil Biomass C (mg /kg) content in arsenic contaminated area of Faridpur sadar	213
118.	Effect of different organic matters on post-harvest soil Biomass N (mg /kg) content in arsenic contaminated area of Faridpur sadar	214

Table No.	Description	Page No.
119.	Average values of bio-physicochemical properties of initial soil samples in saline areas of Batiaghata, Khulna	215
120.	Effect of different organic matters on post-harvest soil pH of the salinity affected experimental sites Batiaghata, Khulna	215
121.	Effect of different organic matters on post-harvest soil N (%) content of the salinity affected experimental sites Batiaghata, Khulna	216
122.	Effect of different organic matters on post-harvest soil OC (%) content of the salinity affected experimental sites Batiaghata, Khulna	216
123.	Effect of different organic matters on post-harvest soil P (mg/kg) content of the salinity affected experimental sites Batiaghata, Khulna	217
124.	Effect of different organic matters on post-harvest soil available S (mg/kg) content of the salinity affected experimental sites Batiaghata, Khulna	217
125.	Effect of different organic matters on post-harvest soil exchangeable K (cmol/kg) content of the salinity affected experimental sites Batiaghata, Khulna	218
126.	Effect of different organic matters on post-harvest soil Zn (mg/kg) content of the salinity affected experimental sites Batiaghata, Khulna	218
127.	Effect of different organic matters on post-harvest soil CEC (cmol/kg) content of the salinity affected experimental sites Batiaghata, Khulna	218
128.	Effect of different organic matters on post-harvest soil EC (dS/m) content of the salinity affected experimental sites Batiaghata, Khulna	219
129.	Effect of different organic matters on post-harvest soil NH_4-N (mg/kg) content of the salinity affected experimental sites Batiaghata, Khulna	219
130.	Effect of different organic matters on post-harvest soil NO_3-N (mg/kg) content of the salinity affected experimental sites Batiaghata, Khulna	220
131.	Effect of different organic matters on post-harvest soil Bulk density (g/cm^3) of the salinity affected experimental sites Batiaghata, Khulna	220
132.	Effect of different organic matters on post-harvest soil Biomass C (mg /kg) content of the salinity affected experimental sites Batiaghata, Khulna	221
133.	Effect of different organic matters on post-harvest soil Biomass N (mg /kg) content of the salinity affected experimental sites Batiaghata, Khulna	221
134.	Average values of bio-physicochemical properties of initial soil samples in heavy metal polluted areas of Bhaluka, Mymensingh	222
135.	Effect of different organic matters on post-harvest soil pH content of heavy metal polluted area of Bhaluka, Mymensingh	223
136.	Effect of different organic matters on post-harvest soil total N (%) content of heavy metal polluted area of Bhaluka, Mymensingh	223
137.	Effect of different organic matters on post-harvest soil OC (%) content of heavy metal polluted area of Bhaluka, Mymensingh	224
138.	Effect of different organic matters on post-harvest soil available P (mg/kg) content of heavy metal polluted area of Bhaluka, Mymensingh	224
139.	Effect of different organic matters on post-harvest soil available S (mg/kg) content of heavy metal polluted area of Bhaluka, Mymensingh	225
140.	Effect of different organic matters on post-harvest soil exchangeable K (cmol/kg) content of heavy metal polluted area of Bhaluka, Mymensingh	225
141.	Effect of different organic matters on post-harvest soil Zn (mg/kg) content of heavy metal polluted area of Bhaluka, Mymensingh	225
142.	Effect of different organic matters on post-harvest soil CEC (cmol/kg) content of heavy metal polluted area of Bhaluka, Mymensingh	226
143.	Effect of different organic matters on post-harvest soil NH_4-N (mg/kg) content of heavy metal polluted area of Bhaluka, Mymensingh	226
144.	Effect of different organic matters on post-harvest soil NO_3-N (mg/kg) content of heavy metal polluted area of Bhaluka, Mymensingh	227
145.	Effect of different organic matters on post-harvest soil Pb (mg/kg) content of heavy metal polluted area of Bhaluka, Mymensingh	227
146.	Effect of different organic matters on post-harvest soil Cd (mg/kg) content of	228

Table No.	Description	Page No.
	heavy metal polluted area of Bhaluka, Mymensingh	
147.	Effect of different organic matters on post-harvest soil Ni (mg/kg) content of heavy metal polluted area of Bhaluka, Mymensingh	228
148.	Effect of different organic matters on post-harvest soil bulk density (g/cm^3) of heavy metal polluted area of Bhaluka, Mymensingh	229
149.	Effect of different organic matters on post-harvest soil Biomass C (mg /kg) content of heavy metal polluted area of Bhaluka, Mymensingh	229
150.	Effect of different organic matters on post-harvest soil Biomass N (mg /kg) content of heavy metal polluted area of Bhaluka, Mymensingh	229
151.	The pH, organic carbon (OC) and nitrogen status in cowdung, cowdung slurry, rice husk biochar, vermicompost and tricocompost	230
152.	Physical and chemical properties of organic materials used in the experiment	244
153.	Physico-chemical characterization of mineralized soil sample	244
154.	Interaction effect of different organic materials (OM) and irrigation management (IM) practice on total nitrogen content of industrial polluted soil at different days after incubation (DAI)	248
155.	Interaction effect of different organic materials (OM) and irrigation management (IM) practice on nitrate nitrogen content of industrial polluted soil at different days after incubation	248
156.	Interaction effect of different organic materials (OM) and irrigation management (IM) practice on ammonium nitrogen content of industrial polluted soil at different days after incubation (DAI)	249
157.	Interaction effect of different organic materials (OM) and irrigation management (IM) practice on organic carbon mineralization of industrial polluted soil at different days after incubation (DAI)	249
158.	Interaction effect of different organic materials (OM) and irrigation management (IM) practice on biomass carbon content of industrial polluted soil at different days after incubation	250
159.	Interaction effect of different organic materials (OM) and irrigation management (IM) practice on biomass nitrogen content of industrial polluted soil at different days after incubation (DAI)	250
160.	Interaction effect of different organic materials (OM) and irrigation management (IM) practice on soil pH of industrial polluted soil at different days after incubation (DAI)	252
161.	Effect of organic materials on nutrient status of post-harvest soil of T. aman rice 2020	258
162.	Effect of different organic matters on post-harvest soil Carbon sequestration (t/ha) of the arsenic contaminated soil Faridpur	270
163.	Effect of different organic matters on post-harvest soil Carbon sequestration (t/ha) of the selected experimental site of Khulna	271
164.	Effects of organic naterials and chemical fertilizers on soil bulk density, carbon stock and carbon sequestration after T. aman rice	273
165.	Chemical properties of collected soil samples of base line survey	274
166.	Physical properties of collected soil samples of base line survey	275
167.	Biological properties of collected soils for base line survey	276
168.	Nutrient status of the used organic materials	280
169.	Effect of different organic amendments with no mulch on the yield of Maize (var DON 111) in two sites of Kalaparaupazila in consecutive two years	283
170.	Effect of different organic amendments with no mulch on the postharvest soil parameters of Maize (var. DON 111) in two sites of KalaparaUpazila in consecutive two years	284
171.	Effect of different organic amendments with mulch on the yield of Maize (var. DON 111) in two sites of Kalapara Upazila in two years	287
172.	Effect of different organic amendments with mulch on the post-harvest soil parameters of Maize (var. DON 111) in two sites of Kalapara Upazila in two years	288

Table No.	Description	Page No.
173.	pH and EC (dS/m) value of initial soils ofT. aman (var. BRRI dhan52) field in two sites of Kalapara Upazila	290
174.	Effect of different organic amendments on the yield of T. aman (var. BRRI dhan52) in two sites of Kalapara Upazila in two years	293
175.	Effect of different organic amendments on the post-harvest soil parameters of T.aman (var. BRRI dhan52) in two sites of Kalapara Upazila	295
176.	Initial soil chemical properties	297
177.	Post harvest soil chemical properties	297
178.	Initial soil physical properties	297
179.	Post harvest soil physical properties	298
180.	Initial soil biological properties	298
181.	Post harvest soil biological properties	298

List of Figures

Figure No.	Description	Page No.
1.	Location of sampling sites of Belabo upazilla	30
2.	Location of sampling sites of Godaghari upazilla	31
3.	Location of sampling sites of Dumuria upazilla	31
4.	Fabricated biochar making device (heat generated by wooden materials & electric control) and biochar produced.	33
5.	Soil pH dynamics in acid soil using different amending materials under (a) field condition and (b) standing water condition	35
6.	Changing of soil pH under field and standing water condition	36
7.	Soil organic carbon concentration dynamics using different organic amendment under (a) field condition and (b) standing water condition	37
8.	Changes acid soil organic carbon concentration using different organic amendment under (a) field condition and (b) standing water condition	38
9.	Carbon mineralization rate (k) calculate followingkinetic model using different organic amendment under (a) field condition and(b) standing water	39
10.	NH_4-N dynamics in acid soil under (a) field condition and (b) standing water condition	40
11.	NO_3-N dynamics in acid soil under (a) field condition and (b) standing water	40
12.	Cumulative Mineralization of NH_4-N (ppm)and NO_3-N (ppm) dynamics in acid soil under (a) field condition and (b) standing water	41
13.	Carbon reduction trends in different organic materials added soil under field condition (a) and standing water (b) under drought soils of Rajshahi Region.	42
14.	Cumulative Mineralization of carbon (ppm) under (a) field condition and (b) standing water in drought soils of Rajshahi Region.	43
15.	Rate of mineralization of organic carbon using different organic compound under (a) field condition and (b) standing water condition at drought soils of Rajshahi Region	44
16.	NH_4-N and NO_3-N dynamics under (a) field condition and (b) standing water condition at drought soils of Rajshahi Region	45
17.	Cumulative mineralization of NH_4-N and NO_3-N in (a) field condition and (b) standing water condition at drought soils of Rajshahi Region	46
18.	Carbon reduction trends in different organic materials added soilunder field condition (a) and standing water (b) under saline soils of Khulna Region.	47
19.	Cumulative Carbon reduction using different organic materials added soilunder field condition (a) and standing water (b) under saline soils of Khulna Region.	48
20.	Carbon mineralization rate using different organic materials added soil under field condition (a) and standing water (b) under saline soils of Khulna Region.	49
21.	Carbon mineralization rate using different organic materials added soil under field condition (a) and standing water (b) under saline soils of Khulna Region.	50
22.	Carbon mineralization rate using different organic materials added soilunder field condition (a) and standing water (b) under saline soils of Khulna Region.	51
23.	Field experiment on acid soil of Belabo showing comparative performance of organic materials and dolomite for correction of soil acidity and cauliflower productivity during 2018-19, 2019-20 and 2020-21, respectively.	52
24.	Field experiment on acid soil of Belabo showing comparative performance of organic materials and dolomite for correction of soil acidity and Okra productivity during 2018-19, 2019-20and 2020-21, respectively.	54
25.	Field experiment on acid soil of Belabo showing comparative performance of organic materials and dolomite for correction of soil acidity and Indian spinach productivity.	55
26.	Nitrogen & Phosphorus balance in cauliflower-okra-Indian spinach at acidic soil of Belabo (average of 3 year)	57
27.	Potassium & Sulphur balance in cauliflower-okra-Indian spinach at acidic soil of Belabo (average of 3 year)	58

Figure No.	Description	Page No.
28.	Monthly average temperature and precipitation over three experimental years.	59
29.	Monthly average soil water content over three experimental years.	60
30.	Improvement of soil health in unfavorable eco-system (drought soil) with organic amendment for sustainable crop production (crop: mustard; Variety: BARI Sharisha-14)	61
31.	Improvement of soil health in unfavourable eco-system (drought soil) with organic amendment for sustainable crop production (crop: T. Aman; variety: BRRI dhan 88)	63
32.	Improvement of soil health in unfavourable eco-system (drought soil) with organic amendment for sustainable crop production (crop: T. Aman)	66
33.	Nitrogen & Phosphorus balance in mustard-boro-T. Aman at drought prone soil of Godagari (average of 3 year)	67
34.	Potassium & Sulphur balance in mustard-boro-T.Aman at drought prone soil of Godagari (average of 3 year)	67
35.	Monthly average temperature and precipitation over three experimental years	68
36.	Salinity levels (dS m^{-1}) of soil in sweet gourd field during 2018-2019	69
37.	Salinity levels (dS m^{-1}) of soil in sweet gourd field during 2020-2021	69
38.	Salinity levels (dS m^{-1}) of soil in sweet gourd field during 2021-2022	70
39.	Field experiment on saline soil of Dumuria on Sweet gourd applying different organic amendments.	71
40.	Improvement of soil health in unfavourable eco-system (saline soil) with organic amendment for sustainable crop production (crop: T. Aman; BRRI dhan-78)	73
41.	Nitrogen & Phosphorus balance in sweet gourd-Fallow-T. Aman at saline soil of Dumuria (average of 3 year)	74
42.	Potassium & sulphurs balance in sweet gourd-Fallow-T. Aman at saline soil of Dumuria (average of 3 year)	75
43.	Soil organic carbon mineralization rate under acidic soil (Norsingdi)	75
44.	Soil organic carbon mineralization rate under drought soil (Rajshahi)	76
45.	Soil organic carbon mineralization rate under saline areas (Kulna)	77
46.	The concentration of soil Fe (PPM) of Sripur and Gazipur industrially polluted rice soil. (46a) The concentration of Mn, Zn, Cu (ppm) in Sripur and Gazipur industrially polluted rice soil (46b)	80
47.	The concentration of heavy metals (Pb, Ni, Cr and Cd) in the Sripur and Gazipur industrially polluted rice soil	81
48.	The population of total bacteria, free living N_2 fixing bacteria (NFB) and phosphate solubilizing bacteria (PSB) in the Sripur and Gazipur industrially polluted rice soil	82
49.	The population of total fungus in the Sripur and Gazipur industrially polluted rice soil (49a) The population of total actinomycetes in the Sripur and Gazipur industrially polluted rice soil. (49b)	82
50.	Effect of different organic amendments and chemical fertilizer on NH_4-N mineralization in the polluted and un-polluted soils of Sripur Gazipur	84
51.	Effect of different organic amendments and chemical fertilizer on soil organic C content in the polluted and un-polluted soils of Sripur Gazipur.	86
52.	Effect of different organic amendments and chemical fertilizer on soil organic C mineralization rate (*k)* in the polluted and unpolluted soils of Sripur Gazipur.	87
53.	Effect of different organic amendments and chemical fertilizer on soil available P mineralization in the polluted and un-polluted soils of Sripur Gazipur.	88
54.	Effect of different organic amendments and chemical fertilizer on soil exchangeable K mineralization in the polluted and un-polluted soils of Sripur Gazipur.	89
55.	Effect of different organic amendments and chemical fertilizer on Zn mineralization in the polluted and un-polluted soils of Sripur, Gazipur.	90

Figure No.	Description	Page No.
56.	Effect of different organic amendments and chemical fertilizer on Cu mineralization in the polluted and un-polluted soils of Sripur, Gazipur.	91
57.	Effect of different organic amendments and chemical fertilizer on Mn mineralization in the polluted and un-polluted soils of Sripur, Gazipur.	92
58.	Effect of different organic amendments and chemical fertilizer on Fe^{++} mineralization in the polluted and un-polluted soils of Sripur, Gazipur.	93
59.	Effect of different organic amendments and chemical fertilizer on Pb mineralization in the polluted and un-polluted soils of Sripur, Gazipur	94
60.	Effect of different organic amendments and chemical fertilizer on Cd mineralization in the polluted and un-polluted soils of Sripur, Gazipur	95
61.	Effect of different organic amendments and chemical fertilizer on soil bacteria population in the polluted and un-polluted soils of Sripur Gazipur	97
62.	Relationship between soil organic matter and soil Fe^{++} content at Sripur soil	126
63.	Different forms of soil carbon in drought prone areas of Bangladesh	130
64.	Microbial biomass content in different drought prone areas of Bangladesh	131
65.	Nitrogen status in different locations of drought prone areas of Bangladesh	131
66.	Phosphorus status in different locations of drought prone areas of Bangladesh	132
67.	K status in different locations of drought prone areas of Bangladesh	133
68.	Fe and Cu status in different locations of drought prone areas of Bangladesh	133
69.	Cu and Zn status in different locations of drought prone areas of Bangladesh	134
70.	Effect of improved soil management practices on soil quality	134
71.	Effect of different soil moistures on the rate of carbon dioxide emission (FC: field capacity and CSW: continuous standing water)	136
72.	Effect of different organic amendments on the rate of carbon dioxide emission (CT: control, CD: cowdungbioslurry, BC: biochar, OF: organic fertilizer and VC: vermicompost)	137
73.	Interaction effect between moisture levels and organic amendments on the rate of carbon dioxide emission (FC: field capacity and CSW: continuous standing water, cont: control, CD: cowdungbioslurry, BC: biochar, OF: organic fertilizer and VC: vermicompost)	137
74.	Effect of different soil moistures on cumulative carbon dioxide emission (FC: field capacity and CSW: continuous standing water)	138
75.	Effect of different organic amendments on cumulative carbon dioxide emission (cont: control, CD: cowdungbioslurry, BC: biochar, OF: organic fertilizer and VC: vermicompost)	138
76.	Interaction effect between moisture levels and organic amendments on cumulative carbon dioxide emission (FC: field capacity and CSW: continuous standing water, cont: control, CD: cowdungbioslurry, BC: biochar, OF: organic fertilizer and VC: vermicompost)	139
77.	Effect of moisture levels and organic amendments on organic carbon content water levels (FC: field capacity, CSW: continuous standing water), organic amendments (CD:cowdung, BC:biochar, VC:vermicompost,OF:organic fertilizer)	139
78.	Interaction effect between moisture levels and organic amendments on organic carbon content (FC: field capacity and CSW: continuous standing water, cont: control, CD: cowdungbioslurry, BC: biochar, VC: vermicompost and OF: organic fertilizer)	140
79.	Effect of moisture levels and organic amendments on the amount of soil in different soil fractions	140
80.	Effect of interaction between moisture levels and organic amendments on the amount of soil in different soil fractions	140
81.	Effect of different moisture levels on organic carbon content in different soil aggregate fractions	141
82.	Effect of organic amendments on organic carbon content in different soil aggregate fractions	141

Figure No.	Description	Page No.
83.	Interaction effect between moisture levels and organic amendments on organic carbon contentin different soil aggregate fractions (FC: field capacity and CSW: continuous standing water, cont: control, CD: cowdungbioslurry, BC: biochar, VC: vermicompost and OF: organic fertilizer)	142
84.	Effect of organic amendments and moisture levels on C degradation rate constant: water levels (FC: field capacity, CSW: continuous standing water), organic amendments (CD: cowdung, BC: biochar, OF: organic fertilizer, VC: vermicompost and cont: control)	142
85.	Effect of different water levels on NH_4^+- N content in soil at different durations (FC: field capacity and CSW: continuous standing water)	144
86.	Effect of different organic amendments on NH_4^+- N content in soil at different durations	144
87.	Interaction effect between moisture levels and organic amendments on NH_4^+- N content in soil at different durations (FC: field capacity and CSW: continuous standing water, cont: control, CD: cowdungbioslurry, BC: biochar, OF: organic fertilizer and VC: vermicompost)	145
88.	Effect of different water levels on NH_4^+- N content in soil at different durations (FC: field capacity and CSW: continuous standing water)	146
89.	Effect of different organic amendments on NH_4^+- N content in soil at different durations	147
90.	Interaction effect between moisture levels and organic amendments on NO_3^- -N content in soil at different durations (FC: field capacity and CSW: continuous standing water, cont: control, CD: cowdungbioslurry, BC: biochar, OF: organic fertilizer and VC: vermicompost)	147
91.	Effect of water levels, organic amendments and their interactions on total N content in soil	148
92.	Effect of water levels, organic amendments and their interactions on extractable K content in soil	148
93.	Effect of chemical fertilizers and organic fertilizers on organic carbon at different depths of soil	152
94.	Effect of chemical fertilizers and in combination with organic fertilizers on total nitrogen at different depths of soil	152
95.	Effect of chemical and organic fertilizers on K content in soil	153
96.	Effect of chemical fertilizers and in combination with organic fertilizers on Fe and Mn content at different depths of soil	153
97.	Effect of chemical fertilizers and in combination with organic fertilizers on Cu and Zn content at different depths of soil	153
98.	Effect of different treatments on benefit –cost ration of boro-T. aman-rabi cropping pattern	154
99.	Soil aggregates mean weight diameter at acid and char land soil sites as measured prior to experimentation	158
100.	Soil aggregate size distribution (% dry mass) at acid and charland soil sites as measured prior to experimentation	159
101.	Biochar plant at BAU	160
102.	Biochar produced in the BAU biochar plant and used in the current experiment	160
103.	Land preparation and treatment application in the field at Madhupur	162
104.	Mustard grown in acid soil at Madhupur site in an annual mustard-Boro-T. Aman rice pattern	164
105.	T. Aman rice grown in field at Madhupur site in an annual mustard–Boro–T. Aman rice pattern	164
106.	Effects of different treatments on MBC and MBN at Madhupur site (PM = Poultry manure, RHB = Rice husk biochar, PMB = Poultry manure biochar, RD = Recommended dose of fertilizer)	166
107.	Effects of different treatments on basal respiration at Madhupur site	166

Figure No.	Description	Page No.
108.	Distribution of aggregate size fractions (bars=average and line=SEM, n=10) of the 0-15 cm layer of field under different treatments	170
109.	Field site visit during maize growing stage and meeting with farmers at Islampur Charland	176
110.	Effects of different treatments on MBC and MBN at Islampur soil	177
111.	Effects of different treatments on basal respiration at Islampur site	177
112.	Distribution of aggregate size fractions (bars=average and line=SEM, n=10) of the 0-15 cm layer of field under six treatments (Control, Poultry Manure, Poultry Manure Biochar, Organic Fertilizer, Vermicompost, Recommended Dose)	181
113.	Carbon mineralization pattern over time at acid soil site	187
114.	Carbon mineralization pattern during the incubation period at char land soil site	188
115.	Trend of net mineral N (NH_4+-N + NO_3--N) mineralization from different treatments in acidic soil with field capacity and continuous standing water moisture status. Net mineralization is calculated as the difference in amount between amended soil and control. Error bars represent standard errors of the means (n=3)	189
116.	Trend of net mineral N (NH_4+-N + NO_3--N) mineralization from different treatments in charland soil with field capacity and continuous standing water moisture status. Net mineralization is calculated as the difference in amount between amended soil and control. Error bars represent standard errors of the means (n=3)	189
117.	Changes in TN contents in the incubated soil between day 0 and 120 at acidic soil site	190
118.	Percentage of TN mineralization in the incubated during the whole incubation period in FC and CSW conditions	190
119.	Changes in TN contents in the incubated soil between day 0 and 120 at acidic soil site	191
120.	Percentage of TN mineralization in the incubated during the whole incubation period in FC and CSW conditions	191
121.	Trend of P mineralization from different treatments in charland soil with field capacity and continuous standing water moisture status. Error bars represent standard errors of the means (n=3)	192
122.	Trend of S mineralization from different treatments in charland soil with field capacity and continuous standing water moisture status. Error bars represent standard errors of the means (n=3)	193
123.	Mean available S in soil in FC and CSW conditions in acidic soil site	193
124.	Mean available S in soil in FC and CSW conditions in acidic soil site	193
125.	Soil sampling from DekharHaor, Sunamgonj	193
126.	Soil bulk density in various locations of Dekarhaor	203
127.	Soil bulk density in various depths of Dekarhaor	203
128.	Soil samples collection from Saline area of Batiaghata upazila, Khulna	214
129.	Soil samples collection from heavy metal polluted area of Bhaluka, Mymensingh	222
130.	Adsorption percentage of Cd^{2+} by different organic materials in heavy metal polluted soil. CD = Cowdung, CDS = cowdung slurry, RHB = rice husk biochar, VC = vermicompost and TC = tricocompost, DAI = Days after incubation	231
131.	Adsorption percentage of Pb^{2+} by different organic materials in heavy metal polluted soil. CD = Cowdung, CDS = cowdung slurry, RHB = rice husk biochar, VC = vermicompost and TC = tricocompost	232
132.	Adsorption percentage of Ni^{2+} by different organic materials in heavy metal polluted soil. CD = Cowdung, CDS = cowdung slurry, RHB = rice husk biochar, VC = vermicompost and TC = tricocompost	232
133.	Desorption percentage of Cd^{2+} by different organic matter. CD = Cowdung, CDS = cowdung slurry, RHB = rice husk biochar, VC = vermicompost and TC = tricocompost	233
134.	Desorption percentage of Pb^{2+} by different organic matter. CD = Cowdung, CDS	233

Figure No.	Description	Page No.
	= cowdung slurry, RHB = rice husk biochar, VC = vermicompost and TC = tricocompost	
135.	Desorption percentage of Ni^{2+} by different organic matter. CD = Cowdung, CDS = cowdung slurry, RHB = rice husk biochar, VC = vermicompost and TC = tricocompost	234
136.	Effect of different organic matters on organic carbon (%) mineralization of soil (Faridpur), at different incubation period. T_1 = Control, T_2 = Recommended Fertilizer, T_3 = Biochar + Recommended Fertilizer, T_4 = Poultry Manure + Chemical Fertilizer, T_5 = Vermicompost + Chemical Fertilizer, T_6 = Standard Organic Fertilizer + Chemical Fertilizer, DAT = Days After Transplanting	235
137.	Effect of different organic matters on total N (%) of soil (Faridpur), at different incubation period. T_1 = Control, T_2 = Recommended Fertilizer, T_3 = Biochar + Recommended Fertilizer, T_4 = Poultry Manure + Chemical Fertilizer, T_5 = Vermicompost + Chemical Fertilizer, T_6 = Standard Organic Fertilizer + Chemical Fertilizer	235
138.	Effect of different organic matters on Biomass C (mg /kg) of soil (Faridpur), at different incubation period.	236
139.	Effect of different organic matters on Biomass N (mg/kg) of soil (Faridpur), at different incubation period. T_1 = Control, T_2 = Recommended Fertilizer, T_3 = Biochar + Recommended Fertilizer, T_4 = Poultry Manure + Chemical Fertilizer, T_5 = Vermicompost + Chemical Fertilizer, T_6 = Standard Organic Fertilizer + Chemical Fertilizer	237
140.	Effect of different organic matters on NO_3-N (mg/kg) of soil (Faridpur), at different incubation period. T_1 = Control, T_2 = Recommended Fertilizer, T_3 = Biochar + Recommended Fertilizer, T_4 = Poultry Manure + Chemical Fertilizer, T_5 = Vermicompost + Chemical Fertilizer, T_6 = Standard Organic Fertilizer + Chemical Fertilizer	237
141.	Effect of different organic matters on NH_4-N (mg/kg) of soil (Faridpur), at different incubation period. T_1 = Control, T_2 = Recommended Fertilizer, T_3 = Biochar + Recommended Fertilizer, T_4 = Poultry Manure + Chemical Fertilizer, T_5 = Vermicompost + Chemical Fertilizer, T_6 = Standard Organic Fertilizer + Chemical Fertilizer	238
142.	Effect of different organic matters on organic carbon (%) mineralization of soil (Batiaghata, Khulna), at different incubation period. T_1 = Control, T_2 = Recommended Fertilizer, T_3 = Biochar + Recommended Fertilizer, T_4 = Poultry Manure + Chemical Fertilizer, T_5 = Vermicompost + Chemical Fertilizer, T_6 = Standard Organic Fertilizer + Chemical Fertilizer	239
143.	Effect of different organic matters on total N (%) of soil (Batiaghata, Khulna), at different incubation period. T_1 = Control, T_2 = Recommended Fertilizer, T_3 = Biochar + Recommended Fertilizer, T_4 = Poultry Manure + Chemical Fertilizer, T_5 = Vermicompost + Chemical Fertilizer, T_6 = Standard Organic Fertilizer + Chemical Fertilizer	239
144.	Effect of different organic matters on Biomass C (mg /kg) of soil (Batiaghata, Khulna), at different incubation period. T_1 = Control, T_2 = Recommended Fertilizer, T_3 = Biochar + Recommended Fertilizer, T_4 = Poultry Manure + Chemical Fertilizer, T_5 = Vermicompost + Chemical Fertilizer, T_6 = Standard Organic Fertilizer + Chemical Fertilizer	240
145.	Effect of different organic matters on Biomass N (mg/kg) of soil (Batiaghata, Khulna), at different incubation period. T_1 = Control, T_2 = Recommended Fertilizer, T_3 = Biochar + Recommended Fertilizer, T_4 = Poultry Manure + Chemical Fertilizer, T_5 = Vermicompost + Chemical Fertilizer, T_6 = Standard Organic Fertilizer + Chemical Fertilizer	241
146.	Effect of different organic matters on NO_3-N (mg/kg) of soil (Batiaghata, Khulna), at different incubation period. T_1 = Control, T_2 = Recommended Fertilizer, T_3 = Biochar + Recommended Fertilizer, T_4 = Poultry Manure +	241

Figure No.	Description	Page No.
	Chemical Fertilizer, T_5 = Vermicompost + Chemical Fertilizer, T_6 = Standard Organic Fertilizer + Chemical Fertilizer	
147.	Effect of different organic matters on NH_4-N (mg/kg) of soil (Batiaghata, Khulna), at different incubation period. T_1 = Control, T_2 = Recommended Fertilizer, T_3 = Biochar + Recommended Fertilizer, T_4 = Poultry Manure + Chemical Fertilizer, T_5 = Vermicompost + Chemical Fertilizer, T_6 = Standard Organic Fertilizer + Chemical Fertilizer	242
148.	Soil preparation for mineralization study of heavy metal polluted areas of Bhaluka	243
149.	Mineralization Study under field capacity and CSW condition (Laboratory)	243
150.	Mineralization study of organic materials under field capacity and continuous standing water condition (Laboratory condition)	245
151.	Effect of different organic amendment on (A.) Total N, (B.) NO_3-N, (C.) NH_4-N, (D.) OC, (E.) Biomass C, (F.) Biomass N of heavy metal polluted soil at different incubation period	246
152.	Effect of different moisture regimes on (A.) Total N, (B.) NO3-N, (C.) NH4-N, (D.) OC, (E.) Biomass C, (F.) Biomass N of heavy metal polluted soil at different incubation period	247
153.	Effect of (a) different organic materials (OM) and (b) irrigation management (IM) practices on pH change at different incubation period of industrial polluted soil	251
154.	Eeffect of different A. organic materials (OM) and B. Irrigation management (IM)	252
155.	Map of study area (24.22 N and 90.24 E)	253
156.	Initial soil sample collection for physical and chemical analysis	254
157.	Effect of organic materials on release of A. nitrogen, B. ammonium nitrogen, C. nitrate nitrogen, D. Organic carbon, E. Microbial biomass carbon and F. microbial biomass nitrogen in soils at different days after transplanting of rice in industrial polluted soil. (Con = control, CDS= cowdung slurry, RHB = rice husk biochar, CD = cow dung,VC = vermicompost, TC =trico-compost and BI= bacteria inoculant).	256
158.	pH level of soil samples under different organic materials applied plots in industrial polluted soil (Con = control, CDS= cowdung slurry, RHB = rice husk biochar, CD = cow dung, VC = vermicompost, TC =trico-compost and BI= bacteria inoculant).Error bars show the standard error of the mean ($p< 0.05$).	257
159.	Field experiment of Boro rice 2019 in Faridpur	258
160.	Effects of organic and inorganic fertilizers on straw yields of Boro (t/ha) rice during 2019 and 2020 in Faridpur research field.	259
161.	Effects of organic and inorganic fertilizers on grain yields of Boro (t/ha) rice during 2019 and 2020 in Faridpur research field.	260
162.	Effects of organic and inorganic fertilizers on straw yields (t/ha) of T. aman during 2019 and 2020 in Faridpur research field.	260
163.	Effects of organic and inorganic fertilizers on grain yields (t/ha) of T. aman rice during 2019 and 2020 in Faridpur research field.	261
164.	Field experiment of T. aman rice 2019 in Khulna	261
165.	Effects of organic and inorganic fertilizers on straw yield of T. aman (t/ha) rice during 2019 and 2020 in Khulna research field. T_1 = Control, T_2 = Recommended Fertilizer, T_3 = Biochar + Recommended Fertilizer, T_4 = Poultry Manure + Chemical Fertilizer, T_5 = Vermicompost + Chemical Fertilizer, T_6 = Standard Organic Fertilizer + Chemical Fertilizer	262
166.	Effects of organic and inorganic fertilizers on grain yields of T. aman (t/ha) rice during 2019 and 2020 in Khulna research field. T_1 = Control, T_2 = Recommended Fertilizer, T_3 = Biochar + Recommended Fertilizer, T_4 = Poultry Manure + Chemical Fertilizer, T_5 = Vermicompost + Chemical Fertilizer, T_6 = Standard Organic Fertilizer + Chemical Fertilizer	263

Figure No.	Description	Page No.
167.	Field experiment of T. aman in Bhaluka	263
168.	Effects of organic and inorganic fertilizers on straw yields of Boro (t/ha) rice during 2019 and 2020 in Bhaluka research field.	264
169.	Effects of organic and inorganic fertilizers on grain yields of Boro (t/ha) rice during 2019 and 2020 in Bhaluka research field.	264
170.	Effects of organic and inorganic fertilizers on straw yields of T. aman (t/ha) rice during 2019 and 2020 in Bhaluka research field.	265
171.	Effects of organic and inorganic fertilizers on grain yields of and T. aman (t/ha) during 2019 and 2020 in Bhaluka research field.	266
172.	Field experiment of Boro rice 2019 in Bhaluka	266
173.	Soil aggregate stability in various locations of Dekarhaor	267
174.	Soil aggregate stability in various depths of Dekarhaor	268
175.	Carbon stock in various locations of Dekarhaor	269
176.	Carbon stock in various depths of Dekarhaor	269
177.	Effect of different organic matters on Soil Stable aggregate content (%) of the Faridpur experimental site.	270
178.	Effect of different organic matters on Soil Stable aggregate content (%) of the Khulna experimental site.	271
179.	Aggregate stability of harvest soil samples under different organic materials applied plots in industrial polluted soil.	272
180.	Map of Kalapara Upazila	273
181.	Analysis of soil samples	275
182.	Estimation of bacterial population	276
183.	Effectv of different organic amendments on cumulative CO_2-C mineralization under field capacity in the saline soils of Kalapara, Patuakhali	277
184.	Effect of different organic amendments on cumulative CO_2-C mineralization under continuous standing water in the saline soils of Kalapara, Patuakhali	277
185.	Effect of different organic amendments on cumulative NH_4^+- N mineralization under field capacity in the saline soils of Kalapara, Patuakhali	278
186.	Effect of different organic amendments on cumulative NH_4^+- N mineralization under continuous standing water in the saline soils of Kalapara, Patuakhali	278
187.	Effect of different organic amendments on cumulative NO_3^-- N mineralization under field capacity in the saline soils of Kalapara, Patuakhali	279
188.	Effect of different organic amendments on cumulative NO_3^-- N mineralization under continuous standing water in the saline soils of Kalapara, Patuakhali	279
189.	Maize yield increased by different organic amendments over control treatment in Nilgonj union of Kalapara Upazila.	281
190.	Maize yield increased by different organic amendments over control treatment in Latachapli union of Kalapara Upazila.	281
191.	Maize yield increased by different organic amendments over control treatment in Nilgonj union of Kalapara Upazila	285
192.	Maize yield increased by different organic amendments over control treatment in Latachapli union of Kalapara Upazila.	286
193.	Pictorial view of first field experiment (Maize; var. DON 111)	289
194.	T. aman yield increased by different organic amendments over control in Nilgonj union of KalaparaUpazila	291
195.	T. aman yield increased by different organic amendments over control in Latachapli union of Kalapara Upazila	292
196.	Some pictorial view of field experiment (T. aman; var. BRRI dhan52).	296

Executive Summary

Problem soils (soils under unfavourable ecosystems) are very complex to manage for crop production. Among the problem soils, acidic soil, drought prone soil, arsenic and otherindustrialheavy metal polluted soil, Char land, Haor areas and saline soils of some selected areas in Bangladesh are dominant. Organic amendment can restore these problem soils to productive soils.In Bangladesh, intensive cropping with modern crop varieties, use of less or no organic manures and crop residues result in decreased soil organic carbon and plant nutrients leading to severe land degradation. Applied organic materials transform into stable forms of carbon with high adsorption sites. These adsorption sites might help in adsorbing heavy metals and formation of organo-mineral complexes that ultimately ameliorate environment and improve soil health. Therefore, a PBRG sub-project was initiated with seven research organizations and universities comprising BARI, BRRI, BINA, BAU, BSMRAU and SAU with the coordination of BARC component. The project started on 11 March 2018 through signing of the Letter of Agreement (LoA) with the total project cost of Tk. 36608063 (as revised budget) and continued up to 28 February 2022 with the following general objectives: i. bio-physicochemical characterization of soil in the climate vulnerable and polluted areas; ii. examining potential of different organic materials for amending problem soils and improving crop yields in the study areas; and iii. quantification of the effects of different organic materials on carbon sequestration, improvement of soil properties and crop productivity in the selected areas.

Soil sampling protocol for baseline information 30 composite soil samples collected from each 12 selected Upazillas. Initial soil samples collected at a depth of 0-15 cm. Thus, the total number of samples for 12 study locations (Upazillas) for all components is 360 (30 x 12 x 1). For carrying out the research, replicated and composite initial soil samples were collected at 3 sampling depths (0-15, 15-30, 30-45 cm) from experimental fields. Finally, after completion of field experiments for consecutive three years, post-harvest soil samples were collected and analyzed. Analyses of soil samples were completed for texture, moisture, bulk density, porosity, soil aggregate stability, pH, organic carbon (total, labile and non-labile), nutrients N, P, K, Ca. Mg, Na, S, B, Zn, CEC, water holding capacity, field capacity, biomass C and biomass N, and heavy metals Pb, Cd, Ni, As, by following standard unified protocols. Rice husk was used for biochar production at 300-450˚C using modified developed method (Rahaman et al., 2020). Mineralization and heavy metal adsorption-desorption studies were conducted using the method described by Standford and Smith (1972) and Alam (2020), respectively. A series of field experiments were conducted with different organic materials as treatments for sustainable crop production in climate vulnerable areas of Bangladesh by the seven organizations.

Key results/ Achievements by objectives during sub-project period by the implementing components are; **BARI component** conducted experiment on “Comparative performance of organic material and dolomite for correction of soil acidity” was conducted on Cauliflower-Okra-Indian spinach cropping pattern at Vabla, Belabo. Among all amendments, PM biochar @ 2 t ha^{-1} + 100% RF (T_3 treatment) yielded highest total system (cauliflower) yield of 108.1 t ha^{-1} which is 33.2% yield increase over un-amended chemical fertilizer treated plot (T_6 treatment). “Improvement of soil health in unfavorable eco-systems (drought soil) with organic amendments for sustainable crop production” was conducted on Mustard - Boro - T. aman cropping pattern at Alimgonj, Godagari, Rajshahi. Among all organic amendments, RH biochar @ 2 t ha^{-1} + 100% RF (T_3 treatment) yielded highest total system (rice) yield of 14.4 t ha^{-1} which is 27.7% yield increase over un-amended chemical fertilizer treated plot (T_2 treatment). “Improvement of soil health in unfavorable eco-systems (saline soil) with organic amendments for sustainable crop production” were conducted on Sweet-gourd-Fallow-T. aman cropping pattern at Digolia, Shahos, Dumuria. Among all organic amendments, RH

biochar @ 2 t ha^{-1} + 100% RF (T_3 treatment) yielded highest total system (rice) yield of 14.2 t ha^{-1} which is 328.7% yield increase over un-amended chemical fertilizer treated plot (T_2 treatment). **BRRI component** conducted total 12 experiments at Mirzapur, Pirojali and Sripur during 2018-20 with the objective to ameliorate heavy metal polluted soil and improve rice yield by organic amendment. Biochar, VC, poultry manure, organic fertilizer and bacteria inoculum were applied as organic source along with chemical fertilizer as IPNS basis. OM application rate was 2 t ha^{-1} except bacteria inoculum. In the field experiments, there was little or no significant positive effect found on grain yield of rice due to application of OM's and chemical fertilizer. The studied soils contained high OM and Fe^{+2}, and after 45 days of transplanting severe Fe toxicity appeared in rice plant. There was a positive relationship (r = 0.80) found between soil OM and Fe content of the study areas. There were abundant nutrients due to application of OM but their impact on grain yield was suppressed by Fe toxicity. In general, rice soils of Sripur, Mirzapur and Pirujali were acidic in nature, rich in OM and contaminated with Fe^{++}, Pb, Cd. **BINA component** conducted pot experiment to determine C and N dynamics and other nutrient status in soil. Experiment comprised two factors viz. organic materials (CD: cowdungbioslurry, BC: biochar, OF: organic fertilizer and VC: vermicompost including control meaning only soil) and moisture levels (FC: field capacity and CSW: continuous standing water). Two field experiments were conducted to evaluate the effects of different organic amendments on soil fertility and crop productivity. In case of experiment 1, recommended fertilizer using IPNS + 3.0 t ha^{-1} poultry manure produced higher grain yield (1.77 t ha^{-1}) of mustard. At 15-30cm soil depth, the highest total nitrogen and potassium contents was recorded from T_4 =RF (IPNS) + 3.0 t ha^{-1} vermicompost and T_5=RF (IPNS) + 3.0 t ha^{-1} standard organic fertilizer, respectively. Maximum organic carbon was found at 0-15cm soil depth. Maximum Zn content (0.35 and 0.20 ppm) was obtained from T_1 and T_5 treatments, respectively. In respect of experiment 2, recommended fertilizer using IPNS + 3.0 t ha^{-1} poultry manure produced higher grain and high yields of mustard and lentil over recommended doses of chemical fertilizer. **BAU component** conducted two experiments for two consecutive years in two sites with contrasting soil types and pH: acidic soil in Madhupur (AEZ 28; clay loam soil with low pH) and char land soils in Islampur (AEZ 9; sandy loam soil with near neutral pH). Higher crop yield was recorded from organic amended plots than the chemical alone at both sites, suggesting a possibility of increasing crop production with higher cropping intensity (three crops in the pattern instead of two). The quality of biochars and other organic materials and their field application showed that poultry manure biochar (PMB) may be a potential amendment for improving crop productivity and soil health at both sites. The PMB, organic fertilizer and vermicompost improve soil microbial properties and enzyme activities resulting in higher microbial diversity. Thus, PMB and compost can be recommended as the best nutrient management practices in degraded acidic and char land soils, especially, in terms of cropping system productivity, C sequestration, and soil quality. The key outputs by the Department of Soil Science of **BSMRAU** are: in average, the maximum grain yield 5.43 t/ha was recorded in the T_4 (Poultry Manure + Chemical Fertilizer) treatment which was statistically similar to T_5 (Vermicompost + Chemical Fertilizer) treatment (5.38 t ha^{-1}) followed by T_3 (Biochar + Recommended Fertilizer) treatment (4.66 t ha^{-1}) as compared to the lowest yield (3.56 t ha^{-1}) of T_1 (control) treatment. After consecutive two seasons, the grain yield in T_4 treatment of both T. aman and boro rice was increased by 33-40% over control treatment in all sites. Mineralization and nutrient dynamics of organic materials under the field capacity and continuous standing water at laboratory and field conditions to investigate the impact of various organic materials for determining how fast organic matter mineralizes and releases nutrients into the soil. The soil was treated with six types of organic materials, *viz.* cowdung (CD), cowdung slurry (CDS), rice husk biochar (RHB), vermicompost (VC), Tricocompost (TC) and bacterial inoculant (BI) under field capacity and continuous standing water condition with control treatment. At incubation periods, different organic materials have a significant impact on carbon, nitrogen, ammonium and nitrate

nitrogen mineralization in soils at different days after incubation. The similar mineralization trends of carbon and nitrogen maintained the order of CDS>CD>VC>TC>BI>RHB>Control and CDS>CD>VC>TC>BI>RHB>Control respectively both in the laboratory and field conditions. The trend of heavy metals (Pb, Cd and Ni) adsorption and desorption capacities were found with the following orders of RHB>VC>CD>CDS>TC and TC>CDS>CD>VC>RHB, respectively. The significantly positive impact exhibited in different organic matters on carbon sequestration in soil and the highest was observed in biochar treated plot. Similar trend of results was found in case of stable aggregate content in soils. **SAU component** conducted experiment on "Improvement of soil health in unfavorable eco-systems (saline soil) with organic amendments for sustainable crop production." It was conducted on maize and T. aman at two sites in Nilgonj and in Latachapli union of Kalapara under Patuakhali district. Data obtained from second year (2020) field experiments of maize under mulch condition showed that the highest grain yield (8.83 t ha^{-1} at Nilganj and 6.83 t ha^{-1} at Latachapli sites) was recorded from treatment T_3 (rice husk biochar @ 2 t ha^{-1} + 100% chemical fertilizer), whereas under non-mulch condition, the highest grain yield (8.66 t ha^{-1} at Nilgonj and 6.56 t ha^{-1} at Latachapli sites) was also from the same treatment. Maximum grain yield of T. aman rice cultivation of 2020 (4.43 t ha^{-1} at Nilgonj and 3.76 t ha^{-1} at Latachapli sites) at Kalapara, Patuakhali were obtained from rice husk biochar @ 2 t ha^{-1} + 100% chemical fertilizer) treated plot. On the other hand, the lowest grain yield of maize (both mulch and non-mulch condition) and T. aman was obtained in control condition. From postharvest soil analysis, it is clearly found that more organic carbon sequestration has been found in the plots which were treated with biochar organic amendment than other organic materials treated plots. From the data of different Table, it is found that treatment T_3 receiving 100% recommended fertilizer along with 2 t ha^{-1} rice huskbiochar successfully reduces the accumulation of Na ion in soil as well less Na^+ in plant tissue and thus accelerate more uptake of K^+ ion by plant than other treatments.

Concluding statement/recommendations:

- **i.** Biochar showed the potential for ameliorating problem soils by increasing MBC, MBN, carbon sequestration, soil aggregate stability and also adsorption of heavy metals as compared to other organic materials. Increase yield of crops were also recorded in all selected problem soils. Therefore, application of biochar can be suggested to use as organic materials to soils in order to increase soil carbon, improve soil health mitigate global warming.
- **ii.** Other organic amendments (vermi-compost, Tricho-compost, poultry manure, household wastes, organic fertilizers, crop residues, biochar etc.) improve soil resilience and increase its productive capacity in the climate vulnerable and polluted areas.
- **iii.** SDGs can be achieved by maintaining soil health through organic amendments because of its direct connection with food security, reduction of hunger, adaptation to and mitigation of climate change, and water quality.
- **iv.** Further studies are needed for management of other problem soils to strengthen food security and national progress.

Keywords: Adsorption and desorption; Biochar; Bio-physicochemical; Carbon sequestration; Dolomite; Mineralization; Organic amendments; Problem soils

PBRG Sub-project Completion Report (PCR)

A. Sub-project Description

1. **Title of the PBRG sub-project:** Improvement of soil health and crop productivity of major problem soils of Bangladesh through organic amendments.

2. **Implementing organization (s):**

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Implementing Organization		
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6.	**SSD, SAU**	Prof. Dr. Alok Kumar Paul, Professor, SSD, SAU- PI

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	Dr. Sultan Ahmmed	From 04-09-2018 to 04-08-2020
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4. Sub-project budget (Tk.):

4.1 Total: (in Tk. As **37126906.00** (Three crore seventy one lac twenty six thousand nine hundred six) approved

4.2 Latest Revised: (in Tk. as **36608063.00** (Three crore sixty six lac eight thousand sixty three) revised

5. Duration of the sub-project:

5.1 Start date (based on LoA signed): March, 2018

5.2 End date: February, 2022

6. Background of the sub-project: Application of chemical fertilizers has been increasing in the world for enhancing cropping diversity and intensity for feeding the teeming population. However, sole application of chemical fertilizers not only increased economic loss but also caused several concerns for soil biological and physico-chemical degradation. Climate change, buildup of soil salinity and acidity, development of heavy metals including arsenic are major concerns which degrade soil health and hinder crop production in Bangladesh (Rahman et al., 2005; Akter et al. 2012; Rahman et al., 2016). Soil is regarded as the primary recipient of toxic elements such as heavy metals (Karim et al, 2014), especially the top soils (0-25 cm) are mostly contaminated through different industrial activities. Micronutrients of the soil are essential for plant growth however; they can be toxic when it exceeds its threshold concentration. Heavy metals do not attend in any metabolic activities but they also accumulate in the soil layers. Soil microbes are responsible for all kinds of biogeochemical activities in terrestrial soil including nutrient cycling and promote plant growth. During last two decades, Bangladesh has experienced a dramatic expansion of industrialization. Sripur-Gazipur is considered as one of the most important industrial areas in Bangladesh. Bangladesh is one of the most climate vulnerable countries in the world. The effects of climate change in agriculture can no longer be ignored and further climate risks to agriculture are expected to increase in coming decades (World Bank, 2012). Productivity of different crops in Bangladesh has been decreased because of degradation of soil health through adverse climatic events and pollution of different sources. Salinity is an environmental problem which is expected to aggravate because of climate change and sea level rise (IWM, 2014). Soil and water salinity is a burning issue which is increasing at an alarming rate in the coastal areas. Increasing soil acidity is also a major concern, especially in the Madhupur Tract. High concentration of different heavy metals in soils of industrial areas and arsenic in soils mainly in the Ganges Floodplains may cause reduction in crop yields as well as long term risks to ecosystems and humans health. The present rice production in the country is 34.86 MT (AIS, 2016), which needs to increase 44.5 MT in 2050 (Kabir et al., 2015). To ensure the food security in the south Asia it is estimated that annual rice and wheat production has to be increased by 1.1% and 1.7%, respectively in the next four decades (Ladha et al., 2003; Gathala et al., 2013). Moreover, the agricultural land is declining every year by 1% because of new human

settlement, industrial expansion and road construction in many Asian countries including Bangladesh and India. Globally, it is estimated that feeding the world population will require 60% more yield in 2050 (FAO, 2014). Such an increase in agricultural production needs to be accomplished without jeopardizing soil and environment. Agriculture sector has some impact on climate change through greenhouse gas (GHG) emission, while the sector not only emits greenhouse gases, but also can sequester huge amount of carbon in soil if managed properly (Rahman, 2013; Rahman *et al.,* 2016). It is hypothesized that resource conservation technologies comprising soil and crop management practices (minimum tillage, vermi-compost, tricho-compost, poultry manure, household wastes, organic fertilizers, crop residues, biochar etc.) can improve soil resilience and increase its productive capacity in the climate vulnerable and polluted areas and therefore studies are needed in these issues.

7. Sub-project general objective (s):

i. Bio-physicochemical characterization of soil in the climate vulnerable and polluted areas
ii. Examine potentiality of different organic materials for amending problem soils and improving crop yields in the study areas
iii. Quantify the effects of different organic materials on carbon sequestration
iv. Development of climate smart technology packages for major crops and cropping patterns in Bangladesh.

8. Sub-project specific objectives (component wise):

Components	Specific objectives
BARC	**i.** To coordinate, supervise, monitor and evaluate the project activities of the component organizations. **ii.** To compile, edit and finalize the reports and submit to PIU-BARC
BARI	**iii.** Characterize the bio-physicochemical properties of soil in the climate vulnerable areas of Dumuria (saline), Godagari (drought) and acidic soils of Belabo **iv.** Evaluate the effect of organic materials for amending acid soil in Belabo, drought prone soil in Godagari and saline soil in Dumuria. **v.** Mineralization study of organic materials and assess their effect on carbon sequestration, soil properties improvement and crop productivity in the selected areas
BRRI	**i.** To characterize the bio-physico-chemical properties of soil in heavy metal polluted areas of Sripur, Gazipur **ii.** To determine mineralization rate of organic materials and evaluate the effect of organic materials for amelioration of heavy metal pollution in Sripur, Gazipur industrial areas **iii.** To determine the effect of organic materials on crop yield and soil health
BINA	**i.** Characterize the bio-physico-chemical properties of soil in the drought prone areas of Nachole, ChapaiNawabganj **ii.** Mineralization study of organic materials and assess the effect of organic materials on carbon sequestration **iii.** Evaluate the effect of tillage methods, amendment and mulch practices of organic residues on soil and crops

BAU	**i.** To characterize the biological and physico-chemical properties of problem soils of charland (Char Dadna, Islampur) and acidic soils (Madhupur) **ii.** To prepare and characterise biochars from different organic sources for amending acid and char land soils **iii.** To investigate effect of biochars and other organic amendments on crop yields, soil health and carbon sequestration **iv.** To measure carbon and N mineralization rate and to evaluate the effect of organic materials for amending acid soils of Madhupur and char land of Islampur.
BSMRAU	**i.** Characterize the bio-physicochemical properties of soil in the climate vulnerable Dekar haor areas of Sunamganj, arsenic area of Faridpur sadar, saline areas of Batiaghata and heavy metal polluted areas of Bhaluka using different organic amendments **ii.** Evaluate the adsorption and desorption isotherms of heavy metals using organic materials including biochar for amending heavy metals in Bhaluka. **iii.** Mineralization study of organic materials and their effects of climate vulnerable and arsenic and heavy metal polluted areas on soil properties and crop productivity and carbon sequestration in the selected areas.
SAU	**i.** Characterize the bio-physico-chemical properties of soil in the saline prone areas of Kalapara, Patuakhali; **ii.** Mineralization study of selected organic materials and assess the effect of organic materials on carbon sequestration and **iii.** Evaluate the effect of organic materials for amending saline soils in the coastal areas of Kalapara, Patuakhali.

9. Implementing location (s):

Organization	Problem Soils Types	Study Location
BARI	Saline, Drought & Acidic	Saline-Dumuria, Drought Godagari Acidic Soils-Belabo
BRRI	Heavy Metal Polluted Soils	Sreepur/Gazipur Industrial Areas
BINA	Drought Prone Soils	Nachole, Chapai Nawabganj
BAU	Charland & Acidic Soils	Char Land-Dadna, Islampur Acidic soils-Modhupur
BSMRAU	Haor Land, Arsenic & Other Heavy Metal Polluted & Saline Soils	Haor –Sunamganj Arsenic-Faridpur, Other heavy metal-Bhaluka, Saline-Batiaghata
SAU	Saline Prone Soils	Kalapara, Patuakhali

10. Methodology in Brief (with appropriate pictures):

BARI Component

Activity 1: Bio-physicochemical analysis of soil in the major problem soils of Dumuria (saline), Godagari (drought) and Belabo (acidic) Soil samples were collected from three vulnerable sites of saline soil (Dumuria, Khulna), drought soil (Godagari, Rajshahi) and acidic soil (Belabo, Narsingdi) were selected for bench mark survey and field experimentation. All the samples will be analyzed for texture, moisture, bulk density, porosity, soil aggregate stability, pH, organic carbon, nutrients N, P, K, Ca, Mg, Na, S, B,

Zn, CEC, water holding capacity, field capacity, biomass C and biomass N, heavy metals Pb, Cd, Ni, As contents following standard protocols (Page *et al*., 1989). Carbon stock and C sequestration will be calculated using the following equation 1 and 2, respectively (Rahman *et al*., 2016).

Carbon stock (t ha^{-1}) = Carbon concentration (%) x bulk density (g cm^{-3}) x depth (cm) ….. (1)

Carbon sequestration (t ha^{-1}) = Final C stock (t ha^{-1}) – Initial C stock (t ha^{-1}) …….. (2)

Biochar production and analyzed

Production of biochar using different available sources (Rice husk, rice straw, maize stover, mustard stover, saw dust, poultry manure etc) were collected and air-dried at room temperature and ground to pass a 10-mesh sieve. The ground crop residues will be then placed in biochar plant. The pyrolysis temperature was control as per requirement and then biochar allowed to cool at room temperature and ground to pass a 60-mesh sieve. Water holding capacity, microbial and organic carbon stability, pH, CEC, N, P, K, S etc. will be analyzed using appropriate methods. The pH values of the soil samples and biochars were mixed with deionized water and determined using a glass electrode (1:2.5 w/v for soil; 1:10 w/v for biochar) (Thomas, 1996). The soil particle-size distribution was determined using a pipette method (Sumner and Miller, 1996). The cation exchange capacity (CEC) was determined using an ammonium acetate method (pH 7.0) (Nelson and Sommers, 1996). The organic C content of the tested soils was determined using a wet oxidation method. The total N was measured using the semi-micro-Kjeldahl procedure (Bremner and Mulvaney, 1982). The inorganic N was extracted using 2 M KCl (1:10 w/v); concentrations of NH4 + -N and NO3 − -N were estimated using steam distillation involving MgO and the Devarda alloy (Mulvaney, 1996).

Activity 2: Mineralization study of organic materials and assess their effect on carbon sequestration, soil properties improvement and crop productivity in the selected areas.
Incubation experiment in amended soils, laboratory incubation is generally used to obtain accurate information about C-mineralization dynamics, and the data can then be fitted to/with kinetic models in order to obtain complementary information such as the C mineralization rates. Therefore, a laboratory under two moisture level field capacity and standing water incubation experiment over 120 days was conducted to study and evaluate C mineralization kinetics in a non-amended soil (i.e. the control) with four types of organic materials (Rice husk biochar, Poultry manure biochar, Vermin-compost, Cow dung, Cowdung slurry, Mazim organic fertilizer, Poultry manure) application. Additionally, lime was used as comparison for acidity amelioration. Totally nine treatments were performed in acid soil study and eight treatments performed for saline and drought soil study and each treatment was set up in triplicate. Organic materials (1.5 g C kg^{-1} soil) will be mixed thoroughly with soil and kept for 9 incubation periods (0, 3, 7, 15, 21, 30, 60, 90, and 120 days). The soil samples were incubated at room temperature (~30˚C). The moisture of the soil was kept at field capacity condition by using distilled water. Soil samples were collected by destructive method. Plastic containers were arranged in completely randomized way. Carbon mineralization rate (k) will be calculated using the following kinetic model (Standford and Smith, 1972).

$C/C_0 = (1-e^{-kt})$ …… (3)

C, C_0, k and t indicate final C, initial C, degradation rate constant and time, respectively. Labile and non-labile fractions of C were determined**.** Along with C mineralization, nitrogendynamics (NH_4^+-N and NO_3^--N) will also be quantified.

Activity 3: Evaluate the effect of organic materials for amending acid soil in Belabo, saline soil in Dumuria and drought soil in Godagari

Improvement of acid soil (at Belabo) management under Cauliflower-Okra-Indian Spinach cropping pattern through organic amendments. There are six treatments viz. absolute control, PM @ 3 t ha^{-1} + IPNSbased inorganic fertilizer, PM biochar @ 2 t ha^{-1}+ IPNSbased inorganic fertilizer, Rice Husk biochar @ 2 t/ha + IPNS based inorganic fertilizer, Dolomite @ 1 t ha^{-1}+ 100% recommended dose chemical fertilizer (RDCF) and 100% RDCF. For drought (Godagari, Rajshahi) and saline (Dumuria, Khulna) soil management, there are Six treatment including Control, 100% RDCF, Biochar (2 t/ha) +100% RDCF, Poultry manure 3 t/ha + rest of the nutrients from chemical fertilizers, Vermicompost 3 t/ha + rest of the nutrients from chemical fertilizers, Organic fertilizer 3 t/ha + rest of the nutrients from chemical fertilizer were applied. Mustard-Boro-T. Aman for drought soil and Sweet gourd- Fallow-T. Aman cropping pattern were followed RCBD with three replications.

Statistical Analysis

The statistical analyses (calculation of means and standard deviations, differences of means) were performed using Statistix 10 package. Results were analyzed by analysis of variance (one-way ANOVA) to test the effects of each treatment. The statistical significance of the mean differences was determined using the least-significant difference (LSD) tests based on a t-test at a 0.05-probability level.

BRRI Component

Industrial polluted area is now a major problem for rice production. Reclamation of such soil and improvement of crop productivity of that soil is a crucial need. To restore soil health with higher crop yield, project activities was performed in three steps. The way for implementing actions to achieve objectives of the study were described under 3 activities:

Activity 1: Benchmark survey to characterize bio-physicochemical properties of the soil of Sripur- Gazipur areas

Specific objective: To characterize the bio-physico-chemical properties of soil in heavy metal polluted areas of Sripur, Gazipur

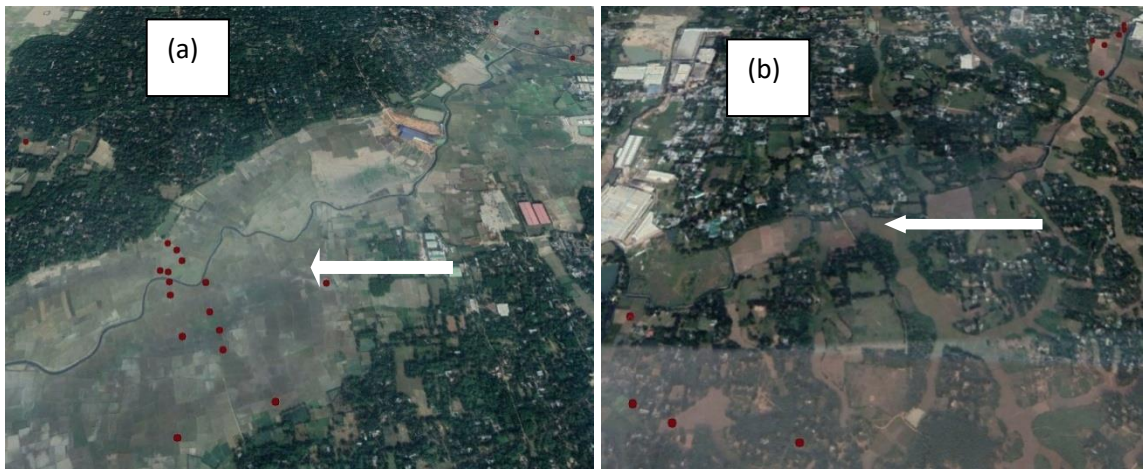
Benchmark Survey: Selected study area was the industrial polluted rice soils of Sripur**,** Gazipur. To fulfill the objectives of the study a benchmark survey was done of the study area. Soil samples were collected from 3 different unions (GPS reading) considering 0-15 soil depths which was replicated 4 locations in each site. All of the samples were analyzed for pH, organic carbon and nutrients N, P, K, Ca. Mg, Na, S, Zn, Fe Pb, Cd, Ni, and As contents. Soil microbial population (bacteria, fungus and actinomycetes) was recorded. A total 30 soil samples (composite of 300 points) were collected and analyzed following methods in Table 1.

Table 1. Methods of soil samples analysis

Parameters	**Methods**
Organic C	Wet oxidation method (Page et al. 1989)
Total N	Kjeldhal systems (Bremner and Mulvaney1982)
Available P	Olsen and Bray method
Ca, Mg, K & Na	Ammonium acetate method
Fe, Cu, Zn, Mn	DTPA
Pd, Cd, Cr	Di-acid extraction method, HNO_3: $HClO_4$ = 2.5:1

Total Bacteria	Nutrient Agar (total plate count)
Fungus	PDA media (total plate count)
Actinomycetes	Acetinimycetes Agar plate
N_2- fixing bacteria	N_2 free media
Phosphate Solubilizing Bacteria (PSB)	Modified Pykovasakaya media

Soil samples were collected after harvest of T. Aman rice by maintaining distance 5m to 500 meter apart from contaminated channel. At Boro season field were irrigated using this contaminated channel water. For benchmark survey 20 samples were collected form Mirzapur and Pirojali union and 10 samples were collected from Sripur industrial area. Soil samples were collected using GPS (Table 2).



a) Satellite map showing the benchmark survey points (red bullets) of Pirojali (North side of channel) and Mirzapur (South side of channel), Gazipur. Arrow showing the contaminated irrigation channel.
b) Satellite map showing the benchmark survey points (red bullets) of Sripur Gazipur. Arrow showing the contaminated irrigation channel.

Table 2. Location of collected soil samples for bench mark survey from Sripur and Gazipur after harvest of T. Aman rice during 2018

Location	**GPS reading (º)**		**Land type**	**Remarks**
	Latitude	Longitude		
*Mirer Vita, Madhukhola, Sripur	24.18151	90.44207	Medium highland	Nearest to polluted cannel (50 M)
**Mirer Vita, Madhukhola, Sripur	24.17949	90.44277	Medium highland	Nearest to polluted cannel (50 M)
*Mirer Vita, Madhukhola, Sripur	24.17912	90.44378	Medium highland	Nearest to polluted cannel (200 M)
*Mirer Vita, Madhukhola, Sripur	24.17880	90.44671	Medium highland	Nearest to polluted cannel (500 M)
*South Bangnahati, Sripur	24.19271	90.45675	Medium highland	Nearest to polluted cannel (30 M)
*South Bangnahati, Sripur	24.19247	90.45672	Medium highland	Nearest to polluted cannel (30 M) but far from factory (100M)
*South Bangnahati, Sripur	24.19220	90.45647	Medium highland	Nearest to polluted cannel (50 M) but far from factory (200M)
*South Bangnahati, Sripur	24.19167	90.45585	Medium highland	Middle point of polluted Cannel (200 M)

*South Bangnahati, Sripur	24.19187	90.45546	Medium highland	Not polluted by Cannel
*South Bangnahati, Sripur	24.19030	90.45549	Medium highland	Far from Factory but polluted by cannel water
***Pirojali, Gazipur Sadar	24.11615000	90.216500	Medium lowland	Nearest to polluted cannel (2M)
***Pirojali, Gazipur Sadar	24.116110000	90.216670	Medium lowland	Nearest to polluted cannel (10M)
***Pirojali, Gazipur Sadar	24.11651667	90.216920	Medium lowland	Distance from polluted cannel (100M)
***Pirojali, Gazipur Sadar	24.11693333	90.216780	Medium lowland	Distance from polluted cannel (200M)
***Pirojali, Gazipur Sadar	24.11720000	90.216570	Medium lowland	Distance from polluted cannel (300M)
***Pirojali, Gazipur Sadar	24.11573333	90.216720	Medium lowland	Distance from polluted cannel (10M)
***Pirojali, Gazipur Sadar	24.11526667	90.216780	Medium lowland	Distance from polluted cannel (200M)
***Pirojali, Gazipur Sadar	24.11388333	90.217120	Medium lowland	Distance from polluted cannel (500M)
***Pirojali, Gazipur Sadar	24.11408333	90.217820	Medium lowland	Distance from polluted cannel (600M)
***Pirojali, Gazipur Sadar	24.11468333	90.217600	Medium lowland	Distance from polluted cannel (400M)
***Pirojali, Gazipur Sadar	24.2411571667	90.217460	Medium lowland	Distance from polluted cannel (50M)
***Pirojali, Gazipur Sadar	24.18845000	90.217040	Medium lowland	Distance from polluted cannel (600M)
****Pirojali, Gazipur Sadar	24.12171667	90.212770	Medium high land	Waste free four crops
***Purbo Dogori, Mirzapur, Gazipur Sadar	24.12676	90.37834	Medium Lowland	Close to Cannel (2 M), Highly contaminated
***Purbo Dogori, Mirzapur, Gazipur Sadar	24.12855	90.37718	Medium Lowland	Distance from Cannel (10 M), Highly contaminated
***Purbo Dogori, Mirzapur, Gazipur Sadar	24.12919	90.37534	Medium Lowland	Distance from Cannel (100 M)
***Purbo Dogori, Mirzapur, Gazipur Sadar	24.11193	90.36486	Medium Lowland	Distance from Cannel (400 M)
***Purbo Dogori, Mirzapur, Gazipur Sadar	24.11346	90.36319	Medium Lowland	Distance from Cannel (200 M)
***Purbo Dogori, Mirzapur, Gazipur Sadar	24.11098	90.36207	Medium Lowland	Distance from Cannel (100 M)
***Purbo Dogori, Mirzapur, Gazipur Sadar	24.11569	90.36652	Medium high land	Distance from Cannel (400 M)

a) *About 3 months under contaminated water (land inundate due to over flow of cannel, Irrigate using cannel water). Rice cropping pattern (Boro–Fallow- T. Aman).

b) ** Always inundate with polluted factory water directly by the factory. Rice cropping pattern (Boro–Fallow- T. Aman).

c) *** About 6-7 months under contaminated water. But crop cultivate using non-polluted irrigation water. Rice cropping pattern (Boro–Fallow- Fallow).

A total 30 soil samples (300 points) were collected from Sripur- Gazipur.

Pictures: Soil Sample collection at different places of Sripur-Gazipur

Activity 2: Study of the mineralization rate of nutrient after organic amendment in the industrial polluted soil under continuous standing water conditions (incubation study)

A laboratory incubation study was performed in the activity 2, using different organic sources and maintaining continuous flooding moisture regimes. Polluted and un-polluted soils (250 g) were incubated at room temperature with different organic sources (1.25 g C kg^{-1} soil + chemical NPK as INMS) for 90 days.

Treatments and deign of experiment:

a) Soil category (polluted and un-polluted),
b) Organic materials (Vermicompost and rice husk biochar)

Study was performed following completely randomized design with 2 factors and 3 replications.

Factor A: Soil

Polluted (S_1) and Un-polluted soil (S_2)

Factor B: Fertilizer

Rice husk biochar + IPNS, Vermicompost + IPNS, Chemical fertilizer and Control

Data collection:

Data were collected for total organic C, NH_4-N, available P, Exch. K, Fe, Cu, Mn, Zn, Pb, Cd, Cr and microbial population. Soil samplings were done at 0, 3, 7, 15, 21, 30, 45, 60 and 90 days interval. A destructive sampling method was followed.
Carbon mineralization rate *(r)* was calculated using the following kinetic model (Standford and Smith, 1972).

$C/C_0 = (1-e^{-kt})$ …… (2)

C, C_0, k and t indicate final C, initial C, degradation rate constant and time, respectively. Other soil parameters were done following standard protocol described in Activity 1.

Activity 3: Improvement of industrial polluted soil health with organic amendments for sustainable crop production

Specific objective: To determine the effect of organic materials on crop yield and soil health
To fulfill the objective a number of total 9 field experiments were conducted in (Boro 2018-2019) at three different locations of Mirzapur, Pirojali and Sripur. An experiment was conducted at Sripur

farmer's field in T. Aman 2019. Soils of Mirzapur and Pirujali were inundated during T. Aman season and not suitable to conduct experiment. Three experiments were conducted in the Boro 2019-20. The treatments were described in Table 3:

Table 3. Treatment description of field experiments at Sripur and Gazipur conducted during study period.

1) Location: Mirzapur **Year: Boro 2018-19** **Treatment:** **T_1=** Vermicompost 3 ton/ha + IPNS (N-P-K-S @40-0-48-10) **T_2=** Biocher 2 ton/ha + Chemical fertilizer (N-P-K-S @100-20-80-10) **T_3=** Mazim OF 3 ton/ha + (N-P-K-S @40-0-35-10) **T_4=** Chemical fertilizer (N-P-K-S @100-20-80-10) **T_5=** No Fertilizer Design RCBD with 3 reps Each Plot Size: 5m X 6m Variety: BRRI dhan29 Farmer's name: Amdad Hossain	**2) Location: Pirujali** **Year: Boro 2018-19** **Treatment:** **T_1=** Vermicompost 3 ton/ha + IPNS (N-P-K-S @40-0-48-10) **T_2=** Biocher 2 ton/ha + Chemical fertilizer (N-P-K-S @100-20-80-10) **T_3=** Mazim OF 3 ton/ha + (N-P-K-S @40-0-35-10) **T_4=** Chemical fertilizer (N-P-K-S @100-20-80-10) **T_5=** No Fertilizer Design RCBD with 3 reps Each Plot Size: 5m X 6m Variety: BRRI dhan29 Farmer's name: Kitab Ali
3) Location: Pirujali **Year: Boro 2018-19** **Treatment:** **T_1=** Vermicompost 3 ton/ha + IPNS (N-P-K- S @40-0-48-10) **T_2=** Poultry manure 3 ton/ha + IPNS (N-P-K-S @40-0-40-10) **T_3=** Mazim OF 3 ton/ha + (N-P-K-S @40- 0- 35-10) **T_4=** Chemical fertilizer (N-P-K-S @100-20- 80-10) **T_5=** No Fertilizer Design RCBD with 3 reps Each Plot Size: 5m X 6m Variety: BRRI dhan28 Farmer's name: Anish Ali	**4) Location: Sripur** **Year : Boro 2018-19** **Treatment:** **T_1=** Biochar 2 ton/ha + 80 kg/ha K **T_2=** 100 kg/ha k **T_3=** Biochar 2 ton/ha **T_4=** Chemical fertilizer (N-P-K-S @100-20-80-10) **T_5=** No Fertilizer Design RCBD with 3 reps Each Plot Size: 5m X 6m Variety: Hira (Hybrid) Date of transplanting : 13/01/2019 Farmer's name: Abul Hossain
5) Location: Mirzapur **Year: Boro 2018-19** **Treatment:** **T_1=** Vermicompost 3 ton/ha + IPNS (N-P-K-S @40-0-48-10) **T_2=** Biocher 2 ton/ha + Chemical fertilizer (N-P-K-S @100-20-80-10) **T_3=** Mazim OF 3 ton/ha + (N-P-K-S @40-0-35-10) **T_4=** Chemical fertilizer (N-P-K-S @100-20- 80-10) **T_5=** No Fertilizer Design RCBD with 3 reps Each Plot Size: 5m X 6m	**6) Location: Mirzapur** **Year: Boro 2018-19** **Treatment:** **T_1=** Vermicompost 3 ton/ha + IPNS (N-P-K-S @40-0-48-10) **T_2=** Biocher 2 ton/ha + Chemical fertilizer (N-P-K-S @100-20-80-10) **T_3=** Mazim OF 3 ton/ha + (N-P-K-S @40-0-35-10) **T_4=** Chemical fertilizer (N-P-K-S @100-20-80-10) **T_5=** No Fertilizer

Variety: BRRI dhan29 Farmer's name: Ainal Haque	Design RCBD with 3 reps Each Plot Size: 5m X 6m Variety: BRRI dhan29 Farmer's name: Md. Rafiqul Islam
7) Location: Sripur **Year: Boro 2018-19** **Treatment:** **T_1=** Vermicompost 3 ton/ha + IPNS (N-P-K- S @40-0-48-10) **T_2=** Biocher 2 ton/ha + Chemical fertilizer (N-P-K-S @100-20-80-10) **T_3=** Mazim OF 3 ton/ha + (N-P-K-S @40-0- 35-10) **T_4=** Chemical fertilizer (N-P-K-S @100-20- 80-10) **T_5=** No Fertilizer Design RCBD with 3 reps Each Plot Size: 5m X 6m Variety: BRRI dhan29 Farmer's name: Md. Rafiqul Islam	**8) Location: Sripur** **Year: Boro 2018-19** **Treatment:** **T_1=** Vermicompost 3 ton/ha + IPNS (N-P-K-S @40-0-48-10) **T_2=** Biocher 2 ton/ha + Chemical fertilizer (N-P-K-S @100-20-80-10) **T_3=** Mazim OF 3 ton/ha + (N-P-K-S @40-0-35-10) **T_4=** Chemical fertilizer (N-P-K-S @100-20-80-10) **T_5=** No Fertilizer Design RCBD with 3 reps Each Plot Size: 5m X 6m Variety: BRRI dhan29 Farmer's name: Md. Rafiqul Islam
9) Location: Sripur **Year: Boro 2018-19** **Treatment:** **T_1=** Vermicompost 3 ton/ha + IPNS (N-P-K-S @40-0-48-10) **T_2=** Biocher 2 ton/ha + Chemical fertilizer (N-P-K-S @100-20-80-10) **T_3=** Mazim OF 3 ton/ha + (N-P-K-S @40-0-35-10) **T_4=** Chemical fertilizer (N-P-K-S @100-20- 80-10) **T_5=** No Fertilizer Design RCBD with 3 reps Each Plot Size: 5m X 6m Variety: BRRI dhan29 Farmer's name: Md. Nasir Uddin	**10**) **Location: Sripur** **Year: T. Aman 2019** **Treatment:** **T_1 =** Control **T_2 =** Biochar (2 ton /ha) + IPNS **T_3 =** Balanced Chemical fertilizer **T_4 =** Bacterial inoculum (Bacillus spp) **T_5** = Vermicompost (2 ton /ha) + IPNS Design RCBD with 3 reps Each Plot Size: 8m X 4m Variety: BRRI dhan49 Farmer's name: Md. Rafiqul Islam
11) Location: Sripur, Mirzapur, Pirujali **Year: Boro 2019-20** **Treatment:** **T_1 =** Inoculum + Chemical fertilizer (N-P-K-S @100-20-80-10) **T_2 =** Biochar (2 ton /ha) + IPNS **T_3 =** Vermicompost + IPNS **T_4 =** Chemical fertilizer (N-P-K-S @100-20-80-10) **T_5 =** Control Design RCBD with 3 reps Each Plot Size: 5m X 6m Variety: BRRI dhan29 Farmer's name: Md. Rafiqul Islam.	

Data collection:

Data Collection: Plant growth and yield parameter and plant nutrient uptake were determined after harvest of every crop.

BINA Component

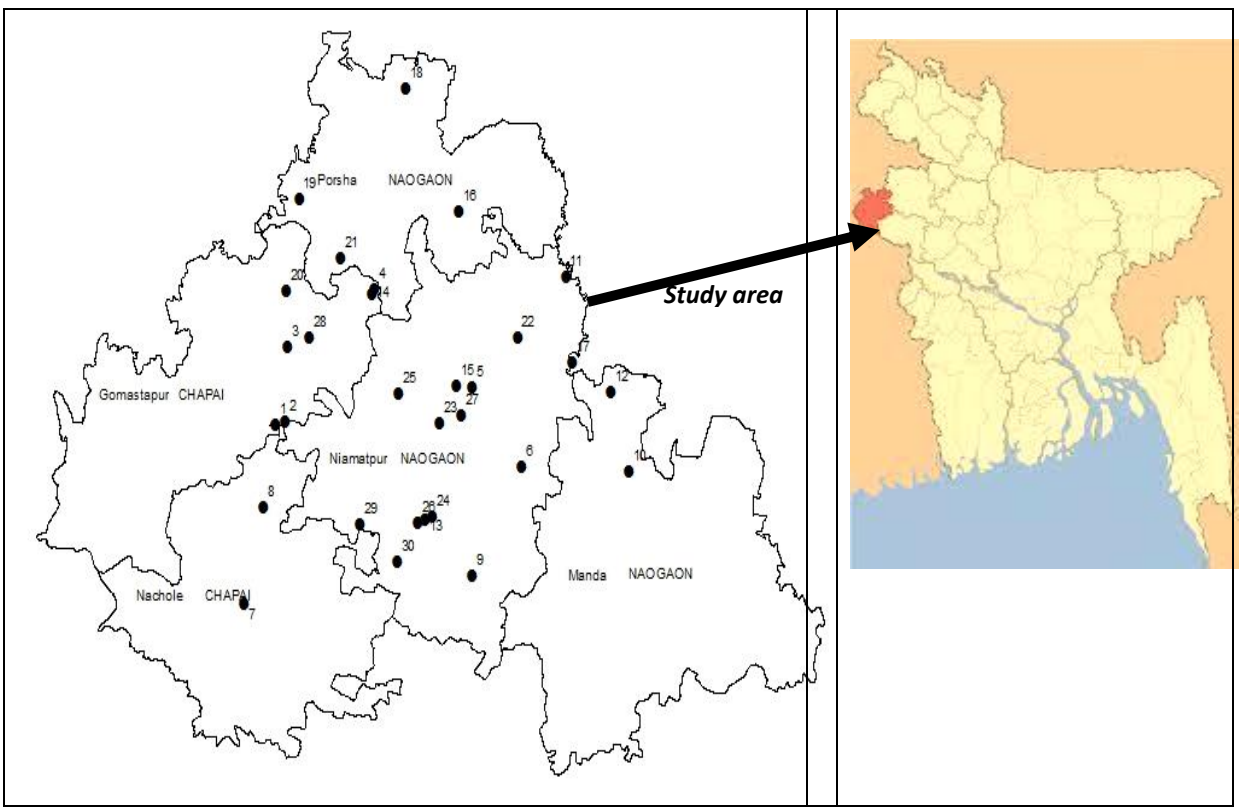
Experiment 1: Benchmark survey to characterize biophysico- chemical properties of soil in the selected study areas

Site description

The research area is located in drought prone areas at north-wastern part (24°40'262"N-24°48'881"N and 88°17'752"E-88°28'832"E) of Bangladesh (Figure 1 and Table 4). The mean elevation is 25 m. The mean annual precipitation and mean annual temperature are 160 mm and 25°C, respectively. A total of 30 composite soil samples (3 samples/spot) were collected from (0 – 15 cm depth) from different locations with GPS information.

Soil preparation for analysis

Collected soil samples were brought to the Soil Science Laboratory, Bangladesh Institute of Nuclear Agriculture (BINA), Mymensingh.Soil samples were air dried, ground and passed through a 2-mm sieve and prepared for routine analysis of texture with particle size (%sand, silt and clay), colour, bulk density, moisture content, water holding capacity, porosity, void ration, pH, organic, inorganic, active and passive carbon, microbial biomass C, nitrogen content, available phosphorus, extractable K, Ca, Na, Fe, Cu, Mn and Zn. Fresh soil was used for microbial biomass C determination.



Map showing the soil sampling sites of drought prone areas of Bangladesh

Soil texture

Particles size (sand, silt and clay)distributions were analyzed using a laser particle size analyzer (Microtrac S3500, USA). Microtrac S3500 particle size analyzer with a 780 nm wavelength laser beam was used for studying particle size distribution (PSD) of soil samples. The analysis was carried out in the laboratory of Soil Science Division, BINA. A pinch amount of soil was used for particle size analysis. Microtrac employs three lasers to emit laser light into particles from the best angle. Microtrac FLEX software was used for the percentage of sand, silt and clay particles and these size fractions were used for the determination of soil texture with the help of triangular diagram designed by Marshall by Marshal.

Table 4. General soil information of sampling sites

Districts	Upazilla	Total area(ha)	AEZs	Land types(no.)	Soil series(no.)	General soil types
Chapainawanganj	Nachole	283.68				
	Gomostapur	26116	6, 11, 26	5	17	5
Naogaon	Porsha	25282	6, 25, 26	5	7	5
	Niamatpur	44931	11, 25, 26	5	14	5
	Manda	40982	3, 11, 25	5	23	5

Bulk density

Bulk density is measured by the following equation:

$$\text{Bulk density (g cm}^{-3}\text{)} = \frac{\text{Weight of the dry soil}}{\text{Volume of the soil}}$$

Soil bulk density is defined as the oven-dry weight of soil per unit of its bulk volume. Bulk density is expressed in the unit of g/cm^3.

Soil moisture (%)

Soil samples were collected by auger from three spots per sample. Moist samples were weighed immediately, dried to constant weight in an oven at 105 ^{0}C (for about 48 hours) and reweighted after cooling in desiccator. Calculate the soil moisture content by determining the loss in weight on drying and the weight of the oven soil as follows:

$$\text{Soil moisture content (\%)} = \frac{\text{(wt. of wet soil + core wt.)} - \text{(wt. of dry soil + core wt.)}}{\text{(wt. of wet soil + core wt.)}} \times 100$$

Porosity

The space in the soil is occupie by air and water termed as pore space or porosity.

$$\%\text{Porosity} = \left[1 - \frac{\text{Particle density of soil}}{\text{Bulk density of soil}}\right] \times 100$$

Void ratio

Void ratio is defined as the raion of the volume of the pores to the solids and is expressed as:

$$\text{Void ratio} = \frac{\text{Particle density of soil}}{\text{Bulk density of soil}}$$

Soil pH

Soil pH was determined by glass electrode pH meter. Ten grams of air dried soil was taken in 50 ml beaker and 25 ml of distilled water added to each beaker. The suspension was stirred well for several times during the next 30 minutes and allowed to stand for about an hour.

Then the electrode was immersed into partly settled soil suspension and read the pH by glass-electrode meter.

Soil organic matter

Organic carbon was determined titrimetrically using Walkley and Black method with oxidation of organic matter using potassium dichromate ($K_2Cr_2O_7$). Briefly, 1g soil along with 10 ml 1N $K_2Cr_2O_7$ solution and 20 ml of Cone. H_2SO_4 was taken in a 500 ml conical flask. After 30 minutes rest, about 200 ml distilled water and 10 ml concentrated H_3PO_4 was added. 10-15 drops of diphenylamine indicator ($C_{12}H_{11}N$) was added and titrated against 0.5 N ferrous sulphate ($Fe(NH_4)_2SO_4$. $7H_2O$) until purplish blue color was turned to green color.

Chloroform fumigation methods

30 g fresh soil sample was placed in 100 mL beaker. A small beaker that contained approximately 60 mL of ethanol-free chloroform and a few boiling chips was placed in the center of the dessicator. Once sealed, the dessicator was evacuated for 2 min, causing the chloroform to boil, thereby exposing the samples to chloroform vapor. After 72 h in the dark, the beaker of chloroform was removed from the dessicator, and the dessicator was evacuated 8 times to remove chloroform vapor from the samples. Evacuations were performed by connecting the dessicator to a vacuum for 3 min, then sealing the dessicator from the vacuum, and finally slowly opening it to the atmosphere to refill with air. Each sample was transferred into a 500 mL glass media bottle, and 200 mL of 0.5 mol L^{-1} K_2SO_4 was added. The bottles were then placed on an oscillating shaker for 30 min to thoroughly mix the sample with the K_2SO_4extractant solution. The supernatant was filtered using Whatman No. 42 filters, and collected for C analysis.

Biomass C = (V-B)× N×(100 + ø)/wt × (1000/V) × 100

Biomass C = ($C_{fumigated} - C_{control}$)

Total nitrogen

Total nitrogen content in soil was determined by Semi-Micro Kjeldahl method, following concentrated sulphuric acid digestion and distillation with 40% sodium hydroxide. The ammonia evolved was collected in boric acid indicator and was titrated with 0.005 N sulphuricacid. The % N in soil was calculated by the following formula:

%N = [{(R-B) ×1.4}/ W] ×S where, R= reading of the sample in burette (H2S04). S= strength of H_2S0_4, B= value of blank reading, W = weight of the soil in mg, 1.4= correction factor.

Available phosphorus

Available phosphorus solution from soil was extracted by 0.5 M sodium bi-carbonate and developed blue color by ascorbic acid reduction and measured the color colorimetrically with the help of UV-spectrophotometer at 890 nm wave length.

Determination of extractable K, Ca and Na

Soil samples were saturated with ammonium acetate (NH_4OAC) solution and the supernatant clear solution was separated and collected. For the above cation the Flame photometer was separated, adjusted and different standard curves were prepared to final out the concentration of the cation but the extracting solution used for each sample was same. The reading was recorded by flame photometer. From each reading the concentration of the ion was obtained from its standard curves.

Determination of extractable Fe, Cu, Mn and Zn

Exchangeable Fe, Cu, Mn and Zn were extracted by adding 25 DTPA into a 100 mL conical flask having 12.5 g soil sample in it. After 2 h shaking of the conical flask, the suspension was shakedfor 2 h at 70-80oscillation per minute (rpm) and the supernatant was decanted and filtered into a 25 mL volumetric flask. The concentration of extracted Fe, Cu, Mn and Zn were determined directly by atomic absorption spectrophotometer.

Experiment 2: Study on the mineralization rate of commonly used organic materials in Bangladesh under field capacity and CSW conditions

Pot experiment was conducted in the laboratory of soil science division at Bangladesh Institute of Nuclear Agriculture (BINA), Mymensingh, Bangladesh. Experiment comprised of two factors, viz. organic materials (CD: cowdung, BC: biochar, OF: organic fertilizer and VC: vermicompost including control) and moisture levels (FC: field capacity and CSW: continuous standing water). The soil used in this study was collected in 2018 from Nacholeupazila of Chapainawabganj in Bangladesh. Soil samples were collected from surface horizon (0–15 cm) using soil auger. The soil was air dried ground, sieved through 2 mm sieve, and kept in plastic bags for physicochemical analysis. General properties (bio-physico-chemical) of the tested soil are presented (Table 2). Organic materials were mixed with soil at 2.5 g C kg^{-1} soil and 0.2 kg soil was used in each pot. General properties (bio-physico-chemical) of the tested soil are presented (Table 2). Nutrient and other elements of organic amendments results are presented (Table 3). Organic materials were mixed with soil at 2.5 g C kg^{-1} soil and 0.2 kg soil was used in each pot.50 mL beaker containing 40 mL of 1.0 N NaOH solutions was placed on soil surface inside the pot to absorb carbon dioxide. The emission of CO_2-C and mineral nitrogen content (NH_4-N and NO_3-N) were measured at 0, 3, 7, 15, 30, 45, 60, 90 and 120th day of incubation.Particles (sand, silt and clay) size distributions were analyzed using a laser particle size analyzer (Microtrac S3500, USA). Microtrac S3500 particle size analyzer with a 780 nm wavelength laser beam was used for studying particle size distribution (PSD) of soil samples. FLEX software was used for calculation of the particle size distribution. The percentage of sand, silt and clay were used for the determination of soil texture on triangular diagram designed by Marshall. Bulk density is measured by the following equation:

$$\text{Bulk density (g cm}^{-3}) = \frac{\text{Weight of the dry soil}}{\text{Volume of the soil}}$$

Soil bulk density is defined as the oven-dry weight of soil per unit of its bulk volume. Bulk density is expressed in the unit of g/cm^3. Soil samples were collected by auger from three sites per sample. Moist samples were weighed immediately, dried to constant weight in an oven at 105 ^{0}C (for about 48 hours) and reweighted after cooling in desiccator. Calculate the soil moisture content by determining the loss in weight on drying and the weight of the oven soil as follows:

$$\text{Soil moisture content (\%)} = \frac{\text{(wt. of wet soil + core wt.)} - \text{(wt. of dry soil + core wt.)}}{\text{(wt. of wet soil + core wt.)}} \times 100$$

The space in the soil is occupied by air and water termed as pore space or porosity.

$$\text{\%Porosity} = \left[1 - \frac{\text{Particle density of soil}}{\text{Bulk density of soil}}\right] \times 100$$

Void ratio is defined as the raion of the volume of the pores to the solids and is expressed as:

$$\text{Void ratio} = \frac{\text{Particle density of soil}}{\text{Bulk density of soil}}$$

Soil pH was determined by glass electrode pH meter. Ten grams of air dried soil was taken in 50 ml beaker separately and 25 ml of distilled water added to each beaker. The suspension was stirred well for several times during the next 30 minutes and allowed to stand for about an hour. Then the electrode was immersed into partly settled soil suspension and read pH by glass-electrode meter.The percentage of organic carbon was determined titrimetrically using Walkley and Black method with oxidation of organic matter using potassium dichromate ($K_2Cr_2O_7$). One gram soil along with 10 ml 1N $K_2Cr_2O_7$ solution and 20 ml of concentrated H_2SO_4 was taken in a 500 ml conical flask. After 30 minutes rest, about 200 ml distilled water and 10 ml concentrated H_3PO_4 was added. 10-15 drops of diphenylamine indicator ($C_{12}H_{11}N$) was added and titrated against 0.5 N ferrous ammonium sulphate until purplish blue color was turned to green color.Total nitrogen content in soil was determined by Semi-Micro Kjeldahl method, following concentrated sulphuric acid digestion and distillation with 40% sodium hydroxide. The ammonia evolved was collected in boric acid indicator and was titrated with 0.005 N sulphuric acid. The % N in soil was calculated by the following formula:

%N = [{(R-B) ×1.4}/ W] ×S where, R= reading of the sample in burette (H_2S0_4). S= strength of H_2S0_4, B= value of blank reading, W = weight of the soil in mg, 1.4= correction factor.

Available phosphorus

Available phosphorus solution from soil was extracted by 0.5 M sodium bi-carbonate and developed blue color by ascorbic acid reduction and measured the color colorimetrically with the help of UV-spectrophotometer at 890 nm wave length.

Soil samples were saturated with ammonium acetate (NH_4OAC) solution and the supernatant clear solution was separated and collected. For the above cation the Flame photometer was separated, adjusted and different standard curves were prepared to final out the concentration of the cation but the extracting solution used for each sample was same. The reading was recorded by flame photometer. From each reading the concentration of the ion was obtained from its standard curves.Exchangeable Fe, Cu, Mn and Zn were extracted by adding 25 DTPA into a 100 mL conical flask having 12.5 g soil sample in it. After 2 h shaking of the conical flask, the suspension was shakedfor 2 h at 70-80oscillation per minute (rpm) and the supernatant was decanted and filtered into a 25 mL volumetric flask. The concentration of extracted Fe, Cu, Mn and Zn were determined directly by atomic absorption spectrophotometer.

The amount of CO_2-C was calculated by using the following formula:

$$mg\ CO2/day = \frac{(T2 - T1)M \times 22}{t}$$

where, T_1= amount of HCl used to analyze NaOH, $T_2 = T_1$ + amount of HCl used to dissolve precipited $BaCO_3$, M= Molarity of HCl, 22= 22 mg CO_2/mL 1 M HCl and t= time in day.

***Ammoniacal nitrogen*:** Take about 10 g of fresh soil into a plastic bottle add 40 mL 1 M KCl solution, shake for half an hour, filter using whatman 42 filter paper. Use 10-20 mL extra KCl solution to rinse out the entire soil from conical flask. Transfer the entire filtrate in micro-kjeldahl flask, add 0.5 g MgO powder, set the flask in distillation system. Distill it for 2minsfor at least 50-60 mL distillate and collect the evolved NH_3 in 15 mL 40% boric acid-mixed indicator, titrate the distillate against 0.005 N H_2SO_4.

Calculation: Exchangeable NH_4-N % in soil= $(V_s\text{-}V_B) * S * 0.014 * 100/W = Z$
Exchangeable NH_4-N (ppm)= $Z * 10^4$
Where, Vs= vol. of H_2SO_4 required for sample titration
V_B= vol. of H_2SO_4 required for blank titration
S= strength of H_2SO_4 W= wt. of oven dry soil.

***Nitrate nitrogen*:** Now take the micro-kjeldahl flask again and add a pinch of Devarda's alloy and 10 mL 1% NaOH and distill it again and collect ammonia in 4% boric acid-mixed indicator solution. Titrate it in same way.

Table 5. Bio-physico-chemical properties of the tested soil

Properties		**Soil**
Textural Class		Silt loam
% Sand		3.87
% Silt		83.39
% Clay		12.74
Bulk density (g cm^{-3})		1.57
Moisture content (%)		21.53
Water holding capacity (%)		57.05
Porosity (%)		41.00
Void ratio		0.69
pH		7.45
Total C (%)		0.99
	Organic C (%)	0.88
	In-organic C(%)	0.10
	Active C (%)	0.41
	Passive C (%)	0.48
Microbial biomass (kg ha^{-1})		147
Total N (%)		0.15
Exchangeable K ($cmol_c$ kg^{-1})		46.16
Exchangeable Ca ($cmol_c$ kg^{-1})		0.072
Exchangeable Na (mg kg^{-1})		1.19
Available P (mg kg^{-1})		41.70
Extractable Fe (mg kg^{-1})		64.74
Extractable Cu (mg kg^{-1})		0.72
Extractable Mn (mg kg^{-1})		5.89
Extractable Zn (mg kg^{-1})		0.58
NH_4-N (mg kg^{-1})		101.00
NO_3-N (mg kg^{-1})		90.00

Table 6. Nutrient status of different organic amendments

Organic materials	pH	OC	Total N	P	K	S	Ca	Fe	Cu	Mn	Zn	CEC
CD	7.2	20.87	1.52	2.20	0.24	0.34	2.39	0.32	0.006	0.028	0.018	10.24
BC	7.5	16.58	1.82	0.09	1.16	0.34	1.06	0.22	0.006	0.018	0.008	19.64
VC	7.3	19.31	1.94	1.92	0.80	0.84	3.50	0.30	0.004	0.032	0.024	11.83
OF	7.2	13.46	1.14	2.11	1.16	0.72	2.40	0.31	0.005	0.019	0.022	10.08

Note: CD-cowdung bioslurry, BC-biochar (rice husk), VC-vermicompost and OF-organic fertilizer

Carbon mineralization

Carbon degradation constant rate was determined by $C_t = C_0 (1- e^{-kt})$ equiation which was modified to calculate C degradation rate constant (k) as follows:

$$k = \left(\frac{1}{t}\right) \times \{ln (C_0) – ln (C_0 – C_t)\}$$

where C_t is the final and C_0 is the initial C status; t indicates time in day, k is the C degradation constant.

Determination of extractable Fe, Cu, Mn and Zn

For the determination of Fe, Cu, Mn and Zn, weigh 12.5 g soil sample in 100 ml conical flask. Add 25 ml DTPA solution. Shake this mixture for two hours on shaker at 70 to 80 oscillation per minute, filter through acid wash distilled water rinsed whatman no. filter paper and collect the filtrate in plastic bottles. Determine the content of micronutrient (Fe, Cu, Mn and Zn) on atomic absorption spectrophotometer. Fe, Cu, Mn and Zn concentrations were determined multiply by 2 the concentration of AAS sample reading. It was expressed in ppm.

Statistical analysis

Data were analyzed using Statistix version 10.0 software. The ANOVA and univeriate were done. Treatment means were compared by the least significant difference (LSD) and standard deviation and graphs were prepared using Microsoft Excel.

Experiment 3: Improvement of soil health in unfavorable eco-systems with organic amendments for sustainable crop production

Field experiments were carried out to evaluate the effect of different organic amendments on soil and crops in drought prone areas of Bangladesh. Under the experiment 3, six treatments such as T_0= control, T_1= 100% recommended fertilizer (RF), T_2= 100% RF + 2.0 biochar (rice husk), T_3=RF (IPNS) + 3.0 t ha^{-1} poultry manure, T_4=RF (IPNS) + 3.0 t ha^{-1}vermicompost and T_5= RF(IPNS) + 3.0 t ha^{-1} standard organic fertilizer in T. aman – Boro – Rabi cropping system. In case of experiment 4, two treatment such as T_1= 100% recommended fertilizer (RF) and T_2=RF (IPNS) + 3.0 t ha^{-1} poultry manure using T. aman-Boro- (wheat/mustard/lentil/chickpea) cropping systems. Experimental design followed randomized complete design with three replications at Nacholeupazilla, ChapaiNawabganj. Soil samples were analyzed using standard methods.

BAU Component

Activity 1: Benchmark survey to characterize biological and physical properties of soil in the selected study sites

For benchmark soil charaterisation, soil samples were collected from the two selected sites are acid soils at Seoratola, Modhupur, Tangail and char land soils at Bahadurpur, Purbopara, Islampur, Jamalpur. Soil samples were collected from each field site considering three replicated composite soils samples. Three soil samples with 3 sampling depths (0-15, 16-30,

1-45 cm) result in 9 soil samples (3 x 3 = 9) from each site and in two sites total of 9+9=18 soil samples were collected initially along with global positioning system (GPS) reading.

Soil properties measured

All the samples will be analyzed for texture, moisture, bulk density, porosity, soil aggregate stability, pH, nutrients N, P, K, Ca. Mg, Na, S, B, Zn, CEC, water holding capacity, field capacity and microbial biomass C and N contents following the standard laboratory protocols: soil organic carbon content has been analysed by wet oxidation method (Walkley and Black, 1934). Soil total N was determined using the Kjeldahl method (Bremmer and Mulvaney, 1982); Soil aggregate stability will be measured by wet sieving method (Patton et al., 2001); Water holding capacity by pressure plate method; Field capacity by pressure plate method; Soil bulk density (ρb) was determined by following the standard core method (McKenzie et al., 2004; Microbial Biomass C by chloroform

fumigation extraction method (Wu *et al*., 1990; Vance et al., 1987) and Microbial Biomass N chloroform fumigation extraction method (Brookes et al., 1985).Soil basal respiration (BR) was measured by the *in-vitro* steady static incubation method (Cheng *et al.*, 2013). A glass electrode pH meter was used to measure the pH of the samples in a 1: 2.5 (soil: water ratio) (Jackson, 1973).

Soil aggregate properties

Soil aggregate size fractionations were performed by using the wet sieving method to obtain water-stable aggregates (De Leenheer & De Boodt, 1967) in 250 g soil over a sequence of sieves with mesh sizes 2.0, 0.85, 0.30, 0.15 and 0.053-mm. Soil aggregate fractions retained on each sieve after being dispersed in water on a planetary shaker at a rate of 31 rpm were transferred to a nickel cup and oven-dried at 65°C until a constant weight was obtained. Respective mass of each aggregate size of soil was converted to the relative percentage (over the total mass of aggregates). Aggregate mean weight diameter (MWD) was estimated using Eqn. 3 below (Van Bavel, 1950; Zheng et al., 2018).

$$MWD = \frac{\sum_{i=1}^{i=n} mi * di}{\sum_{i=1}^{i=n} mi} \qquad (Eqn.\ 3)$$

where *mi* and *di* are weight and the mean diameter of aggregate fraction *i*, respectively.

Aggregate stability index (SI) was obtained by determining the MWD of air-dried soils and that of soils sieved after being dispersed in water on a planetary shaker (Jahangir et al., 2011) following Eqn. 4.

$$\text{Stability Index (SI)} = \frac{1}{instability\ index} \quad (Eqn.\ 4)$$

where Instability Index = MWD (dry sieving) – MWD (wet sieving).

Activity 2: Production of biochar using different available sources and their characterization

Organic materials:
Rice husk and poultry manure. Biochars have been produced through anaerobic pyrolysis in a biochar plant established at BAU.

Biochar production:

Rice and poultry manures have been collected and sun-dried. The materials were then placed in biochar plant. The pyrolysis temperature was raised to the selected value of 400-500 $^{\circ}$C gradually and kept constant for 4-5 h, and then biochar was allowed to cool at room temperature and ground to pass a 60-mesh (0.25 mm) sieve (Chun et al., 2004) and applied in soils at acid and charland site.

Characterization:
Rice husk and Poultry manure biochars were analysed for particle size groups, soil pH, SOC, available P, K and S; CEC and EC.

Activity 3: Comparative performance of organic materials and dolomite for correction of soil acidity-crop performance and soil health evaluation

Treatments

Treatments comprised of poultry manure, rice husk biochar, poultry manure biochar, and dolomite with four replications laid out in a RCBD. Organic materials were applied considering C rate 1 t ha^{-1} and dolomite rate is 1 t ha^{-1} (once in three years). For field study, experiments have been conducting in a farmers' field on a major cropping pattern (Mustard–T. Aus–T. Aman) of Madhupur, Tangail.
Treatment:
T1=Control
T2=Poultry Manure + rest from recommended fertilizer (RF)
T3=Rice husk biochar + rest from RF
T4=Poultry manure biochar + rest from RF
T5=Dolomite (1 t ha^{-1} for every 3 yr)

T6=RF (recommended fertilizer rate; FRG, 2018)

- Replications: 4
- Design: RCBD
- Plot No.: 24
- Plot size: 20 m^2 each

Year 1

Crop 1: Mustard- BARI Sarisha 14; sowing date: 28.11.2018; harvesting date: 14.02.2019
Crop 2: Boro: BRRI dhan28; sowing date: 17.02.2019; harvesting date: 08.05.20219
Crop 3: T. Aman: BRRI dhan71; sowing date: 05.08.2019; harvesting date: 30.10.2019

Year 2

Crop 4: Mustard- BARI Sarisha 14; sowing date: 22.11.2019; harvesting date: 10.02.2020
Crop 5: Boro: Boro: BRRI dhan28; sowing date: 12.02.2020; harvesting date: 06.05.20220
Crop 6: T. Aman: BRRI dhan71; sowing date: 30.07.2020; harvesting date: 25.10.2020

Field and laboratory record and analysis

Soil physical, chemical and biological properties of the initial (before starting of experiments) and final (after completion of two years of study) soils were determined using the method described in activity 1. Yield data of all crops in the cropping patterns were recorded at maturity. System productivity of each cropping pattern was estimated by pooling together with the yield of all crops. The yield of non-rice crop was converted to rice equivalent yield using the below equation:

$$REY\ (ton\ ha^{-1}) = \frac{yield\ of\ non-rice\ crop\ \times\ price\ of\ non-rice\ crop}{price\ of\ rice}$$

where yield of non-rice crop is in ton ha^{-1}; price of crop is in taka.

Plant samples were collected for nutrient uptake after every crop harvest. Rice straw from each plot was chopped separately for each plot and dried at 65°C in an oven until a constant weight was obtained. Similarly rice grain was over dried at 65°C in an oven until a constant weight was obtained and ground using a ball mill grinder and sieved in a 2-mm sieve (Sahlemedhin and Taye, 2000). A 0.1 g of oven dry ground plant sample was taken into a digestion flask to which 1.1 g catalyst mixture (K_2SO4: $CuSO_4.5H_2O$: Se = 100: 10: 1) and 5 ml H_2SO_4 were added. The flasks were swirled and allowed to stand for about 10 minutes. Then heating (380º C) was continued until the digest was clear and colourless. After cooling, the content was taken into 100 ml volumetric flask and the volume was made up to the mark with distilled water. A reagent blank was prepared in a similar manner. This digest was used for total N determination by semi micro-Kjeldahl method as described by Bremner and Mulvaney (1982).

Total N uptake by crops was determined by the formula (Rani et al., 2013):

$$N\ uptake\ (kg/ha) = \frac{N\ content\ (\%) - Total\ dry\ mass\ production\ (kg/ha)}{100} \quad (Eqn.\ 1)$$

The NUE expressed as percentage (%) was determined as described by Moll et al. (1982) as follow as:

$$NUE\ (\%) = \frac{N\ uptake\ from\ fertilized\ plot - N\ uptake\ from\ control}{Applied\ N} \times 100 \quad (Eqn.\ 2)$$

Soil sampling and measurement of carbon pools and management indices

Soil sampling and analysis

Soil samples were randomly collected at 0-15 cm depth from each replicated plot using a 10 cm internal dia. auger from geo-referenced sites in each plot, composited, and stored in sealable plastic bags. We collected a total of 24 soil samples for each Madhupur and Islampur site. A portion of field-moist soil was processed after sieving through a 2 mm mesh to remove visible organic residues and rock pieces (if any), then analyzed for MBC and associated biological properties. The other portion of the field-moist soil was air-dried under shade at room temperature (~25º C) for two weeks and processed (2 mm sieved) to analyze for selected physical and chemical properties.

Soil carbon pools and basal respiration

Microbial biomass carbon (B_c) was determined using the fumigation extraction method (Vance *et al.,* 1987) from the relationship

$$B_c = F_c/k_c,$$

where F_c = [(CO_2-C evolved from fumigated soil, 0-10 days) - (CO_2-C evolved from non-fumigated soil)] and k_c, the proportion of microbial C evolved as CO_2 = 0.45 for 10-day incubations at 25°C (Jenkinson and Ladd, 1981).

Microbial biomass N (MBN) was determined following the method described by Brookes et al. (1985). For this, the field moist soils were incubated in chloroform fumigated environment in a desiccator for 72 h. Extraction of the fumigated soils for MBC and MBN was carried out using 0.5 M K_2SO_4. Parallel to this, soil extraction was also carried out for soils which were incubated at the same conditions without fumigation, called non-fumigated samples. The microbial biomass C was analyzed following wet oxidation method (Walkley and Black, 1934) and for analyzing microbial biomass N semi-micro Kjeldahl method was followed (Bremner and Mulvaney, 1982). The estimated differences between the fumigated and non-fumigated samples provided the MBC and MBN. The results of microbial biomass C and N was expressed as mg kg^{-1}.

Basal respiration (BR), as a measure of soil biological activity, was measured using the gas entrapment method by Hutchinson and Mosier (1981) and Sullivan *et al.,* (2010). CO_2 monitoring was performed by transferring 2 g sediment samples from different treatment units into a glass vial. The vials were placed in closed 1 liter glass jar. A glass vial containing 10 ml 1 N NaOH was also placed inside each jar to trap CO_2 resulting from substrate mineralization. The NaOH trap was periodically replaced. $BaCl_2$ (10 ml) was added to the NaOH trap and the amount of CO_2 produced by each microorganism. The evolved CO_2 was then determined by titration. Excess NaOH in solution was titrated against 1.0 M HCl using phenolphthalein indicator.

The SOC concentration was determined by following the standard wet oxidation method (Black, 1965). Particulate organic carbon (POC) was determined following Cambardella & Elliot (1992). In brief, 20 g of soil was dispersed by shaking for 15 h on an end-over-end shaker in 100 ml of 5 g L^{-1} sodium hexametaphosphate solution. The dispersed soil suspension was passed through a 53 mm sieve and after rinsing several times with distilled water, the material retained on the sieve was dried at 105°C. Dried samples were ground and analyzed for organic carbon. The POX_C, as a measure of chemically labile C pool, was determined spectrophotometrically upon mild oxidation of air-dried soil with a neutral $KMnO_4$ solution (Weil et al., 2003). Soil bulk density was determined by following the standard core method (McKenzie et al., 2004). Antecedent soil moisture content was measured using the thermo-gravimetric method (Black, 1965).

Soil carbon lability and management indices

Using the measured SOC, MBC, POC, and POX_C data, the CMI was calculated (Islam et al., 2021; Franzluebbers et al., 2002) as follows:

$$CMI = CPI \times CLI$$

where CPI is the C pool index and CL_I is the C lability index, which were calculated as:

CPI = TOC in the treatment soil/TOC in the control

CL_I= CL in the treatment soil/CL in the control
where CL refers to the lability of C (CL = Labile C/Non-labile C).

The labile C pool was considered the portion of SOC that was measured as the POXC pool. The non-labile C pool was calculated by subtracting the POXC content from the TOC. The calculated CMIs were normalized (CMI) by dividing the values with the highest CMI values in the database to a relative scale of >0 to ≤100, considering higher CMI values are better indicators of SOC accumulation and lability in response to different treatments.

Soil carbon stocks

TOC, POC, POXC and MBC stocks at 0-15 cm depth were calculated by multiplying their concentration with the sampling depth of 15 cm and concurrently measured antecedent bulk density.

Microbial population

The microbial population in soil was determined using the dilution spread plate technique as described by Akande and Adekayode (2019). For bacteria and fungi, Nutrient Agar (NA) and Potato Dextrose agar (PDA) were the preferred growth mediums. A 1 ml aliquot of the sample was pipetted into a sterile test tube and serially diluted in six more test tubes, each holding 9 ml of sterile distilled water, to achieve a dilution ratio of 10^{-6}. 20 ml of cold (45º C) sterile molten agar medium was pipette separated aseptically into various sterile petridishes, spun gently for equal distribution of the inocula, allowed to set, and incubated at 30–37º C for 24 hours (for bacterial), and at 25–27º C for 72 hours (for fungi). Microbial colonies were counted and recorded correctly for bacteria at the end of the incubation period (24 hours), and for fungus at the end of the incubation period (72 hours).PSB was isolated and counted using a dilution plate method using hydroxy apatite media (Katznelson & Bose, 1959; Narsian et al., 1994). The soil samples were serially diluted up to a 10^{-6} dilution, plated on Petridishes, and incubated at 35±2º C for seven days to isolate PSB. PSB colonies were visually recognized from the clear zone around the bacterial colony at the conclusion of the incubation period. After 3-5 days of incubation, PSB was counted by looking for a halo/solubilization zone surrounding bacterial colonies surrounded by a turbid white background.

Statistical analysis

A one-way analysis of variance (ANOVA) was performed using different treatments as a random variable. The distribution of data for normality was checked before ANOVA. Data were statistically analyzed to ascertain the significant differences in treatment effects using Statistix 10 software. A post-hoc test was performed to separate differences between treatments using the Tukey-Kamer's multiple comparison. All statistical analyses were considered significant at $p \leq 0.05$, unless otherwise mentioned.

Activity 4: Improvement of soil health in Charland with organic amendments for sustainable intensification and better crop production

Treatments:

Another experiment was conducted at charland soil site for two years as mentioned below. The below treatments have been applied in charland soils in a Maize – Jute - T. Aman rice pattern.

Charland soils site

T1= Control
T2= Poultry Manure 3 t ha^{-1} + rest from recommended fertilizer (RF)
T3= RF + Poultry Manure Biochar (2 t ha^{-1})
T4= Vermicompost 3 t ha^{-1} + rest from RF
T5= Organic fertilizer 3 t ha^{-1} + rest from RF
T6= Recommended Fertilizer (RF; FRG 2018)

- Replications: 4
- Design: RCBD
- Plot No.: 24
- Plot size: 20 m^2 each

Year 1

Crop 1: Maize- Kaveri; sowing date: 02.11.2018; harvesting date: 19.04.2019
Crop 2: Jute: Tosha; sowing date: 25.04.2019; harvesting date: 08.08.2019
Crop 3: T. Aman: BRRI dhan71; sowing date: 16.08.2019; harvesting date: 05.11.2019

Year 2

Crop 4: Maize- Kaveri; sowing date: 12.11.2019; harvesting date: 28.04.2020
Crop 5: Jute: Tosha; sowing date: 25.04.2020; harvesting date: 12.08.2020
Crop 6: T. Aman: BRRI dhan71; sowing date: 17.08.2019; harvesting date: 06.11.2020

Plant analysis and determination of nitrogen use efficiency (NUE)

Rice grain and straw and all parts of cob (i.e., grain, outer sheath and kernel) and stover of maize and the grain and straw of rice from each plot were chopped separately and dried at 65° C in an oven until a constant weight was obtained. The oven dried samples were then ground and sieved in a 2-mm sieve (Sahlemedhin and Taye, 2000). A 0.1 g of oven dry ground plant sample was taken into a digestion flask to which 1.1 g catalyst mixture (K_2SO_4: $CuSO_4.5H_2O$: Se = 100: 10: 1) and 5 ml H_2SO_4 were added. The flasks were swirled and allowed to stand for about 10 minutes. Then heating (380º C) was continued until the digest was clear and colourless. After cooling, the content was taken into 100 ml volumetric flask and the volume was made up to the mark with distilled water. A reagent blank was prepared in a similar manner. This digest was used for total N determination by semi micro-Kjeldahl method as described by Bremner and Mulvaney (1982). Total N uptake and NUE were estimated following the methods described in Activity 4.

Field and Laboratory record and analysis
Field and lab data were recorded and analysed following the methods mentioned in Activity 4.

Soil sampling and measurement of carbon pools and management indices
These parameters were measured and estimated by following the methods described under Madhupur site

Statistical analysis
A one-way analysis of variance (ANOVA) was performed using different treatments as a random variable. The distribution of data for normality was checked before ANOVA. Data were statistically analyzed to ascertain the significant differences in treatment effects using Statistix 10 software. A post-hoc test was performed to separate differences between

treatments using the Tukey-Kamer's multiple comparison. All statistical analyses were considered significant at $p \leq 0.05$, unless otherwise mentioned.

Activity 5: Study on the mineralization rate of commonly used organic materials in Bangladesh in the acidic and Charland soils under field capacity and continuous standing water (CSW) conditions (incubation study)

A laboratory incubation study was conducted in the Department of Soil Science at BAU using four different types of organic materials maintaining 2 moisture regimes. Soils from the two selected sites (acidic soils at Madhupur and char land soils at Islampur) were used for the mineralization study. Each category soil (250 g) was incubated at room temperature (25° C) with different organic sources (1.25 g C kg^{-1} soil + chemical NPK as INMS) for 120 days. Carbon and N mineralization rate kinetics (k) was calculated following a kinetic model described by Stamford and Smith (1972).

Treatments and deign of experiment:

1. Organic materials (vermicompost, poultry manure, rice husk biochar, poultry manure biochar);
2. Soil category (acid and charland soils);
3. Moisture regime (field capacity and continuous standing water)

Design: Completely randomized design with 3 factors and 3 replications.

Collection of organic materials

Four types of organic materials, viz. vermicompost, poultry manure, rice husk biochar, and poultry manure biochar were used in this study. Vermicompost was collected from The Dept. of Agronomy at BAU, poultry manure from Poultry Farm of BAU, rice husk biochar and poultry manure biochars were prepared at the Soil Science Field Laboratory. The poultry manures were sundried, ground and passed through a 2-mm sieve before it was used for biochar preparation. The chemical composition of the manures was shown in Table 7.

Table 7. Chemical properties of different organic amendments

Manure	C (%)	N (%)	P (%)	K (%)	S (%)	C:N	C:P	C:K	C:S	pH	CEC (meq/100 g soil)
Organic Fertilizer	7.27	0.61	0.08	0.11	0.04	11.9	90.9	66.1	181.8	7.3	10.07
Poultry Manure	8.56	1.85	0.08	0.1	0.08	4.6	107.0	85.6	107.0	8.3	12.29
Rice Husk Biochar	18.62	1.57	0.11	0.13	0.11	11.9	169.3	143.2	169.3	7.5	19.54
Poultry Manure Biochar	27.76	2.74	0.14	0.14	0.13	10.1	198.3	198.3	213.5	8.5	35.68
Vermicompost	7.57	1.08	0.10	0.06	0.04	7.01	76	126	189	7.7	11.83

Incubation Experiment

The factorial experiment comprised three main factors, i.e., soil (acidic soil and char land soil), moisture level (field capacity and 2 cm of standing water) and organic treatments. Organic treatments were applied IPNS basis, except the biochar, considering the nutrient content in the organic treatments plus rest of the nutrients from chemical fertilizer. The nutrient application rate was fixed following the FRG (2018). Treatments included 1) control, 2) poultry manure + rest of the nutrient from chemical fertilizer, 3) rice husk biochar + full dose of chemical fertilizer, 4) vermicompost + rest of the nutrient from chemical fertilizer, and 5) poultry manure biochar + full dose of chemical fertilizer. Organic amendments were applied @ 1.25 g C kg^{-1} soil. All the treatments were applied on an N-equivalent basis at the rate of 120 mg N kg^{-1} soil. Phosphorus, K, and S were also added to each plastic container (including control) at the rates of 10.67, 50.67 and 4 mg P, K, S kg^{-1} soil. An amount of 250 g (oven dry weight basis) was weighed into a series of plastic containers. Five hundred and forty (540) plastic containers were used during the whole incubation period. The soil was thoroughly mixed with the organic amendments. The moisture content of the soil was adjusted to maintain field capacity (22-25% moisture) and a 2 cm standing water condition 1 week prior to actual incubation to stabilize the microbial activity. The soils in the plastic containers were incubated for up to 120 days at room temperature (25°C). Each container was covered with a polythene sheet to prevent rapid loss of water due to evaporation. The containers were weighed at every alternate day and the weight loss was supplemented by distilled water. Incubation period involved 9 sampling events, i.e., on day 0, 3, 7, 15, 21, 30, 60, 90, and 120 (after amendments application). For quantification of C, N, P and S, a set of samples were withdrawn at each sampling dates as destructive samplings. The data were corrected for moisture content and expressed on oven dry weight basis.

Data collection:

Destructive soil sampling was performed on each sampling event during the incubation. After air drying and sieving, soil samples were analysed total organic C, NH_4-N, NO_3-N, available P, Exch. K, and available S on day 0, 3, 7, 15, 21, 30, 60, 90 and 120 of incubation. Total number of samples were (5*3*9) 135 for one moisture regime, so for two moisture regimes total samples were 135+135=270 and for two study sites total number of soil samples were 540.

Carbon stock and C sequestration was calculated using the following equation 1 and 2, respectively (Rahman et al., 2016).

Carbon stock (t ha^{-1}) = Carbon concentration (%) x bulk density (g cm^{-3}) x depth (cm) ….. (1)

Carbon sequestration (t ha^{-1}) = Final C stock (t ha^{-1}) – Initial C stock (t ha^{-1}) ……..... (2)

Carbon mineralization rate (k) was calculated using the following kinetic model (Standford and Smith, 1972).

$$C/C_0 = (1\text{-}e^{-kt}) \quad \ldots\ldots\ldots\ldots (1)$$

C, C_0, k and t indicate final C, initial C, degradation rate constant and time, respectively.

Fitting of N Release Data to the First Order Kinetic Model

The net N release values were fitted to different kinetic functions. The best fit was the first-order kinetic model. N release potential (N_0) and rate constant (k) for different sources of organic materials were calculated by following an exponential equation (Sihag and Singh, 1999). The equation for N kinetics was $N_t = N_0 (1- e^{-kt})$; where, N_t is the net N release at time t, N_0 is the N release potential, and k is the rate constant.

Soil Extraction and Analysis

Soil samples of all treatments incubated for different intervals were analyzed for total N (TN), available N (NH_4^+–N and NO_3^-–N), soil organic carbon (SOC), available P and S. Initial concentration of all nutrients at day zero was determined by extracting soil samples immediately after incorporation of each amendment. For available N (NH_4^+– N and NO_3^-–N) content, 50 g soil was extracted by shaking with 125 ml of 2M KCl (soil : KCl solution = 1 : 2.5) for 2 h followed by filtration through Whatman No. 41 filter paper. The aliquot was steam distilled with MgO and Devarda's alloy and titrated with 0.01N H_2SO_4 to determine for available N (Keeney and Nelson, 1982). For TN, 1 g of oven dry ground soil sample was taken into a digestion flask to which 1.1 g catalyst mixture (K_2SO4: $CuSO_4.5H_2O$: Se = 100: 10: 1) and 5 ml H_2SO_4 were added. The flasks were swirled and allowed to stand for about 10 minutes. Then heating (380ºC) was continued until the digest was clear and colorless. After cooling, the content was taken into 100 ml volumetric flask and the volume was made up to the mark with distilled water. A reagent blank was prepared in a similar manner. This digest was used for total N determination. After the completion of digestion, 40% NaOH was added with the digest for distillation. The evolved ammonia was trapped into 4% H_3BO_3 solution and 5 drops of mixed indicator of Bromocresol green and methyl red solution. Finally, the distillate was titrated with standard 0.01N H_2SO_4 until the color changed from green to pink (Bremner and Mulvaney, 1982). The amount of N was calculated using the following formula.

$$\text{TN (g kg}^{-1}) = \frac{(T-B)\times N\times 0.014\times 4\times 100\times 10000}{S\times 1000}$$

Where, T= Sample titration value (ml) of standard H_2SO_4; B = Blank titration value (ml) of standard H_2SO_4; N = Strength of H_2SO_4; S = Sample weight in gram; 4 = Dilution factor. Soil pH was measured with the help of a glass electrode pH meter using a soil: water suspension of 1: 2.5, as described by Peech (1965).

Statistical Analysis

The data were subjected to analysis of variance (ANOVA) technique using Statistix 10 software package by Repeated Measures Design. N release kinetics was determined using Sigma-Plot 14.0 software. Post-hoc tests were performed to separate differences among treatments at the same time interval, rate constant and potentially mineralizable nitrogen (N_0) using the Tukey-Kramer multiple comparison. All statistical analyses were considered significant at $p \leq 0.05$, unless otherwise mentioned. For total N analysis treatments were taken as the between-subject factor and time as the within-subject factor. Correlations between total mineral N (N mineralization) and STN were calculated using Microsoft EXCEL package (Microsoft Corporation, Pullman, WA, USA) was used for correlation and regression analysis.

BSMRAU Component

Soil samples were collected from the selected study areas of the climate vulnerable Dekar haor areas of Sunamganj, arsenic area of Faridpur sadar, saline areas of Batiaghata and heavy metal polluted areas of Bhaluka for bio-physicochemical analysis. Rice husk was used for biochar production at 300-450 ^{O}C using modified developed method (Rahaman et al., 2020). Mineralization and heavy metal adsorption-desorption studies were conducted using the method described by Standford and Smith (1972); and M. Jahangir Alam (2020), respectively. A series of field experiments were conducted with different organic materials

for sustainable crop production in climate vulnerable areas of Bangladesh with the following treatments:
T1 = Control, T2 = Recommended Fertilizer, T3 = Biochar + Recommended Fertilizer, T4 = Poultry Manure + Chemical Fertilizer, T5 = Vermicompost + Chemical Fertilizer, T6 = Standard Organic Fertilizer + Chemical Fertilizer

SAU Component

- Mineralization experiment was done in the soil science laboratory, PSTU, Dumki, Patuakhali-8602.
- The field experiment was done in saline soil of Kalapara under Patuakhali district.
- For field experiment, there were six treatment viz. absolute control, 100% chemical fertilizer, biochar @ 2 t ha^{-1} + 100% chemical fertilizer, vermicompost 3 t ha^{-1} with IPNS based inorganic fertilizer, poultry manure 3 t ha^{-1} with IPNS based inorganic fertilizer and standard organic manure (Mazim) 3 t ha^{-1} with IPNS based inorganic fertilizer. These treatments replicated for three times. The design is randomized complete block (RCB). The selected crops are T. aman and maize.
- Yield and yield contributing characteristics of crop were done.
- Post-harvest soils and plant samples were collected and analyzed for different properties.
- All analysis (soil and plant samples) was donein the soil science laboratory, PSTU, Dumki, Patuakhali-8602.
- Collection of biochar was done from BARI, Joydebpur, Gazipur.

11. Results and discussion (with appropriate pictures):

BARI Component

A. Baseline survey and Physico-chemical properties of soil

Baseline survey on soil fertility of Belabo, Godagari and Dumuria upazilla were conducted. About 81 soil sample each from Belabo and Godagari, and 126 soil sample from Dumuria were collected from cultivable land (0-15 cm layer) and analyzed. Map of the sampling spots of Belabo, Godagari and Dumuria are shown in Figure 1 to 3. Summary of soil nutrient status of Belabo, Godagari and Dumuria upazila has been mentioned in Tables 8 to 10.

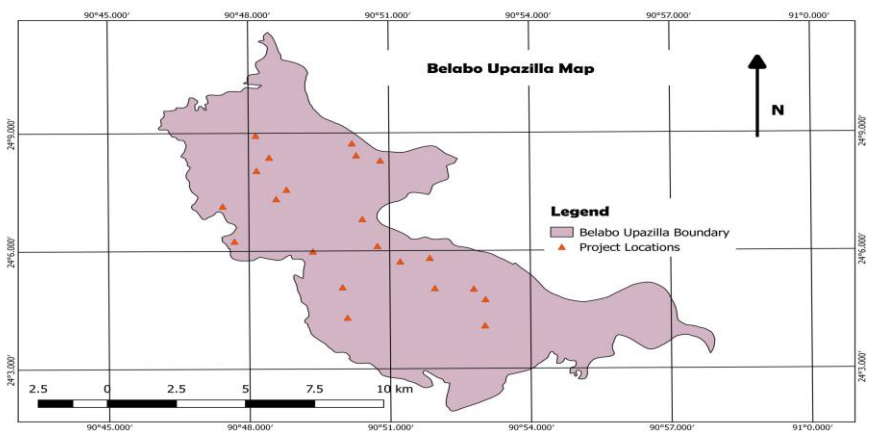


Fig.1. Location of sampling sites of Belabo upazilla

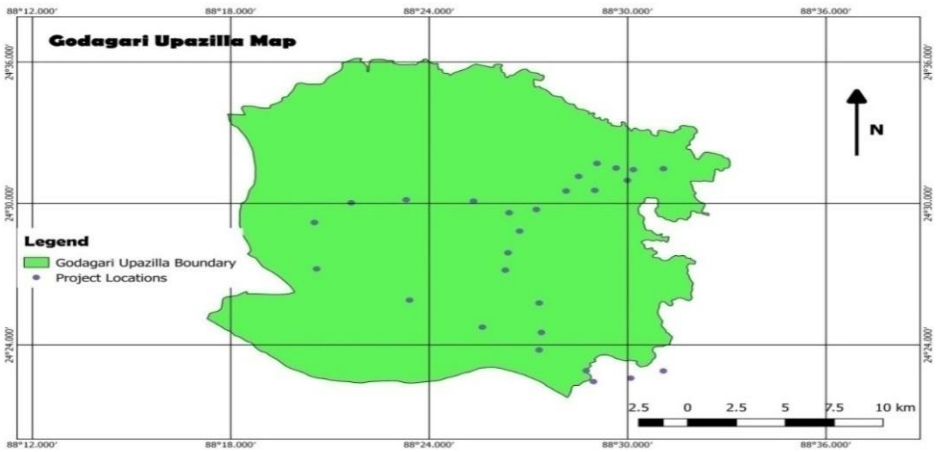


Fig.2. Location of sampling sites of Godagari upazilla

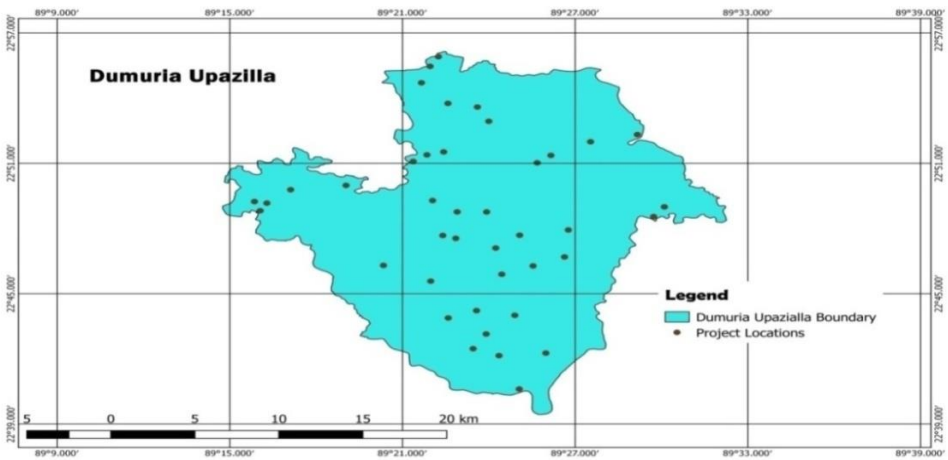


Fig.3. Location of sampling sites of Dumuria upazilla

Table 8a. Banchmark survey of soil physical properties of Belabo upazilla (n-81)

Property	Mean	Standard Deviation	Minimum	Maximum
%Sand	53.35	8.14	35.12	68.72
%Silt	20.35	5.97	9.00	35.00
%Clay	26.31	6.26	16.00	40.72
Moisture (%)	20.91	1.99	13.45	24.85
Bulk density (%)	1.48	0.06	1.39	1.68
Porosity (%)	44.14	2.20	36.60	47.55
Field capacity (%)	26.46	2.02	18.76	29.22

Table 8b. Banchmark survey of soil chemical properties of Belabo upazilla (n-81)

Property	Mean	Standard Deviation	Minimum	Maximum
pH	5.60	0.53	4.70	7.00
OM (%)	1.38	0.44	0.32	2.72
OC (%)	0.80	0.26	0.19	1.58
Mic BC (mg/Kg)	533.52	208.69	66.05	996.40
Total N (%)	0.07	0.02	0.02	0.14
Mic BN (mg/Kg)	118.87	46.47	14.70	222.00
Ca (meq $100g^{-1}$)	5.22	0.17	5.00	5.60
Mg (meq $100g^{-1}$)	1.80	0.09	1.40	2.00
K (meq $100g^{-1}$)	0.10	0.02	0.04	0.13
P ($\mu g\ g^{-1}$)	13.72	15.90	3.00	88.00
S ($\mu g\ g^{-1}$)	30.13	6.41	17.10	51.20
B ($\mu g\ g^{-1}$)	0.25	0.10	0.04	0.50
Cu ($\mu g\ g^{-1}$)	1.89	0.35	1.01	2.54
Fe ($\mu g\ g^{-1}$)	77.46	11.34	50.00	97.00
Mn ($\mu g\ g^{-1}$)	14.21	1.50	10.20	16.30
Zn ($\mu g\ g^{-1}$)	1.67	0.61	0.76	3.01

All soils of Belabo are acidic. Moisture content ranging from 13.45%-24.85%. Soil are low in nitrogen content and high in iron and manganese content (Table 1a & 1b).

Table 9a. Banchmark survey of soil physical properties of Godagari upazilla (n-81)

Property	Mean	Standard Deviation	Minimum	Maximum
%Sand	47.82	3.91	36.00	57.00
%Silt	23.70	5.93	14.00	46.72
%Clay	28.49	3.81	15.28	36.00
Moisture (%)	14.63	1.31	10.66	16.94
Bulk density (%)	1.65	0.03	1.58	1.72
Porosity (%)	36.75	0.85	34.24	38.24
Field capacity (%)	27.89	1.72	21.54	30.50

Table 9b. Banchmark survey of soil chemical properties of Godagari upazila (n-81)

Property	Mean	Standard Deviation	Minimum	Maximum
pH	7.98	0.62	6.10	8.90
OM (%)	1.07	0.36	0.30	2.16
OC (%)	0.62	0.21	0.17	1.26
Mic BC (mg/Kg)	379.23	179.38	118.50	842.20
Total N (%)	0.06	0.02	0.01	0.11
Mic BN (mg/Kg)	97.49	45.69	30.50	215.20
Ca (meq $100g^{-1}$)	11.52	0.76	9.60	12.50
Mg (meq $100g^{-1}$)	3.90	0.25	3.20	4.30
K (meq $100g^{-1}$)	0.20	0.07	0.12	0.36
P ($\mu g\ g^{-1}$)	11.17	14.52	0.00	70.00
S ($\mu g\ g^{-1}$)	35.15	17.62	16.00	111.50
B ($\mu g\ g^{-1}$)	0.30	0.13	0.08	0.68
Cu ($\mu g\ g^{-1}$)	1.80	0.17	1.40	2.20
Fe ($\mu g\ g^{-1}$)	30.23	4.72	20.00	40.00
Mn ($\mu g\ g^{-1}$)	5.77	0.65	4.10	7.00
Zn ($\mu g\ g^{-1}$)	1.38	0.35	0.58	2.00

Moisture content of Godagari soil ranging from 10.66%-16.94%. Soil are low in nitrogen content and high in calcium and magnesium content (Table 2a & 2b).

Table 10a. Banchmark survey of soil physical properties of Dumuria upazilla (n-126)

Property	Mean	Standard Deviation	Minimum	Maximum
%Sand	44.26	7.41	32.00	64.72
%Silt	25.67	7.82	12.72	49.44
%Clay	30.22	5.77	11.52	51.28
Moisture (%)	24.57	1.23	21.45	27.43
Bulk density (%)	1.43	0.02	1.35	1.47
Porosity (%)	46.20	0.69	44.53	48.93
Field capacity (%)	24.52	2.14	18.23	30.21

Table 10b. Banchmark survey of soil chemical properties of Dumuria upazilla (n-126)

Property	Mean	Standard Deviation	Minimum	Maximum
pH	7.85	0.95	5.19	8.91
OM (%)	1.63	0.51	0.53	3.05
OC (%)	0.99	0.62	0.26	6.96
Mic BC (mg/Kg)	719.67	611.19	15.00	6715.00
Total N (%)	0.10	0.10	0.03	1.06
Mic BN (mg/Kg)	162.25	65.87	41.00	578.00
Ca (meq $100g^{-1}$)	14.15	1.93	9.30	16.20
Mg (meq $100g^{-1}$)	4.32	0.43	3.20	4.90
K (meq $100g^{-1}$)	0.20	0.06	0.08	0.38
P ($\mu g\ g^{-1}$)	27.07	25.70	3.00	147.00
S ($\mu g\ g^{-1}$)	81.24	51.56	13.10	379.20
B ($\mu g\ g^{-1}$)	0.59	0.08	0.38	0.76
Cu ($\mu g\ g^{-1}$)	2.75	0.30	1.90	3.60
Fe ($\mu g\ g^{-1}$)	28.72	4.11	20.00	38.00
Mn ($\mu g\ g^{-1}$)	5.38	0.46	4.00	6.40
Zn ($\mu g\ g^{-1}$)	1.02	0.37	0.52	2.55

All soil of Dumuria are alkaline. Moisture content of Dumuria soil ranging from 21.45%-27.43%. Soil are low in nitrogen content and high in calcium and magnesium content (Table 3a & 3b).

B. Fabrication of biochar making device and biochar production
Two types of biochar making device are fabricated by Soil Science Division, BARI (Fig. 4a and 4b). Production of biochar has been started using rice husk, poultry manure through pyrolysis system (Fig. 4c). Quality of biochar from different crop straws have been presented in Table 11.

a. biochar making device (heat generated by wooden materials)	**b.** Electric control biochar making device	**c.** Produced rice husk biochar

Fig. 4. Fabricated biochar making device (heat generated by wooden materials & electric control) and biochar produced

Table 11. Chemical compositions of the biochar samples produced from the straws of maize, wheat, groundnut, chickpea, mustard, rice straw, rice husk, poultry manure and saw dust

Amendment	Maize Stover	Wheat Straw	Groundnut	Chickpea	Mustard Straw	Rice Straw	Rice Husk	Poultry manure	Saw Dust
pH	9.01	9.7	8.2	8.4	9.1	10.2	8.86	9.89	9.2
OC (%)	48.5	39.5	39.5	48.9	45.5	43.2	39.1	23.4	45.8
OM (%)	83.96	68.34	68.25	84.60	78.72	74.79	67.6	40.5	78.7
Total N (%)	2.27	1.91	2.60	2.73	1.54	1.89	2.30	2.38	1.25
CEC(Cmol+/kg)	32.5	38.4	30.7	31.5	37.3	39.5	35.5	44.1	6.52
Ca (%)	2.91	2.70	3.02	3.56	3.07	2.17	1.05	2.43	3.38
Mg (%)	1.48	1.47	2.00	1.81	1.98	1.43	0.48	2.14	1.5
K (%)	1.61	3.14	1.84	3.16	1.06	0.81	1.14	3.33	1.25
P (%)	0.24	0.78	0.54	0.65	0.47	0.33	0.9	0.77	0.03
S (%)	0.17	0.5	0.34	0.29	0.64	0.14	0.33	0.11	0.26
Cu (%)	0.014	0.012	0.023	0.014	0.011	0.016	0.01	0.16	0.05
Fe (%)	0.170	0.064	0.275	0.188	0.062	0.063	0.21	0.26	0.09
Mn (%)	0.074	0.026	0.166	0.082	0.037	0.027	0.02	0.16	0.03
Zn (%)	0.017	0.011	0.032	0.017	0.072	0.019	0.01	0.05	0.03

C. Mineralization study

Three soils derived from different parent material in Bangladesh are selected for the incubation experiment. Rice is the commonly grown crops of the sampled fields. The chemical compositions of the top soils (0-15cm depth) are presented in Table 12.

Characterization of different organic sources

The mean values of the 3 replicates of various organic materials are analyzed and presented in Table 6. Generally, the organic materials are characterized by relatively higher concentration of nutrient element. Greater organic carbon was found in rice husk biochar followed by poultry manure biochar and rest of organic material are ranging from 18.65 to 20.45%. The pH of biochar poultry manure and rice husk was alkaline in nature, whereas, the cowdung, cowdung slurry, poultry manure, vermicompost and Mazim organic fertilizers are neutral. The alkalinity of the organic compound was in decreasing order: poultry manure biochar > rice husk biochar > vermicompost > cowdung, cowdung slurry > poultry manure > Mazim organic fertilizer (Table 13).

Table 12. Chemical compositions of studied soil

Location	pH	OM%	Ca	Mg	K	Total N	P	S	B	Cu	Fe	Mn	Zn
			meq $100g^{-1}$			%	$\mu g\ g^{-1}$						
Vabla, Belabo	5.4	1.7	3.5	1.6	0.22	0.12	12	16	1.1	5.0	33	16	1.8
Alimgonj, Godagari	7.3	1.9	8.1	3.9	0.10	0.065	4	25	0.24	1.7	14	3.5	1.1
Shahosh, Dumuria	7.1	1.55	12.3	4.1	0.14	0.25	22	18	0.21	3.1	11	5.4	0.9
Critical Level	-	-	2.0	0.5	0.12	-	7	10	0.2	0.2	4	1	0.6

Table 13. Chemical compositions of organic materials

Organic materials	pH	OC	Ca	Mg	K	TN	P	S	B	Cu	Fe	Mn	Zn
							%						
Rice Husk Biochar	8.86	39.10	1.05	0.48	1.14	2.30	0.90	0.33	0.00	0.00	0.21	0.02	0.01
Poultry Manure Biochar	9.89	23.4	2.43	2.14	3.33	2.38	0.77	0.11	0.16	0.01	0.26	0.16	0.05
Poultry Manure	7.10	20.45	1.77	0.80	0.64	1.51	1.95	0.48	0.01	0.01	0.34	0.03	0.01
Mazim OF	6.67	17.30	2.01	1.49	1.01	3.07	1.50	1.02	0.01	0.01	0.32	0.03	0.02

Vermicompst	7.11	18.65	3.47	1.58	0.83	1.92	1.95	0.85	0.01	0.01	0.33	0.03	0.02
Cow dung Slurry	7.00	15.55	2.39	1.09	0.23	1.54	2.21	0.33	0.01	0.01	0.30	0.03	0.02
Cow dung	7.10	31.1	2.54	1.15	0.19	1.54	2.20	0.35	0.01	0.01	0.29	0.03	0.01

Soil pH in acid soil

The Belabo experimental soil was generally acidic, and had a very low organic matter (Table 1b). The pH of organic compound was found neutral to slightly alkaline in nature. Organic carbon and total nitrogen content of Biochar was found higher in comparison to cow dung and cow dung slurry (Table 6). Regardless of amendments, soil pH gradually decreased with the increase of incubation time (Fig. 5a & 5b). The results indicated significant differences in pH between control and organic manure amended soils throughout the incubation period (Fig. 6). Dikinya and Mufwanzala (2010) observed that the application of chicken manure irrespective of the application rate did not change the pH of amended soil. Azeez and Van Averbeke (2012) reported that pH of cattle and goat manures are significantly greater than that of poultry manure treatment.

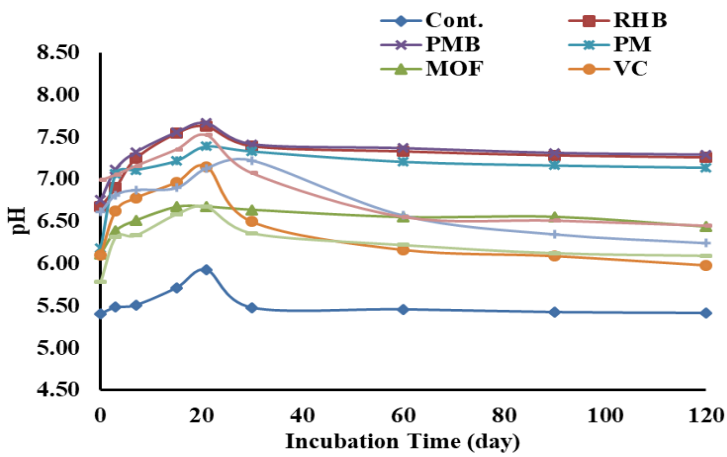


Fig. 5a. Soil pH dynamics in acid soil using different amending materials under field condition

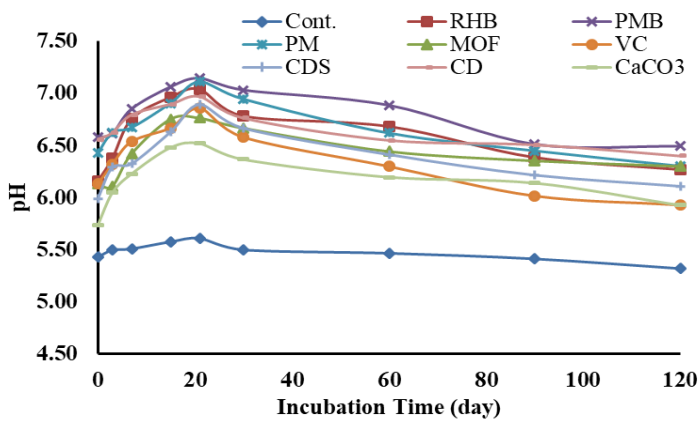


Fig. 5b. Soil pH dynamics in acid soil using different amending materials under standing water condition

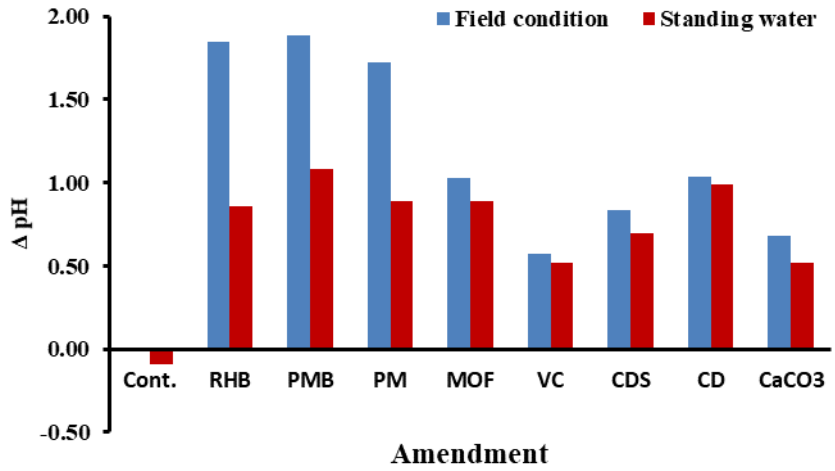
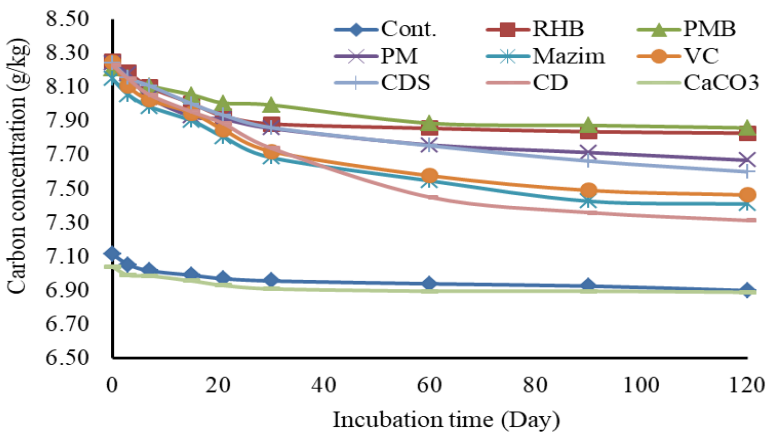


Fig. 6. Changing of soil pH under field and standing water condition

Soil organic carbon content

The result indicates that organic application initially increased soil organic carbon content of organic amended soils (Figure 7a and 7b). Under field condition, organic carbon content was found to be 4.33 to 12.10 % higher in organic treated soils over the initial value. Organic carbon content decreased significantly ($p < 0.05$) in control and poultry manure treated soils. In case of control, organic carbon 11.66% decreased at the end of incubation study. However, no significant difference was found among different periods of incubation when cow dung alone or cow dung slurry, vermicompost and mazim organic fertilizer applied in soil. Among these carbon sources, greater mineralizations occur in CD during the incubation. Lime additions decrease soil organic carbon content from own sources. Comparatively higher content of organic carbon was found under standing water condition (8.2 to 13.87 %). In both conditions, PMB containing organic carbon was greater than other sources.

(a)



(b)

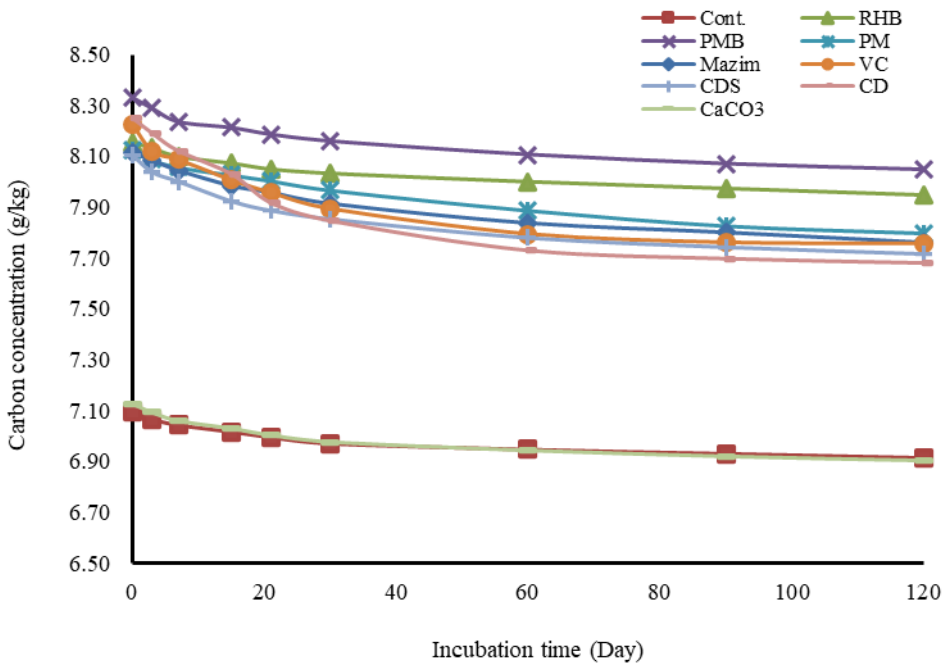
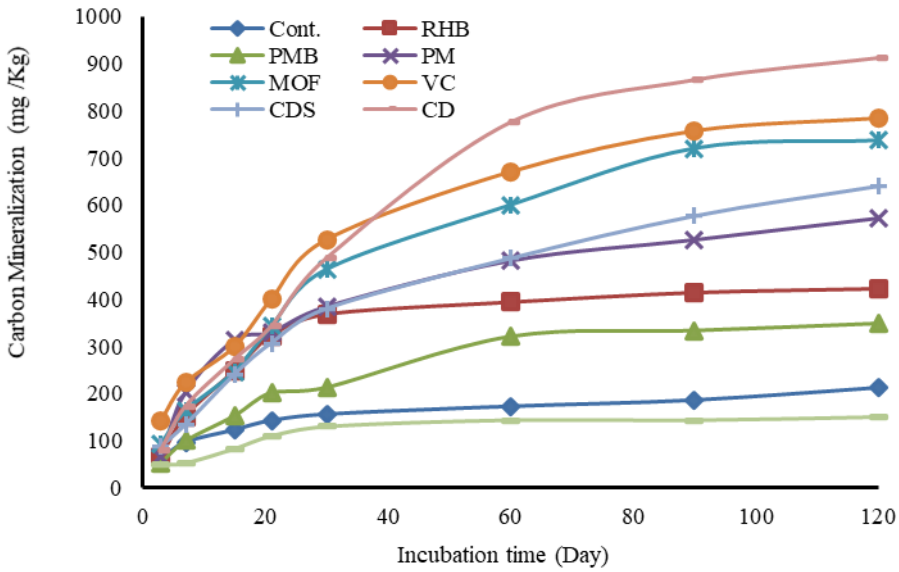


Fig.7. Soil organic carbon concentration dynamics using different organic amendment under(a) field condition and (b) standing water condition

Cumulative Organic carbon mineralization under field condition and standing water condition are shown in Fig. 8a &8b. Under field condition, the highest C mineralization was observed for CD amended (913 mg C kg^{-1} soil) followed by VC (783 mg C kg^{-1} soil) and their after MOF (737 mgC kg^{-1} soil) where without amended soil mineralized 213 mg C kg^{-1} soil. Carbon mineralization was low in biochar treated soil (423 mgC kg^{-1} soil in RHB and 348 mgC kg^{-1} soil in PMB). Under standing water conditions, these values decreased near about40% for the CD, VC and CDS treated soil where50% in MOF treated soil. RHB and 17% under PMB treated soil and 14% under control, respectively.

(a)



(b)

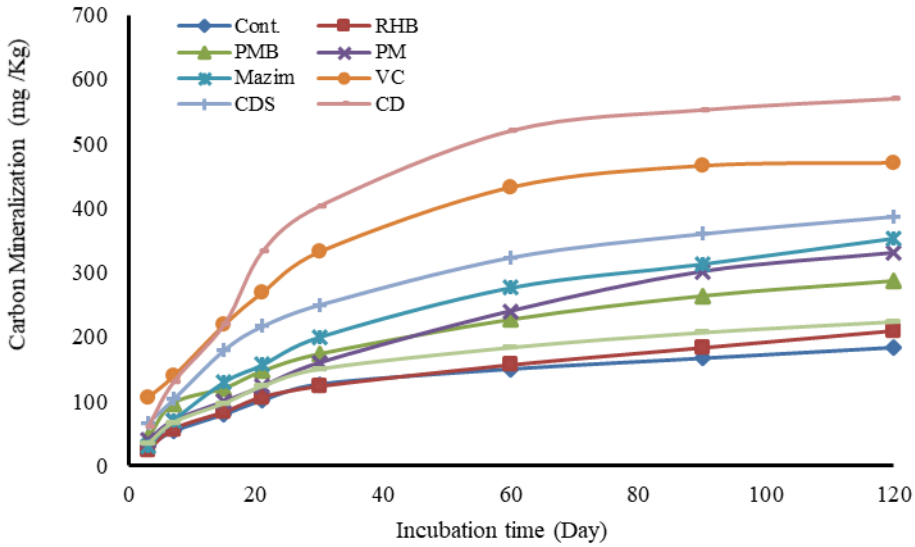
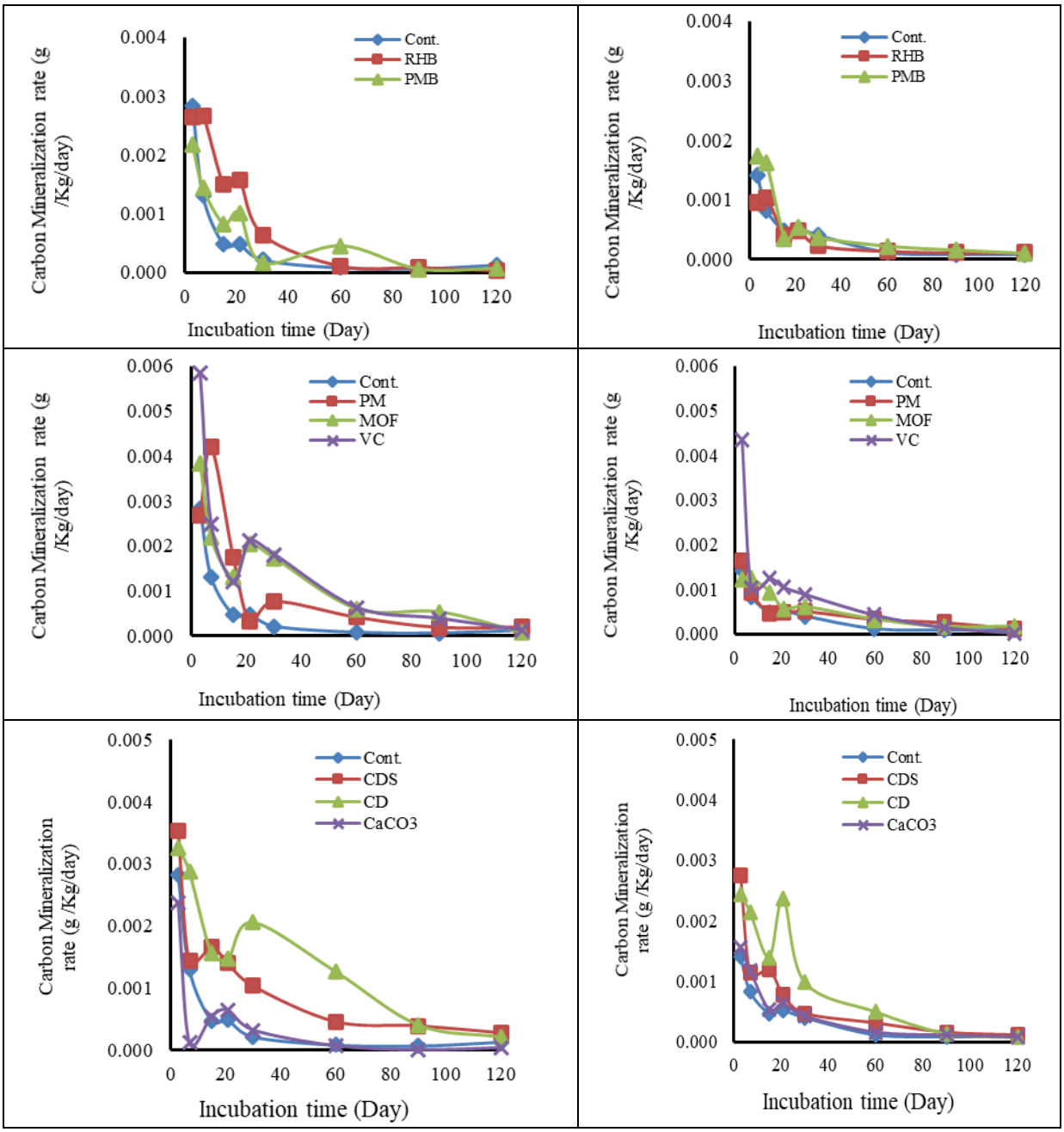


Fig.8. Changes acid soil organic carbon concentration using different organic amendment under (a) field condition and (b) standing water condition

After end of the incubation, SOC content of acid soils increased with organic amendment but high in biochar applied soil than that of noamended soil. Under field condition, the SOC content remarkably increased by 10.09% with rice husk biochar and 10.52% with applied into soil. But 11.77% carbon with rice husk biochar and 13.17% carbon in poultry manure biochar increase under submergence condition due to the direct increase of SOC by the external organic matter input. The carbon concentration found more than field capacity in standing water condition. The organic matter application affected the input of total organic carbon in the soil.

We fitted the results with the model and estimated the maximum of unstable carbon pool as given in Fig. 9. Application of biochar obviously decreased the minimum of unstable carbon and raw organic compound decreased maximum unstable carbon in the incubation period.



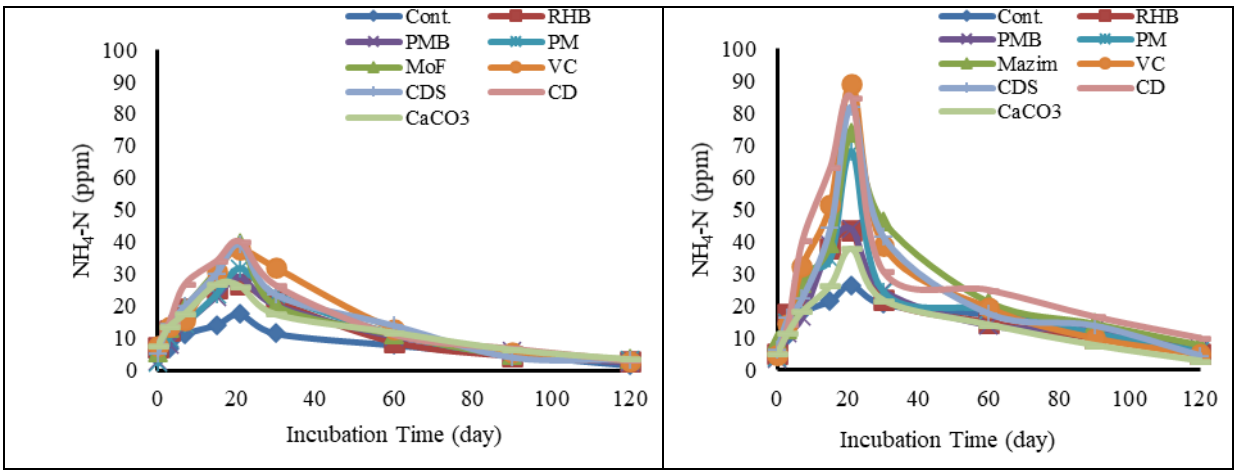
(a) Field condition (b) Standing water

Fig. 9. Carbon mineralization rate (k) calculate following kinetic model using different organic amendment under (a) field condition and(b) standing water

Nitrogen Dynamics in acid soil

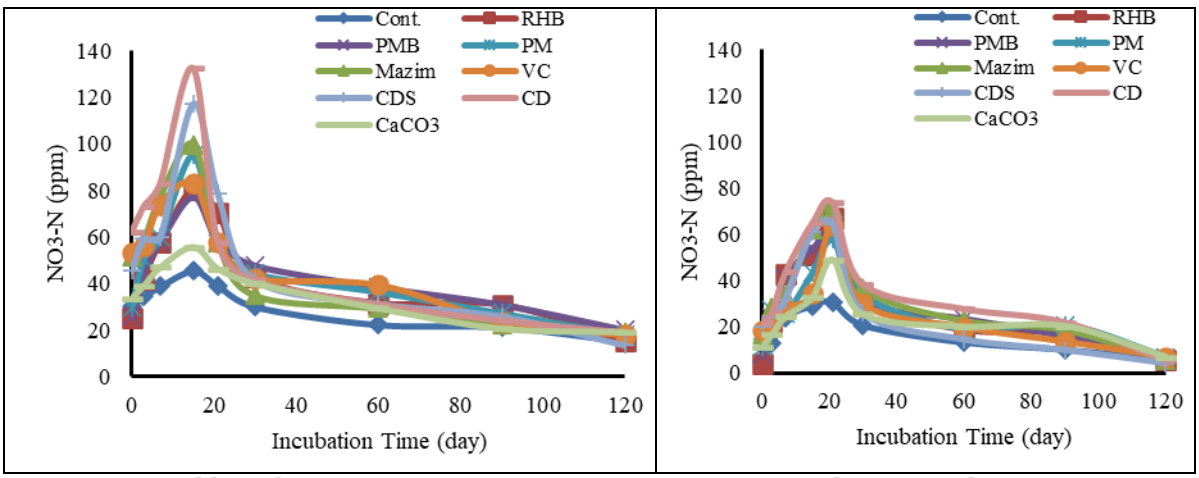
There was a slight release of NH_4 -N in all the organic treatments (Fig.10). As expected the application of organic compound produced higher amount of available NH_4 –N in soils compared to control (no organic was added). The greater amount of NH_4 –N released under standing water condition compare to field condition of soil. The content of NH_4 -N released from control and organic amended soils differed significantly ($p < 0.05$) with time of different incubation. After 21 days of incubation, the highest amount of NH -N4 + was found

when cow dung applied in soil (more than 110% over control) followed by VC (more than 90% over control) in both moisture condition. The greater amount of NO_3 –N released under field condition compare to standing water condition (Fig.11). Compare to control, about 90% higher from CD treated soil in field condition but 113% higher in standing water condition. Lowest NO_3 –N release from biochar treated soil in both moisture level.



Field condition **(a)** Standing water **(b).**

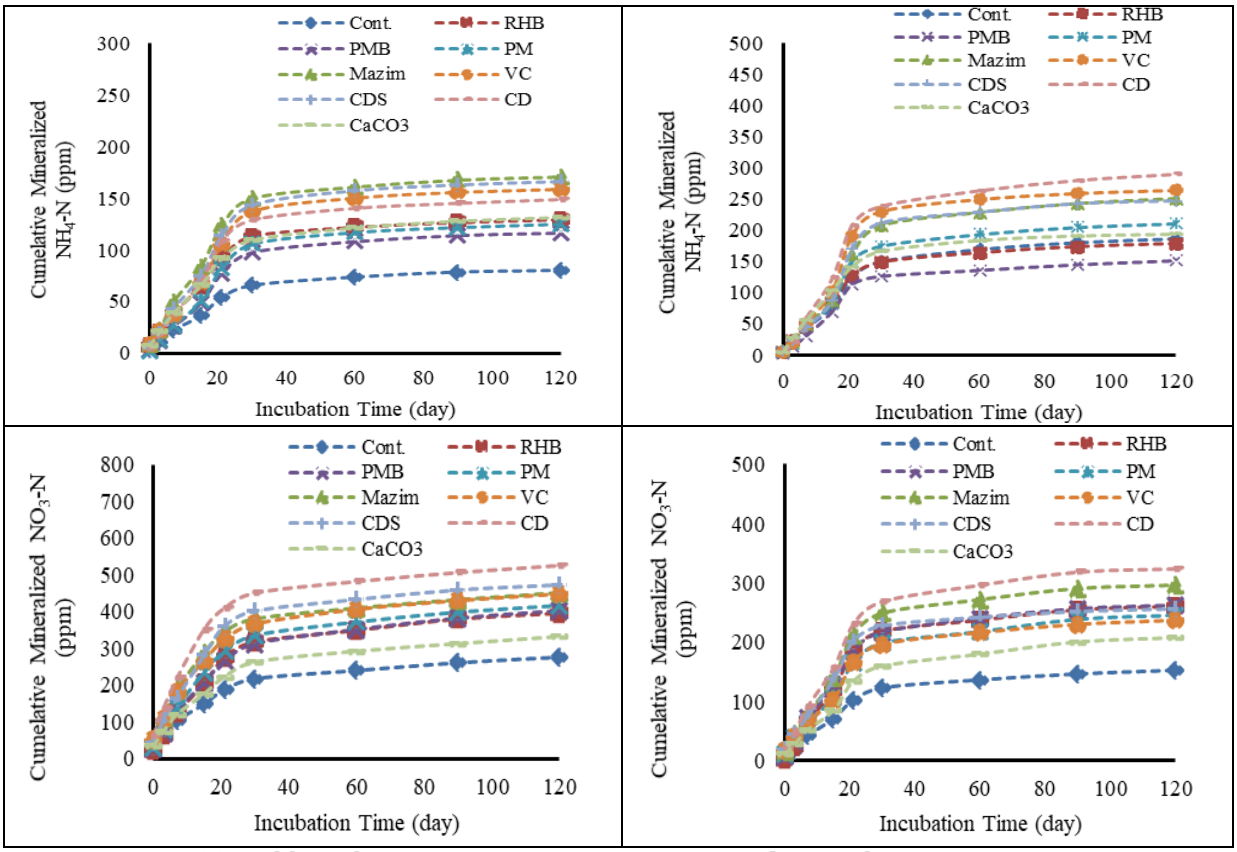
Fig. 10. NH_4-N dynamics in acid soil under (a) field condition and (b) standing water condition



Field condition **(a)** Standing water **(b).**

Fig. 11. NO_3-N dynamics in acid soil under (a) field condition and (b) standing water

Significant positive relationship between N contents and incubation time indicates mineralization of the easily convertible compounds during the incubation period (Fig. 12). The release of nutrients from organic manures and organic fertilizers depends on the types of manure, rates of application and moisture level (Rahman et al. 2013) stated that the mineralization of nitrogen is influenced by incubation period, rate of organic materials application, moisture regime and type of soil. Our results showed higher amount of N increase with incubation time in manure amended soils compared with control soil. Similar results were also reported by other investigators (Dikinya and Mufwanzala, 2010; Vel Murugan and Swarnam, 2013; Duffera, et. al., 1999) observed that processed swine lagoon solids increased the concentrations of NH_4 -N and during the first second weeks and by the second to fourth week after application, the NH_4 -N+ concentrations dropped.



(a) Field condition **(b).** standing water

Fig. 12. Cumulative Mineralization of NH_4-N (ppm)and NO_3-N (ppm)dynamics in acid soil under (a) field condition and (b) standing water

Table 14. Soil chemical properties after end of incubation

Treatment	Ca	Mg	K	P	S	B	Cu	Fe	Mn	Zn
	meq $100g^{-1}$			$\mu g\ g^{-1}$						
Cont.	4.55	1.08	0.18	33.67	31.67	0.33	1.62	66.80	12.14	2.44
RHB	4.59	1.09	0.38	66.67	37.00	0.41	3.45	45.14	8.21	2.32
PMB	6.82	1.62	0.36	45.67	87.33	0.46	3.24	55.98	10.18	3.13
PM	7.62	1.81	0.37	69.00	57.67	0.49	3.36	65.88	11.98	3.22
MOF	7.57	1.80	0.39	93.67	64.33	0.61	3.48	61.46	11.17	3.31
VC	6.44	1.54	0.37	97.33	70.67	0.41	3.33	61.00	11.09	3.37
CDS	7.60	1.81	0.16	96.00	72.00	0.63	1.41	63.43	11.53	3.34
CD	7.57	1.80	0.17	94.67	59.00	0.56	1.56	63.25	11.50	3.24
CaCO3	5.42	1.29	0.14	34.00	38.67	0.37	1.15	63.03	11.46	1.63

Table 15. Soil chemical properties after end of incubation under standing water condition

Treatment	Ca	Mg	K	P	S	B	Cu	Fe	Mn	Zn
	meq $100g^{-1}$			$\mu g\ g^{-1}$						
Cont.	4.78	1.14	0.17	45.00	32.00	0.34	1.56	65.74	11.95	1.54
RHB	4.86	1.16	0.37	36.00	44.33	0.23	3.39	63.80	11.59	1.38
PMB	7.56	1.80	0.37	56.33	74.33	0.71	3.36	59.76	10.86	3.27
PM	7.58	1.80	0.38	71.00	46.00	0.45	3.39	65.17	11.85	3.32
MOF	7.41	1.76	0.37	57.33	78.00	0.48	3.33	64.81	11.78	3.36
VC	6.41	1.53	0.38	44.00	69.67	0.32	3.42	62.33	11.33	3.25
CDS	7.24	1.72	0.15	63.67	53.67	0.32	1.35	64.90	11.80	3.25
CD	7.27	1.73	0.16	62.33	57.33	0.59	1.35	64.19	11.67	3.31
CaCO3	5.30	1.26	0.12	18.33	18.67	0.50	1.12	47.91	8.71	1.12

Trends of C decrease under different organic materials in drought soil

The C contents in different organic material mixed soil decreased with increasing time were shown in Fig. 13. At the end of the incubation period, the result indicates that organic application increased soil organic carbon content of organic amended soils. Under field condition, organic carbon content was found to be 2 to 12 % higher in organic treated soils over the initial value, where organic carbon content decreased significantly ($p < 0.05$) in control soil. In case of control, organic carbon 3% decreased at the end of incubation study. About 10% carbon content increase in biochar treated from without amending soil under standing water condition. More or less similar trends in C decrement under vermicompost, poultry manure, cowdung and cowdung slurry treated soil (Fig.12). Our result showed that except biochar all organic compounds mineralized rapidly in both moisture level where greater in field capacity condition. Carbon degradation of different materials varies depending on the nature and types of organic compound and environmental conditions. Different researchers found a wide range of C degradation rate constants of different materials, but it is very unusual of reproducing similar data as experimental setup and environmental conditions are widely varied from one to another.

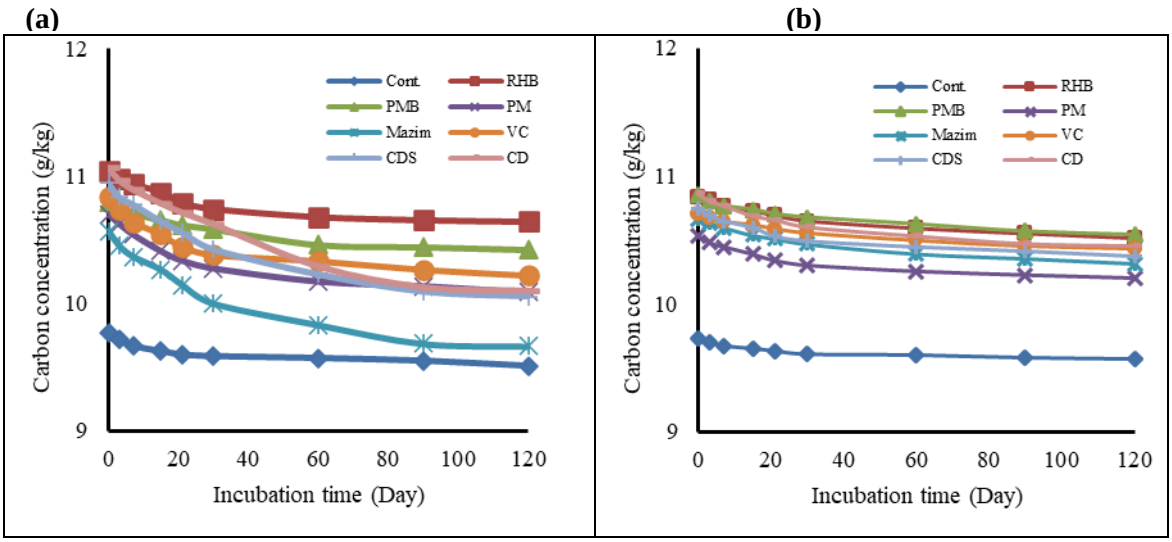


Fig. 13. Carbon reduction trends in different organic materials added soil under field condition (a) and standing water (b) under drought soils of Rajshahi Region.

Carbon mineralization of all organic compounds were increased with time and at the end of the incubation period (120d) it was observed that greater mineralization occur in FC condition compare to standing water condition Carbon mineralization of applied organic compound was statistically different at two moisture level (Fig. 14). In both condition greater mineralization occur in CD than MoF and VC treated soil and lowest in biochar treated soil. Carbon mineralization of non pyrolized organic carbon (CD, MoF, VC and PM) was higher than pyrolized organic carbon (RHB and PMB) because of stability of carbon. The results of Rey et al. (2005) strongly correlated with our results and they reported that most of the labile fractions gets into the top soil is rapidly mineralized over time.

(b)

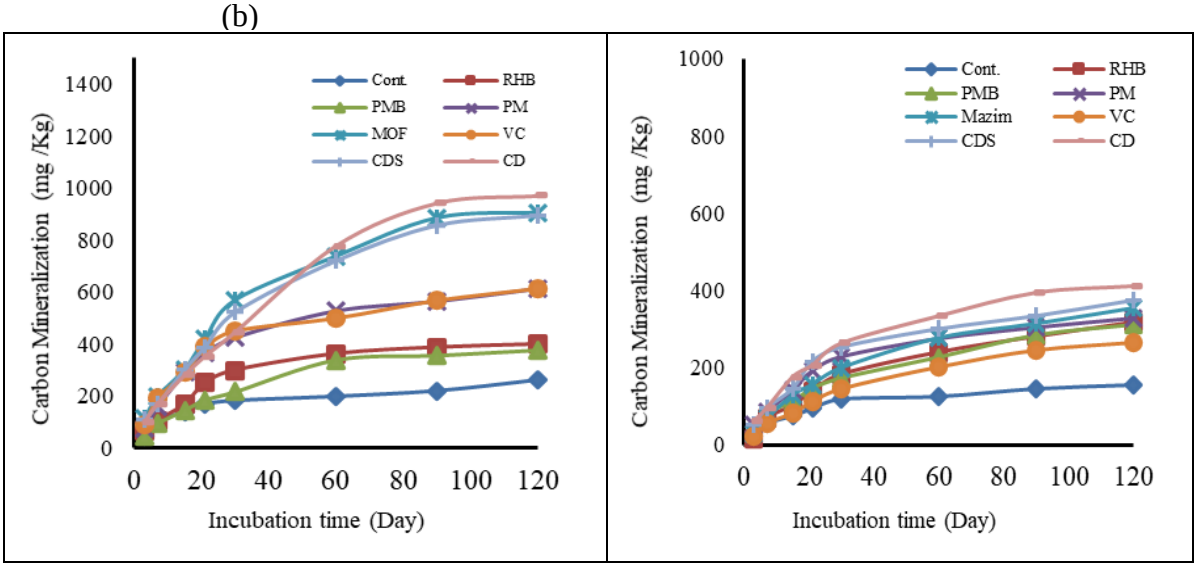
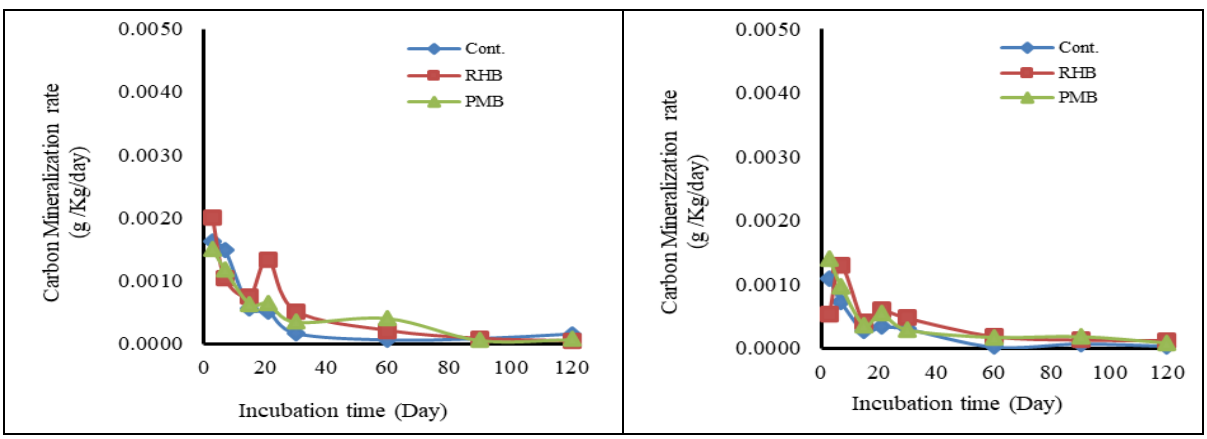
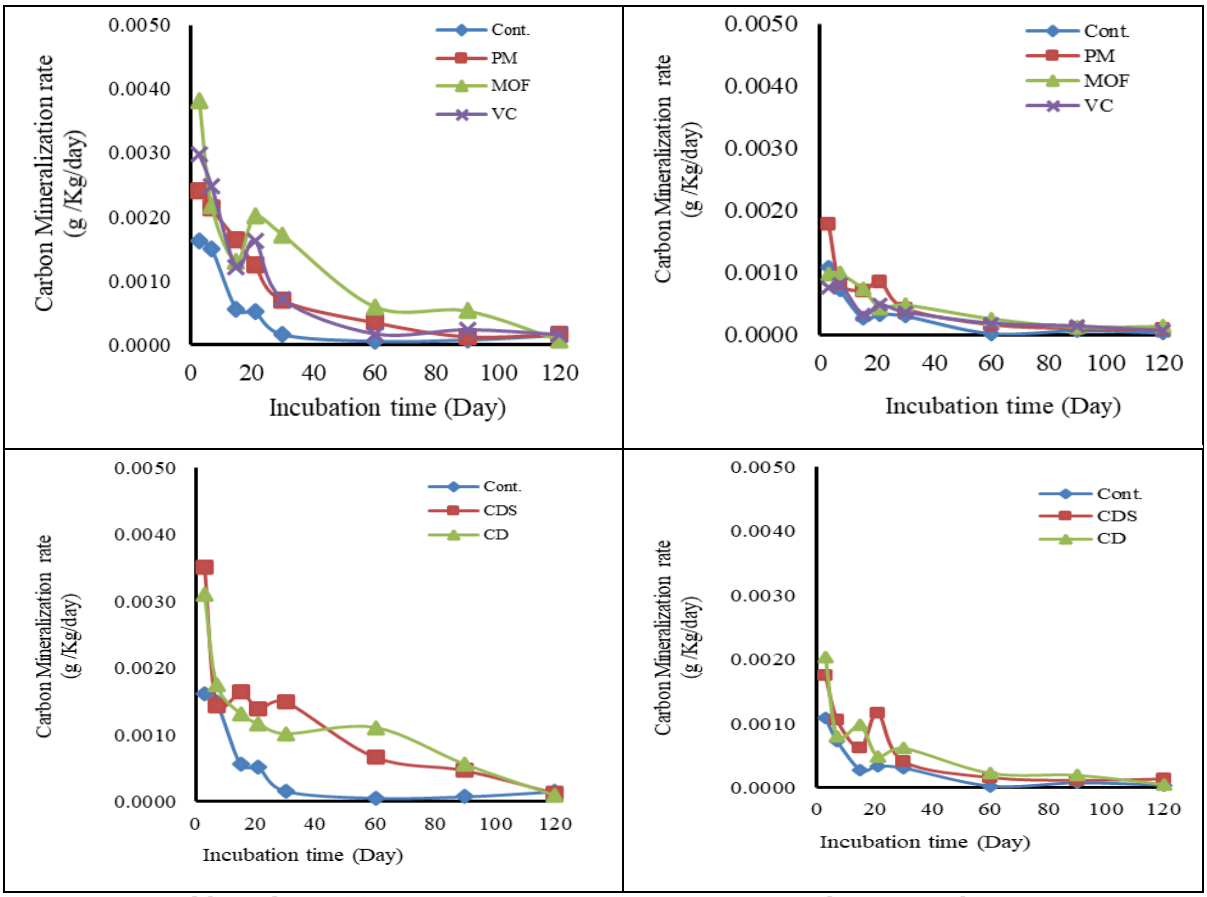


Fig. 14. Cumulative Mineralization of carbon (ppm) under (a) field condition and (b) standing water in drought soils of Rajshahi Region





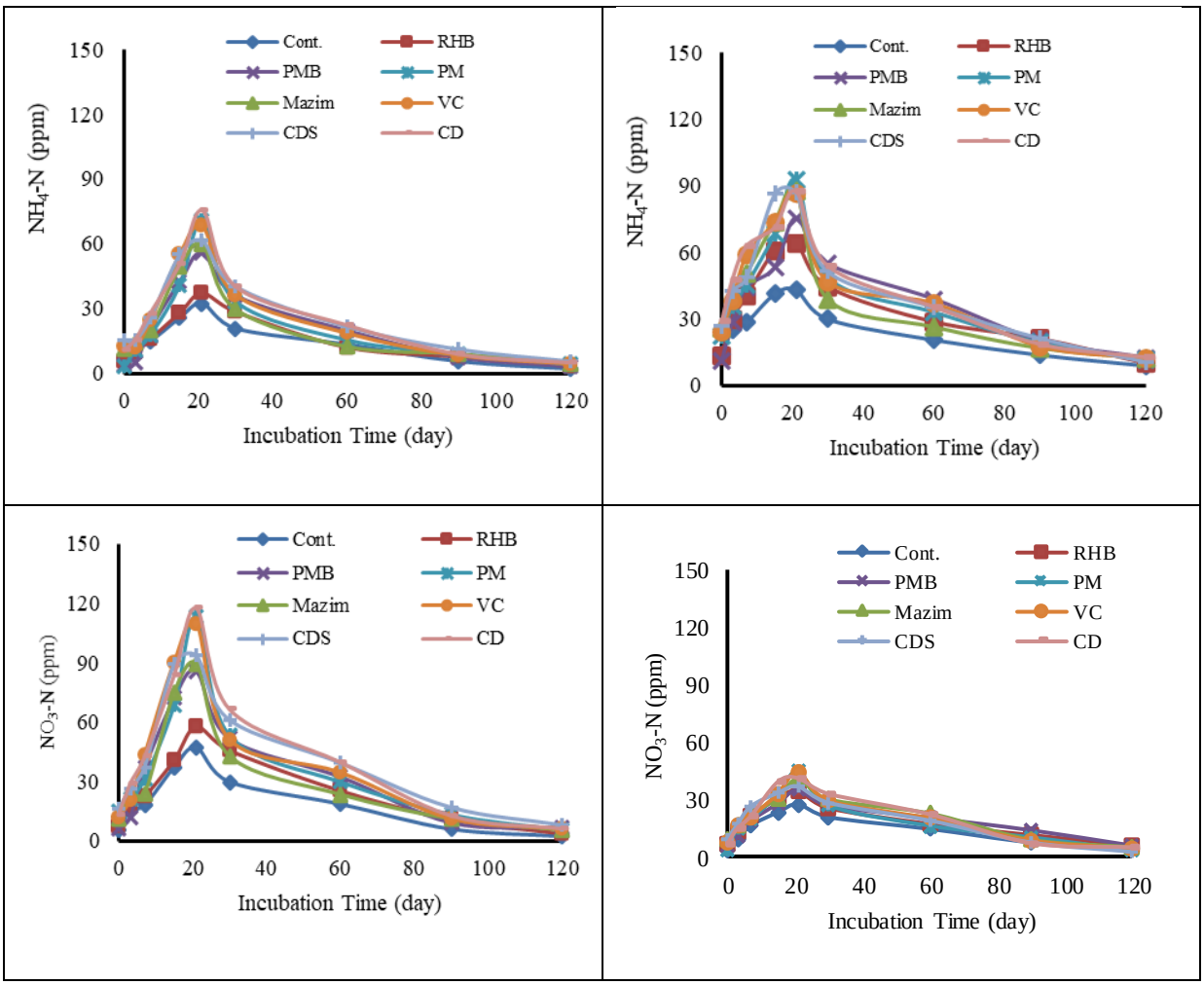
Field condition (a) Standing water (b)

Fig. 15. Rate of mineralization of organic carbon using different organic compound under (a) field condition and (b) standing water condition at drought soils of Rajshahi Region

Carbon mineralization kinetic modelling indicated that the stable organic matter in biochars could be sequestrated in soil for a long time and resulted in high levels of carbon sequestration, especially for the biochars pyrolysed from higher temperatures. The current study indicated that although the biochar addition induced increased soil carbon mineralization at the beginning of the incubation, soil carbon mineralization rates decreased sharply within a short time and then remained very low afterwards. The type of carbon source strongly influenced the carbon mineralization process. The results of 120 days incubation monitoring experiments showed that the mineralization rate of the SOC in all treatments was approximately the same with the incubation time, and the mineralization rate of C showed a tendency of first increasing and then decreasing (Fig. 15), which was consistent with the previous findings (Heuck and Spohn,2016; Marklein, et al., 2016). The different peaks that observed in the graphs may have different reasons but one of its main reasons is the variation of resistance of these substance components against microbial decomposition. The first peak (one to seven days) can be related to the decomposition of readily decomposable materials such as sugars and raw fibers. These substances have a higher decomposition rate and create higher peaks. The second peak (7 to 35 days), can be due to the decomposition of more resistant materials, i.e., cellulose and hemicellulose. However, the hemicellulose has greater resistant to decomposition than cellulose. Since the decomposing microorganisms for each component are different, maybe the composition of microbial community will be changed over time.

Nitrogen dynamics in drought soil

There was a slight release of NH_4 -N in all the organic treatments (Fig.16). The biological decomposition of organic matters caused the production of nitrogen. Generally, NH4 -N and NO3 -N contents at 21th day were higher than initial levels of soils (1st day) and also increased with time and. Significant differences between applications for different organic materials and its nitrogen contents were denoted as different letters in Table 9. As expected the application of organic compound produced higher amount of available NH_4 –N in soils compared to control (no organic was added). The greater amount of NH_4 –N released under standing water condition compare to field condition of soil. The content of NH_4 -N released from control and organic amended soils differed significantly ($p < 0.05$) with time of different incubation. After 21 days of incubation, the highest amount of NH -N4 + was found when cow dung applied in soil (more than 150% over control) followed by MoF (more than 133% over control) in field capacity condition. The greater amount of NO_3-N released under field condition compare to standing water condition. Lowest (about 30 ppm higher from control) NO_3-N release from biochar treated soil in both moisture level compare to control. Greater amount of nitrogen release from readily available content of nitrogen in organic compound.



Field condition **(a)** Standing water (b)

Fig. 16. NH_4-N and NO_3-N dynamics under (a) field condition and **(b)** standing water condition at drought soils of Rajshahi Region.

The observed N mineralization potentials in the orgnic amended soils were significantly higher than in non-amended soils (Table 17). Neglecting the magnitude of cumulative net mineralized N, organic showed a similar pattern of N released with time. Net nitrogen

mineralization followed the same trend observed for NO_3^- -N mineralization (Fig. 17). Nitrogen mineralization can strongly be affected by soil disturbance, as was the case in the present study (Cabrera and Kissel, 1988). It should be stressed that this study was carried out under controlled conditions (i.e., constant temperature and moisture), and organic materials were ground and well mixed with soil. Environmental conditions in the field will be more variable, and thus decomposition rates will vary as microbial populations respond to their environment. Hence, N mineralization in the field may not be accurately estimated by incubation studies.

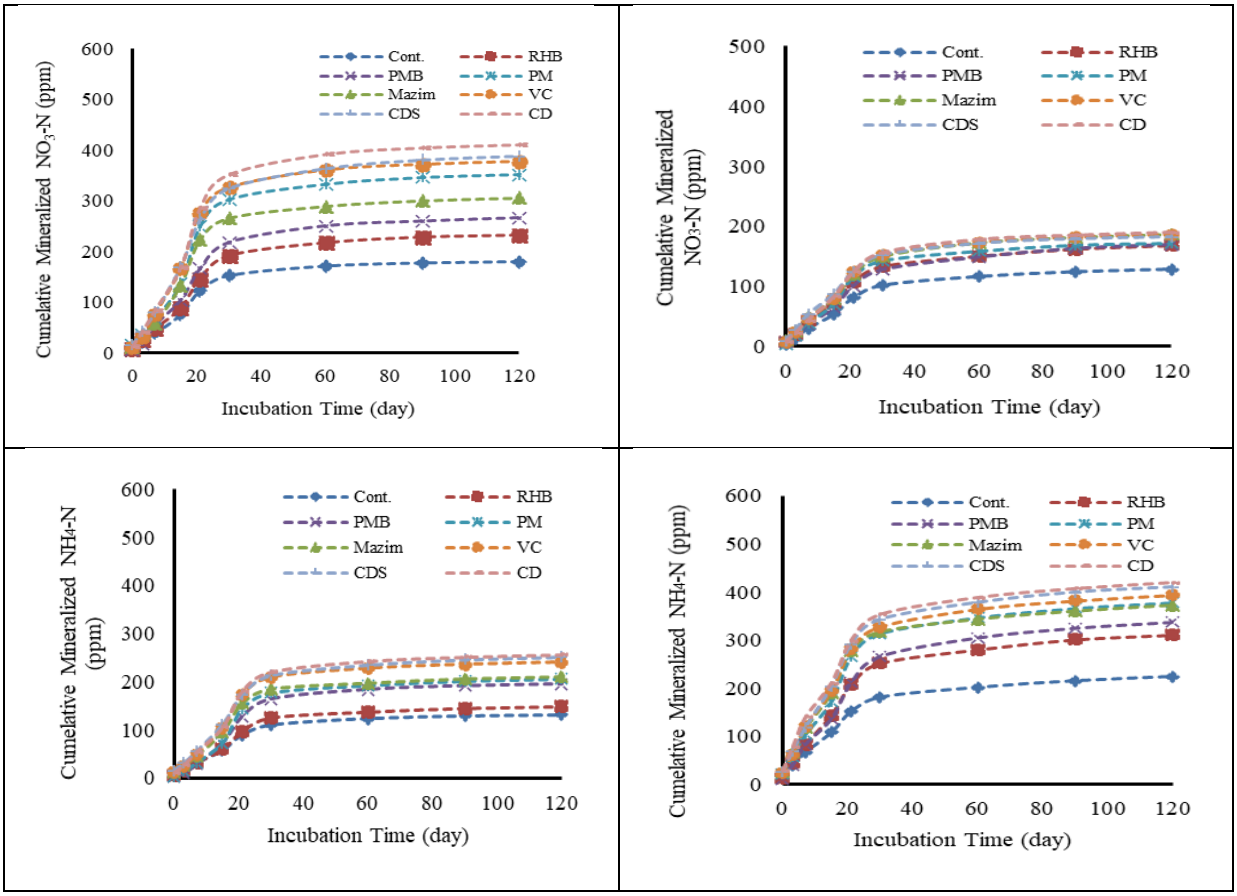


Fig. 17. Cumulative mineralization of NH_4-N and NO_3-N in (a) field condition and (b) standing water condition at drought soils of Rajshahi Region

Table 16. Soil Chemical properties after end of incubation

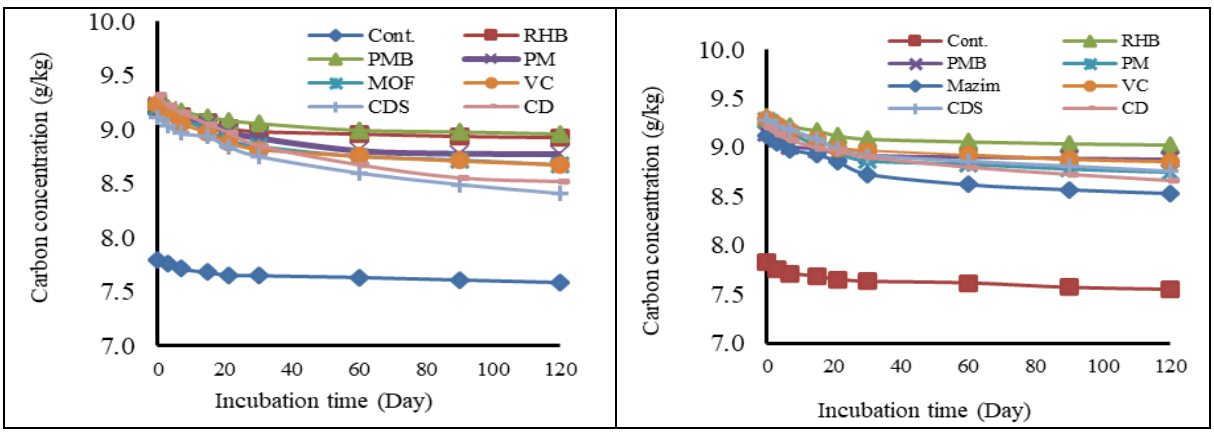
Treatment	Ca	Mg	K	P	S	B	Cu	Fe	Mn	Zn
	meq 100g^{-1}			µg g^{-1}						
Cont.	13.63	3.24	0.19	16.00	72.00	0.31	1.69	66.70	12.13	0.89
RHB	13.35	3.18	0.18	20.00	62.33	0.32	1.62	56.25	10.23	0.95
PMB	15.88	3.78	0.25	34.33	73.33	0.39	2.26	62.57	11.37	3.10
PM	17.44	4.15	0.31	54.67	74.00	0.51	2.77	69.09	12.56	2.50
MOF	16.86	4.01	0.35	45.33	100.00	0.50	3.15	54.42	9.89	2.59
VC	16.09	3.83	0.38	53.00	94.00	0.33	3.39	52.46	9.54	3.15
CDS	15.48	3.69	0.14	98.00	67.33	0.39	1.28	50.91	9.25	3.45
CD	14.98	3.57	0.15	84.67	54.00	0.33	1.35	56.43	10.26	3.42
CaCO3	16.70	3.98	0.13	25.67	47.00	0.44	1.19	57.55	10.46	2.64

Table 17. Soil Chemical properties after end of incubation under standing water condition

Treatment	Ca	Mg	K	P	S	B	Cu	Fe	Mn	Zn
	meq $100g^{-1}$			$\mu g\ g^{-1}$						
Cont.	15.78	3.76	0.16	16.00	38.67	0.44	1.47	65.32	11.88	0.95
RHB	15.34	3.65	0.23	31.00	32.33	0.27	2.05	59.61	10.84	1.03
PMB	14.73	3.51	0.24	34.33	68.67	0.45	2.13	64.20	11.64	2.95
PM	17.29	4.12	0.32	55.00	40.00	0.49	2.88	70.36	12.79	2.73
MOF	15.83	3.77	0.37	44.33	77.00	0.37	3.36	47.97	8.72	2.85
VC	15.62	3.72	0.38	67.67	48.33	0.63	3.42	57.66	10.49	3.15
CDS	15.10	3.60	0.13	98.67	34.33	0.43	1.22	53.92	9.80	3.29
CD	15.10	3.60	0.14	78.00	37.67	0.27	1.26	56.59	10.29	3.17
CaCO3	16.90	4.02	0.17	27.67	31.33	0.31	1.50	66.39	12.07	2.73

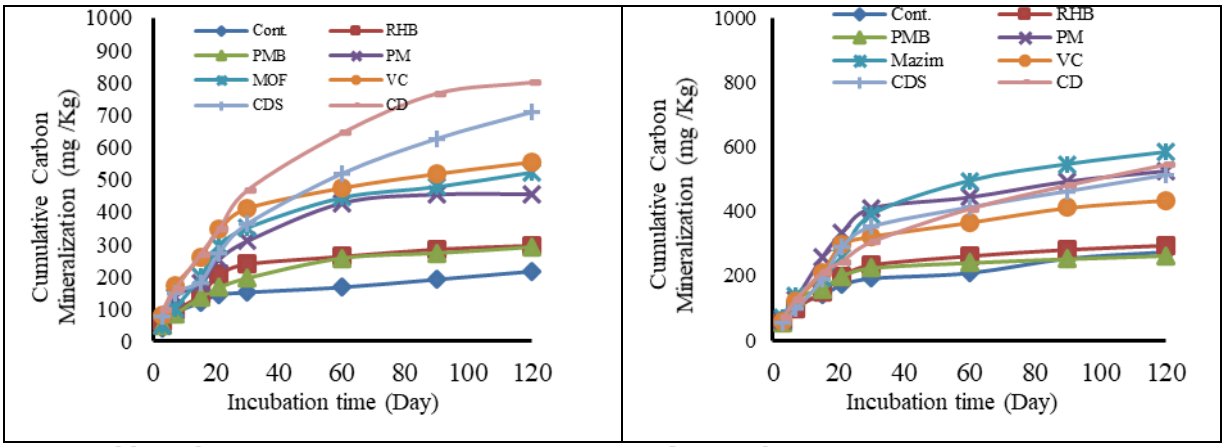
Carbon status in saline region:

Salt-affected soils usually exhibit low organic matter contents primarily due to poor plant growth leading to low inputs of organic materials into the soil. These soils are also subjected to increased losses due to dispersion, erosion and leaching. As a result, SOC contents are frequently smaller in salt-affected soils than in the adjacent non-degraded soils. After 120 days the amendments were applied, soil organic carbon contents were significantly higher in all amended plots than in the control plot and were highest in Biochar amended soil (Fig. 18). Although the same amount of organic carbon was added to the soils, the resulting increase in soil organic carbon differed depending on the amendment. This is consistent with Tejada et al. (2006), who reported that the effect of organic amendments on soil organic carbon depended on the chemical nature of the amendments. On the one hand, the chemical nature of the organic amendment is likely to affect the rate at which it is decomposed by the microbial community Hahn and Quideau (2013).



(a) Field condition **(b)** Standing water

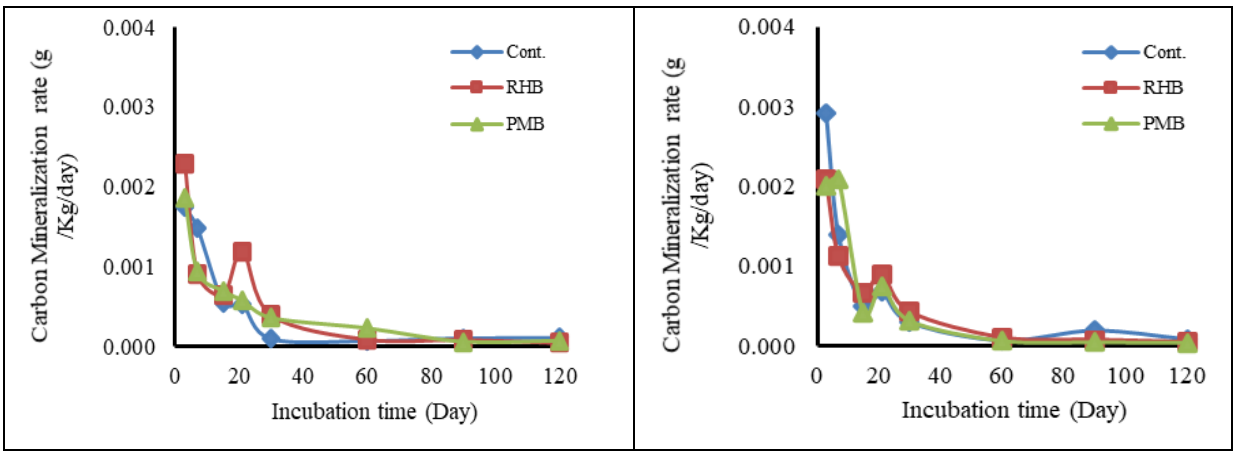
Fig. 18. Carbon reduction trends in different organic materials added soilunder field condition (a) and standing water (b) under saline soils of Khulna Region.

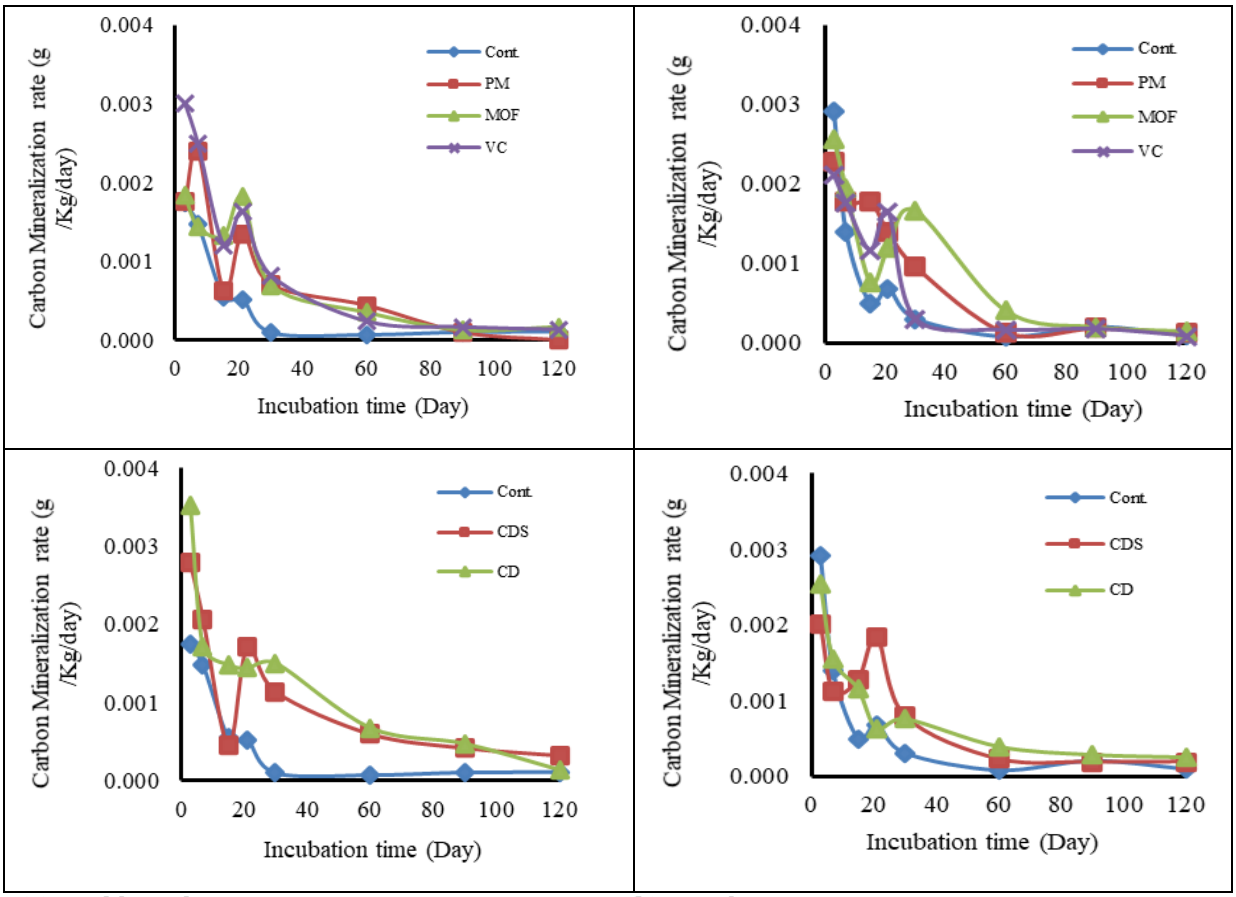


(a) Field condition **(b)** Standing water

Fig. 19. Cumulative Carbon reduction using different organic materials added soil under field condition (a) and standing water (b) under saline soils of Khulna Region

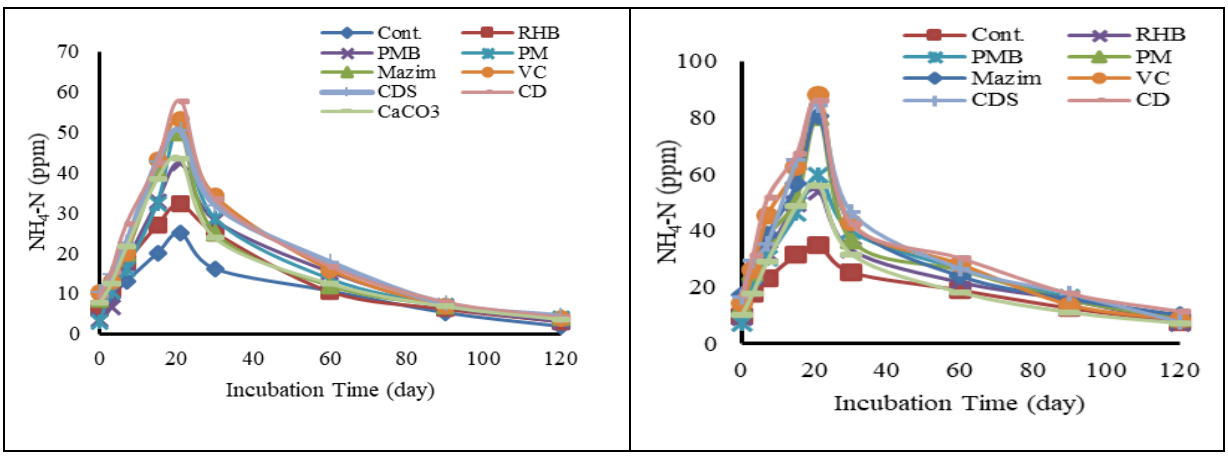
The results of 120 days incubation monitoring experiments showed that the mineralization rate of the SOC in all treatments was approximately the same with the incubation time. The effect of individual amendments on carbon mineralization differed among the treatment. The manure and MOF had similar cumulative carbon mineralization occurred which was much more than Biochar treatment compared to the control. In the saline soil (Fig. 20 and 21), none of the amendments mineralized significantly different total carbon mineralization compared to the any other amendment. The daily and cumulative SOC mineralization dynamics during the 120-day incubation are shown in Fig 21. Under the different amendments, the daily and cumulative SOC mineralization displayed similar trends in the order of CK > Biocahr > VC or PM or OF > CD or CDS.

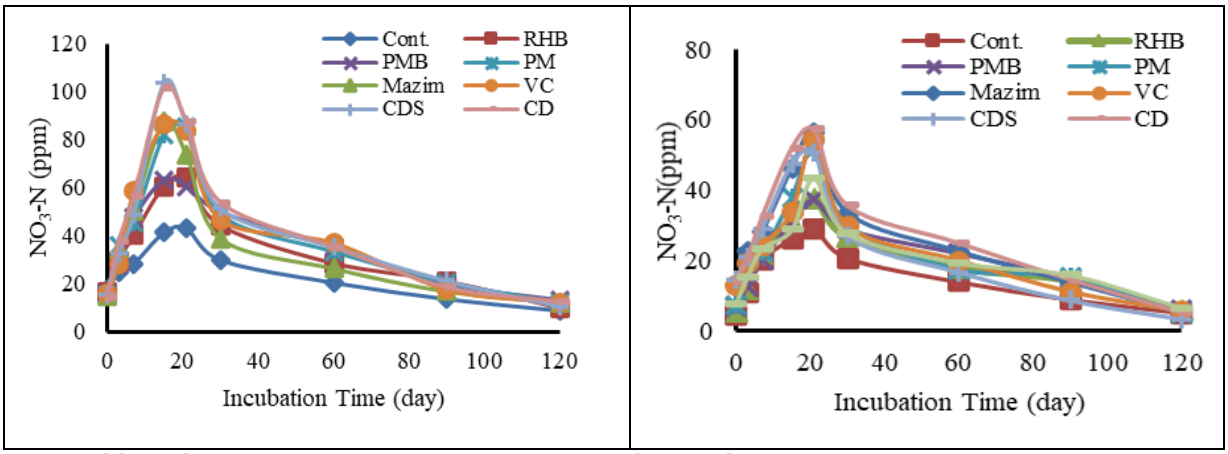




(a) Field condition **(b)** Standing water

Fig 20. Carbon mineralization rate using different organic materials added soilunder field condition (a) and standing water (b) under saline soils of Khulna Region.



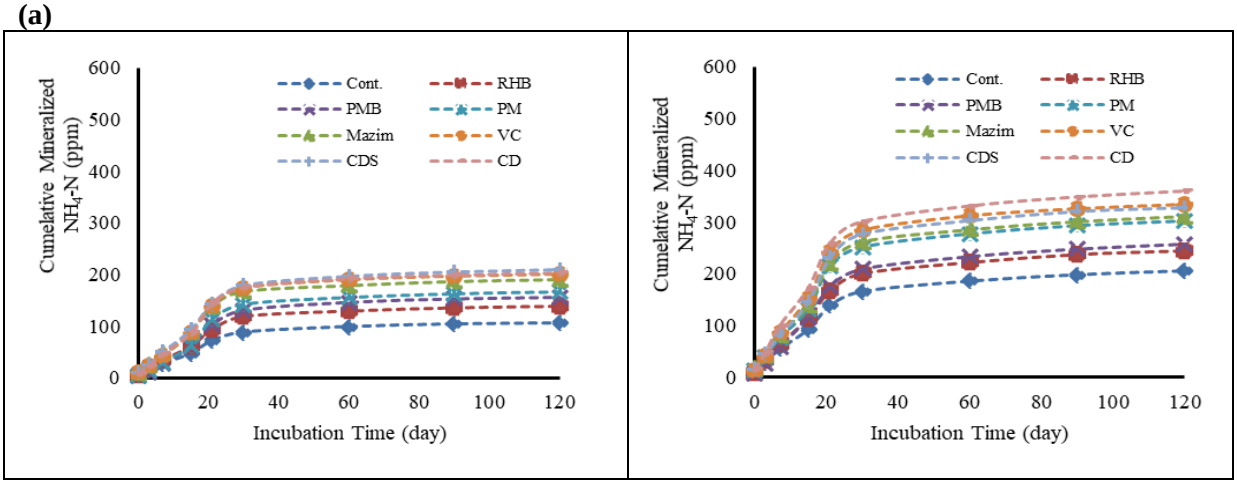


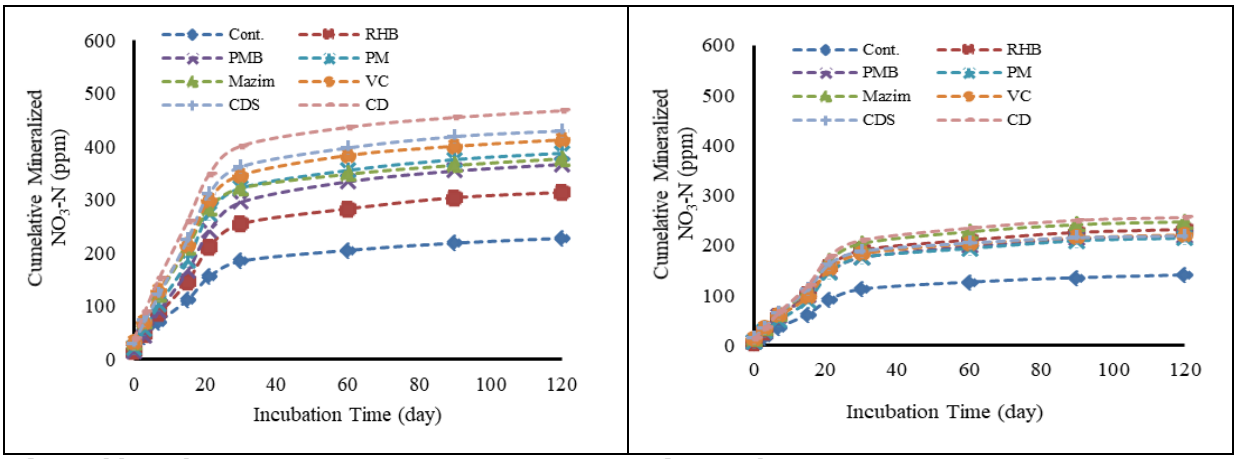
(a) Field condition (b) Standing water

Fig. 21. Carbon mineralization rate using different organic materials added soilunder field condition (a) and standing water (b) under saline soils of Khulna Region.

The mineralized SOC rate reached the maximum value on the first day of incubation and significantly decreased and stabilized after 21 d (Fig. 19).It may also be true for our experiment and explain why the addition of biochar, material containing a high concentration of C and a long residence time in soil, did not lead to a significant increase in carbon mineralization. It would be valuable in the future to include readily available substrates along with leonardite or other stable C soil amendments to better understand the ability of microbial communities to decompose recalcitrant forms of C when another source of energy is present. It was hypothesized that microbial biomass and microbial respiration would be lower in the saline soil.

(a)





(b) Field condition **(b)** Standing water

Fig. 22. Carbon mineralization rate using different organic materials added soilunder field condition (a) and standing water (b) under saline soils of Khulna Region.

Our findings showed that the organic amendments greatly increased the carbon and N content. However, the effects of organic amendments on nutrient availability depend on their chemical composition and decomposition rates. In the current study, application of organic lust carbon in three type of soil, where mineralization process was slower under standing water condition. Obviously, the SOC mineralization rate also shows its own characteristics respectively. On the whole, the greater mineralization occurs in field capacity condition, the lower mineralization in the biochar treated soil. Due to control weather and temperature, mineralization process of field level is little bit different from our result. Carbon mineralization rate increase and decrease due to high and low temperature, rainfall and extend of salinization.

C. Field experiments on acidic soil (Belabo)

A field experiments were conducted on acidic soil at Belabo, Narsingdi. Initial soil nutrient status of Belabo experimental field has been presented in Table 18.

Table 18. Analytical data of the experimental soils of Belabo (Initial soil)

Location	pH	OM%	Ca	Mg	K	Total N %	P	S	B	Cu	Fe	Mn	Zn
			meq 100g^{-1}				µg g^{-1}						
Vabla, Belabo	5.5	1.7	3.5	1.6	0.22	0.12	12	16	1.1	5.0	33	30	2.4
Critical Level	-	-	2.0	0.5	0.12	-	7	10	0.2	0.2	4	1	0.6

Cauliflower:

First, fourth and seventh crop cauliflower (variety: snow white) was harvested from the experimental field during the year 2018-19, 2019-20 and 2020-21, respectively (Fig. 23a and 23b). Data on yield and yield components of cauliflower are analyzed and presented in Table 12. Different organic amendments significantly influenced the yield and yield contributing characters of cauliflower. Curd height, curd circumference, no. of leaves/plant and marketable wt. of individual curd was highest inT_3 treatment (Poultry Manure biochar @ 2 t/ha + IPNS based inorganic fertilizer) and lowest inun-amended T_1 treatment. Moderate curd height, curd circumference, no. of leaves/plant and marketable wt. of individual curd was obtained from 100% chemical fertilizer amended T_6 treatment. Similarly, the highest curd yield (35.75 t ha^{-1} in 2018-19, 28.23 t ha^{-1} in 2019-20& 38.61 t ha^{-1} in 2020-21) was obtained from T_3 treatment (Poultry Manure biochar @ 2 t/ha + IPNS based inorganic fertilizer) which was followed by T_4, $T_2$and T_5treatment. Un-amended T_1 treatment yielded lowest yield (11.63 t ha^{-1} in 2018-19, 9.05 t ha^{-1} in 2019-20& 13.74 t ha^{-1}in 2020-21). Moderate curd yield

(27.74 t ha^{-1} in 2018-19, 20.46 t ha^{-1} in 2019-20 &29.46 t ha^{-1}in 2020-21) was obtained from 100% chemical fertilizer amended T_6 treatment. About 198.1%yield increase over un-amended T_1 treatment and 32.08% yield increase over 100% chemical fertilizer amended T_6 treatment was recorded in T_3 treatment (Poultry Manure biochar @ 2 t/ha + IPNS based inorganic fertilizer).

Fig. 23a **Fig .23b**

Fig. 23a & 23b. Field experiment on acid soil of Belabo showing comparative performance of organic materials and dolomite for correction of soil acidity and cauliflower productivity during 2018-19, 2019-20 and 2020-21, respectively.

Table 19. Effects of different organic amendment on yield and yield contributing characters of cauliflower at Belabo during 2018-20, 2019-20 & 2020-21

Treatment	Curd height (cm)			Curd circumference (cm)		
	2018-19	2019-20	2020-21	2018-19	2019-20	2020-21
T_1 = Control (no fertilizer)	6.63d	5.89e	6.89d	22.67d	18.57d	24.11d
T_2 = PM @ 3 t/ ha+ IPNS based inorganic fertilizer	11.43b	9.78bc	12.14b	41.18ab	35.01ab	43.53ab
T_3 = PM biochar @ 2 t/ha+ IPNS based inorganic fertilizer	12.53a	10.82a	13.98a	46.13a	39.52a	48.78a
T_4 = Rice husk biochar @ 2 t/ha + IPNS based inorganic fertilizer	12.09ab	10.26ab	13.48a	44.83a	37.78ab	46.64ab
T_5 = Dolomite @ 1 t/ha + 100% RF	10.23c	9.02cd	10.14c	39.23bc	33.12bc	41.37bc
T_6 = 100% RF	9.53c	8.71d	9.98c	34.05c	29.12c	36.30c
CV (%)	6.95	6.19	6.31	7.49	8.35	9.15

RF= $N_{120}P_{20}K_{110}S_{20}Zn_2B_1$ kg ha^{-1}

Table 19. Continued

Treatment	No. of leaves/plant			Marketable wt. of individual curd (kg)		
	2018-19	2019-20	2020-21	2018-19	2019-20	2020-21
T_1 = Control (no fertilizer)	8.80e	8.5c	9.4e	0.296d	0.223d	0.338d
T_2 = PM @ 3 t/ ha+ IPNS based inorganic fertilizer	14.9bc	14.2a	16.2b	0.820ab	0.612ab	0.874ab
T_3 = PM biochar @ 2 t/ha+ IPNS based inorganic fertilizer	16.7a	15.1a	17.8a	0.895a	0.678a	0.962a
T_4 = Rice husk biochar @ 2 t/ha + IPNS based inorganic fertilizer	15.9ab	13.1a	16.9ab	0.851ab	0.0646ab	0.940a
T_5 = Dolomite @ 1 t/ha + 100% RF	13.6c	13.0ab	14.2c	0.792b	0.585b	0.816bc
T_6 = 100% RF	11.8d	11.4b	12.3d	0.695c	0.507c	0.749c
CV (%)	6.61	11.49	6.96	8.51	6.70	6.78

Table 19. Continued

Treatment	Yield(t/ha)				% yield increase	
	2018-19	2019-20	2020-21	Average	over T_1 treatment	over T_6 treatment
T_1 = Control (no fertilizer)	11.63c	9.05d	13.74d	11.47	-	-
T_2 = PM @ 3 t/ ha+ IPNS based inorganic fertilizer	32.98a	24.68b	35.08ab	30.91	169.5	19.40
T_3 = PM biochar @ 2 t/ha+ IPNS based inorganic fertilizer	35.75a	28.23a	38.61a	34.20	198.1	32.08
T_4 = Rice husk biochar @ 2 t/ha + IPNS based inorganic fertilizer	34.67a	26.38ab	36.85ab	32.63	184.5	26.05
T_5 = Dolomite @ 1 t/ha + 100% RF	31.95a	23.62bc	33.53bc	29.70	158.9	14.72
T_6 = 100% RF	27.74b	20.46c	29.46c	25.89	125.7	-
CV (%)	7.41	8.30	8.19	-	-	-

Okra:

Second, fifth and eighth crop okra (variety: green finger) was harvested from the experimental field during the year 2019, 2020 and 2021, respectively (Fig. 24a & 24b). Data on yield and yield components of okra are analyzed and presented in Table 20. Different organic amendments significantly influenced the yield and yield contributing characters of okra. Plant height, no. of fruits/plant, single fruit weight and fruit weight/plant was highest in T_3 treatment (Poultry Manure biochar @ 2 t/ha + IPNS based inorganic fertilizer) and lowest in un-amended T_1 treatment. Moderate plant height, no. of fruits/plant, single fruit weight and fruit weight/plant was obtained from 100% chemical fertilizer amended T_6 treatment. Similarly, the highest fruit yield (16.57 t ha^{-1} in 2019, 17.34 t ha^{-1} in 2020 &19.46 t ha^{-1} in 2021) was obtained from T_3 treatment (Poultry Manure biochar @ 2 t/ha + IPNS based inorganic fertilizer) which was followed by T_4, T_2 and T_5 treatment. Un-amended T_1 treatment yielded lowest yield (6.18 t ha^{-1} in 2019, 6.64 t ha^{-1} in 2020 &7.24 t ha^{-1}in 2021). Moderate fruit yield (13.16 t ha^{-1} in 2019, 13.54 t ha^{-1} in 2020 &13.78 t ha^{-1}in 2021) was obtained from 100% chemical fertilizer amended T_6 treatment. About 165.9%yield increase over un-amended T_1 treatment and 31.88% yield increase over 100% chemical fertilizer amended T_6 treatment was recorded in T_3 treatment (Poultry Manure biochar @ 2 t/ha + IPNS based inorganic fertilizer).

Fig.24a **Fig. 24b**

Fig. 24a & 24b. Field experiment on acid soil of Belabo showing comparative performance of organic materials and dolomite for correction of soil acidity and cauliflower productivity during 2018-19, 2019-20and 2020-21, respectively.

Table 20. Effects of different organic amendment on yield and yield contributing characters of okra at Belabo during 2019, 2020 & 2021

Treatment	Plant height(cm)			No. of fruits/plant		
	2019	2020	2021	2019	2020	2021
T_1 = Control (no fertilizer)	0.78d	0.83d	0.88d	11.6d	12.2d	12.9d
T_2 = PM @ 3 t/ ha+ IPNS based inorganic fertilizer	1.04abc	1.09abc	1.12abc	22.6abc	23.2b	24.1b
T_3 = PM biochar @ 2 t/ha+ IPNS based inorganic fertilizer	1.12a	1.19a	1.26a	25.8a	27.2a	29.1a
T_4 = Rice husk biochar @ 2 t/ha + IPNS based inorganic fertilizer	1.09ab	1.14ab	1.20ab	24.2ab	26.6a	28.2a
T_5 = Dolomite @ 1 t/ha + 100% RF	0.99bc	1.06bc	1.07bc	22.1bc	22.4bc	23.0bc
T_6 = 100% RF	0.95c	0.99c	1.02cd	19.2c	19.6c	20.1c
CV (%)	6.96	5.52	7.70	9.11	8.41	9.07

RF= $N_{120}P_{20}K_{100}S_{15}Zn_2B_1$ kg ha^{-1}

Table 20. Continued

Treatment	Single fruit weight (gm)			Fruit weight/plant (gm)		
	2019	2020	2021	2019	2020	2021
T_1 = Control (no fertilizer)	14.8b	14.6b	15.6b	172.2e	182.3d	196.4d
T_2 = PM @ 3 t/ ha+ IPNS based inorganic fertilizer	19.1a	19.2a	19.8a	440.6bc	458.2abc	476.1bc
T_3 = PM biochar @ 2 t/ha+ IPNS based inorganic fertilizer	19.9a	20.6a	20.9a	484.5a	502.4a	598.1a
T_4 = Rice husk biochar @ 2 t/ha + IPNS based inorganic fertilizer	19.4a	20.3a	20.5a	462.4ab	482.3ab	534.2ab
T_5 = Dolomite @ 1 t/ha + 100% RF	18.9a	18.9a	19.2a	418.2cd	432.3bc	449.8c
T_6 = 100% RF	18.1a	18.3a	18.6a	380.4d	395.0c	412.2c
CV (%)	9.25	7.47	7.18	6.40	8.71	8.67

Table 20. Continued

Treatment	Yield (t/ha)				% yield increase	
	2019	2020	2021	Average	over T_1	over T_6
T_1 = Control (no fertilizer)	6.18c	6.64d	7.24d	6.69	-	-
T_2 = PM @ 3 t/ ha+ IPNS based inorganic fertilizer	15.34ab	15.87ab	16.64abc	15.95	138.4	18.24
T_3 = PM biochar @ 2 t/ha+ IPNS based inorganic fertilizer	16.57a	17.34a	19.46a	17.79	165.9	31.88
T_4 = Rice husk biochar @ 2 t/ha + IPNS based inorganic fertilizer	15.96a	16.56ab	18.54ab	17.02	154.4	26.17
T_5 = Dolomite @ 1 t/ha + 100% RF	14.62ab	14.98bc	15.84bc	15.15	126.4	12.28
T_6 = 100% RF	13.16c	13.54c	13.78c	13.49	101.7	-
CV (%)	10.2	8.08	10.35	-	-	-

Indian spinach:

Third, sixth and ninth crop Indian spinach (Variety: BARI Puishak-1) was harvested from the experimental field during 2019, 2020 and 2021, respectively (Fig.25). Data on yield and yield components of Indian spinach are analyzed and presented in Table 21. Different organic amendments significantly influenced the yield and yield contributing characters of Indian spinach. No. of leaves/plant and biomass weight/plant was highest in T_3 treatment (Poultry Manure biochar @ 2 t/ha + IPNS based inorganic fertilizer) and lowest in un-amended T_1 treatment. Moderate no. of leaves/plant and biomass weight/plant was obtained from 100% chemical fertilizer amended T_6 treatment. Similarly, the highest biomass yield (22.86 t ha^{-1} in 2019, 24.17 t ha^{-1} in 2020 &26.59 t ha^{-1} in 2021) was obtained from T_3 treatment (Poultry Manure biochar @ 2 t/ha + IPNS based inorganic fertilizer) which was followed by T_4, T_2 and T_5 treatment. Un-amended T_1 treatment yielded lowest yield (6.98 t ha^{-1} in 2019, 7.40 t ha^{-1} in 2020 &8.02 t ha^{-1}in 2021). Moderate biomass yield (16.53 t ha^{-1} in 2019, 18.31 t ha^{-1} in 2020 &19.05 t ha^{-1}in 2021) was obtained from 100% chemical fertilizer amended T_6 treatment. About 228.5%yield increase over un-amended T_1 treatment and 36.64% yield increase over 100% chemical fertilizer amended T_6 treatment was recorded in T_3 treatment (Poultry Manure biochar @ 2 t/ha + IPNS based inorganic fertilizer).

Fig. 25. Field experiment on acid soil of Belabo showing comparative performance of organic materials and dolomite for correction of soil acidity and Indian spinach productivity.

Table 21. Effects of different organic amendment on yield and yield contributing characters of Indian spinach at Belabo during 2019, 2020 & 2021

Treatment	No. of leaves/plant			Biomass weight/plant (gm)		
	2019	2020	2021	2019	2020	2021
T_1 = Control (no fertilizer)	35.4d	44.2c	47.1d	224e	231d	246d
T_2 = PM @ 3 t/ ha+ IPNS based inorganic fertilizer	103.5ab	112.8ab	114.8b	630bc	646b	681b
T_3 = PM biochar @ 2 t/ha+ IPNS based inorganic fertilizer	117.0a	128.3a	138.2a	726a	737a	790a
T_4 = Rice husk biochar @ 2 t/ha + IPNS based inorganic fertilizer	112.7a	124.8ab	135.1a	676b	712a	764a
T_5 = Dolomite @ 1 t/ha + 100% RF	97.2bc	106.4b	108.8b	587c	618b	642b
T_6 = 100% RF	88.2	96.3b	98.6c	490d	535c	562c
CV (%)	8.17	9.71	6.11	7.41	6.40	6.63

RF: N_{120} kg/ha

Table 21. Continued

Treatment	Yield(t/ha)				% yield increase	
	2019	2020	2021	Average	over T_1 treatment	over T_6 treatment
T_1 = Control (no fertilizer)	6.98d	7.40e	8.02d	7.47	-	-
T_2 = PM @ 3 t/ ha+ IPNS based inorganic fertilizer	20.25ab	21.08bc	22.29bc	21.21	183.9	18.08
T_3 = PM biochar @ 2 t/ha+ IPNS based inorganic fertilizer	22.86a	24.17a	26.59a	24.54	228.5	36.64
T_4 = Rice husk biochar @ 2 t/ha + IPNS based inorganic fertilizer	21.78ab	23.49ab	25.36ab	23.54	215.2	31.09
T_5 = Dolomite @ 1 t/ha + 100% RF	19.26bc	20.14cd	21.15c	20.18	170.2	12.38
T_6 = 100% RF	16.53c	18.31d	19.05c	17.96	140.5	-
CV (%)	9.96	7.91	10.38	-	-	-

RF: N_{120} P_{24} K_{60} S_{20} kg ha^{-1}

Total cauliflower (system) yield

Total cauliflower (system) yield as influenced by different organic amendment has been presented in Table 15. Highest total cauliflower (system) yield of 108.12 t $ha^{-1}yr^{-1}$ was obtained from T_3 treatment (Poultry Manure biochar @ 2 t/ha + IPNS based inorganic fertilizer). Lowest total cauliflower (system) yield of 37.16 t $ha^{-1}yr^{-1}$ was obtained fromun-amended T_1 treatment.

Table 22. Average yield, cauliflower equivalent yield and total cauliflower (system) yield (t ha^{-1} yr^{-1}) of Cauliflower- Okra-Indian spinach

Treatment	Average yield of crops in the pattern			Cauliflower equivalent yield of crops in the pattern		Total cauliflower (system) yield
	Cauliflower	Okra	Indian spinach	Okra	Indian spinach	
T_1	11.47	6.69	7.47	16.73	8.96	37.16
T_2	30.91	15.95	21.21	39.88	25.45	96.24
T_3	34.20	17.79	24.54	44.48	29.45	108.12
T_4	32.63	17.02	23.54	42.55	28.25	103.43
T_5	29.70	15.15	20.18	37.88	24.22	91.79
T_6	25.89	13.49	17.96	33.73	21.55	81.17

Price : 1 kg cauliflower = Tk. 10, 1 kgokra = Tk. 25, 1 kgIndian Spinach = Tk. 12

Apparent Nutrient balance in cauliflower-okra-Indian spinach

Apparent nutrient balance in cauliflower-okra-Indian spinach are presented in Fig. 26 & 27. Nitrogen and potassium balance was found negative and phosphorus and sulphur balance was found positive. After computing actual nutrient balance, more nitrogen and potassium will be added in the cropping system.

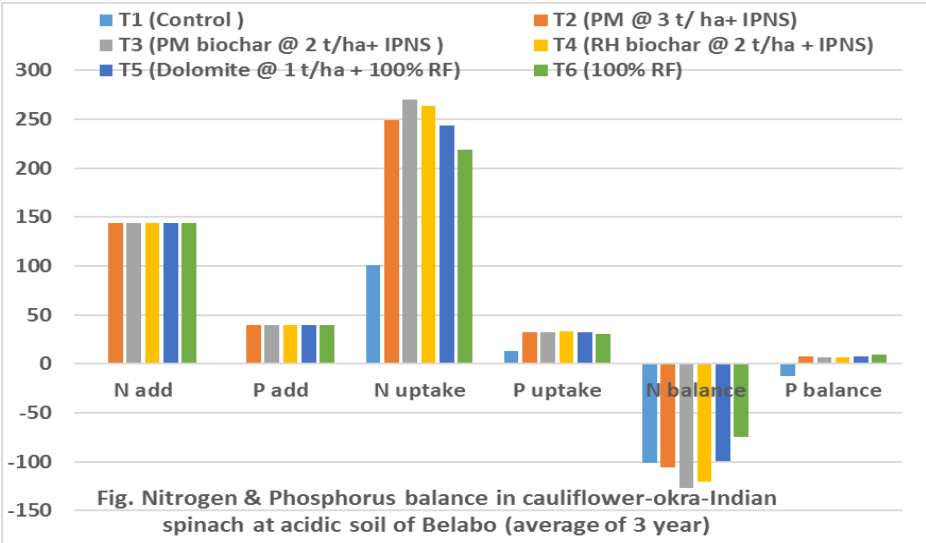


Fig. 26 Nitrogen & Phosphorus balance in Cauliflower-Okra-Indian spinach at acidic soil of Belabo (average of 3 year)

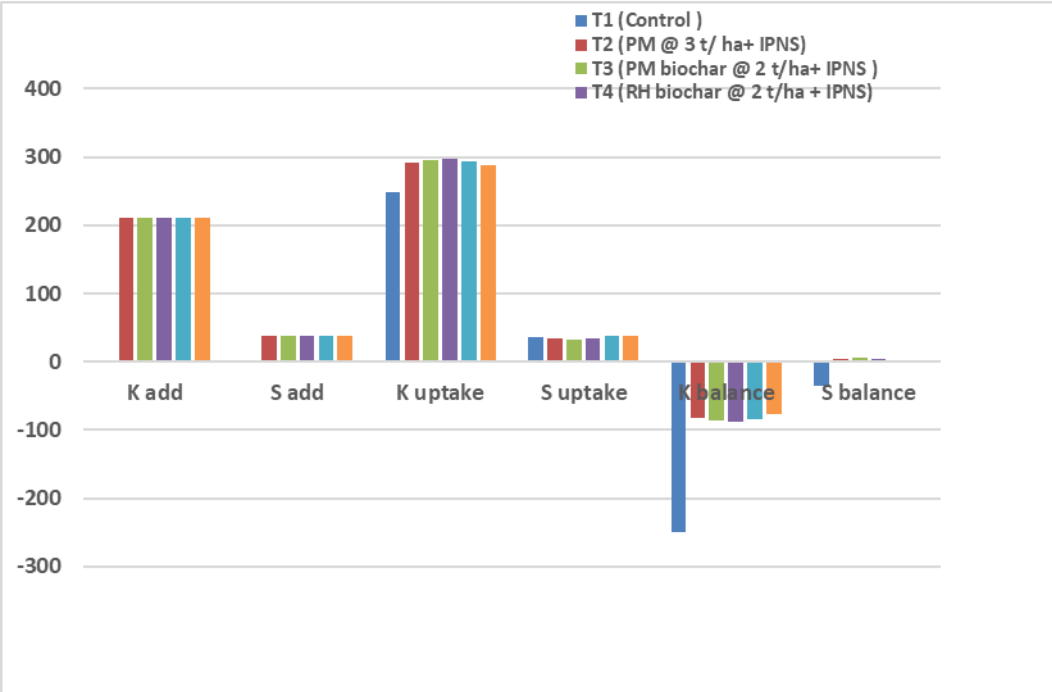


Fig. 27 Potassium & Sulphur balance in Cauliflower-Okra-Indian spinach at acidic soil of Belabo (average of 3 year)

D. Field experiments on drought prone soil (Godagari)

Initial soil nutrient status of Godagari experimental field is presented in Table 23.

Table 23. Initial soil status of the experimental soils of Godagari.

Location	pH	OM%	Ca	Mg	K	Total N %	P	S	B	Cu	Fe	Mn	Zn
			meq $100g^{-1}$				$\mu g\ g^{-1}$						
Alimgonj, Godagari	7.6	1.9	11.1	3.9	0.10	0.065	4	25	0.24	1.7	14	3.5	1.1
Critical Level	-	-	2.0	0.5	0.12	-	10	10	0.2	0.2	4	1	0.6

During the three experimental years, the annual rainfall from March 2018 to February 2021 was 934.70, 656.24, and 1080.60 mm, respectively (Fig. 28). Approximately 97-98% of the precipitation during the rainy season from April to October of the respective year, which indicated that the water requirement of dryland Boro and T.aman well synchronized with the rainy season.

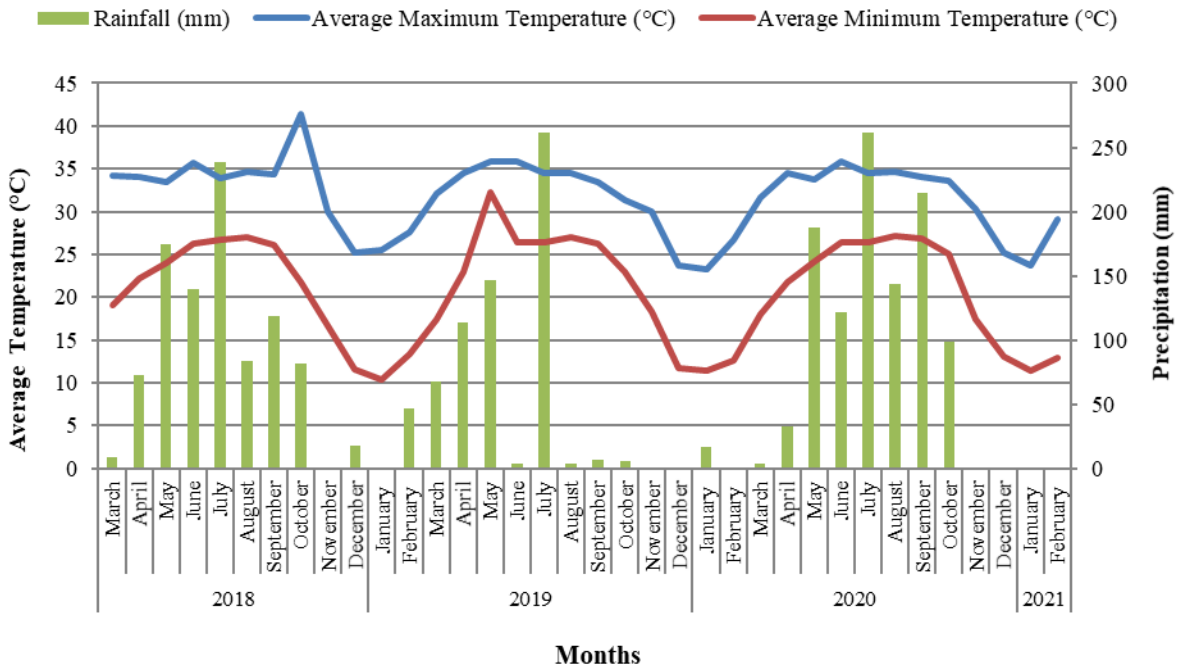
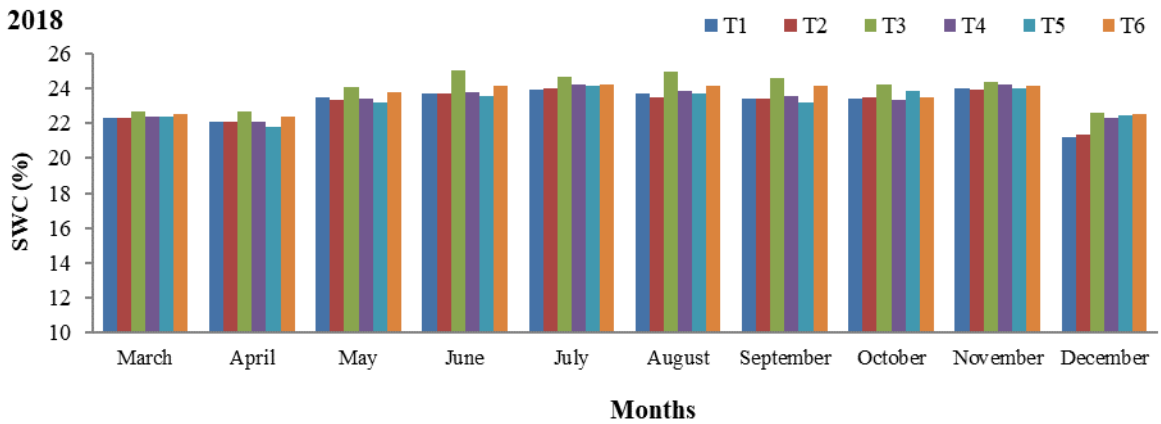


Fig 28. Monthly average temperature and precipitation over three experimental years.

Soil water content of top soil (SWC)

Soil water content of the 0–15 cm ranges from 21-25% (Fig. 29). However, sole chemical fertilizer application and control plots SWC was lower than that of chemical fertilizer combined with organic compound. Based on our measurements, the positive effect of organic compound on soil water content was confirmed. The average moisture content in the biochar amended plots was 23.50% which was 3.66% higher than that of control plot and other organic amended plots increased slightly (around 1%). But sole chemical fertilizer treated soil decreased SWC (0.38%). Our results from the field conditions show that the application of 2t/ha of biochar significantly affect the soil water content within the top soil layer.



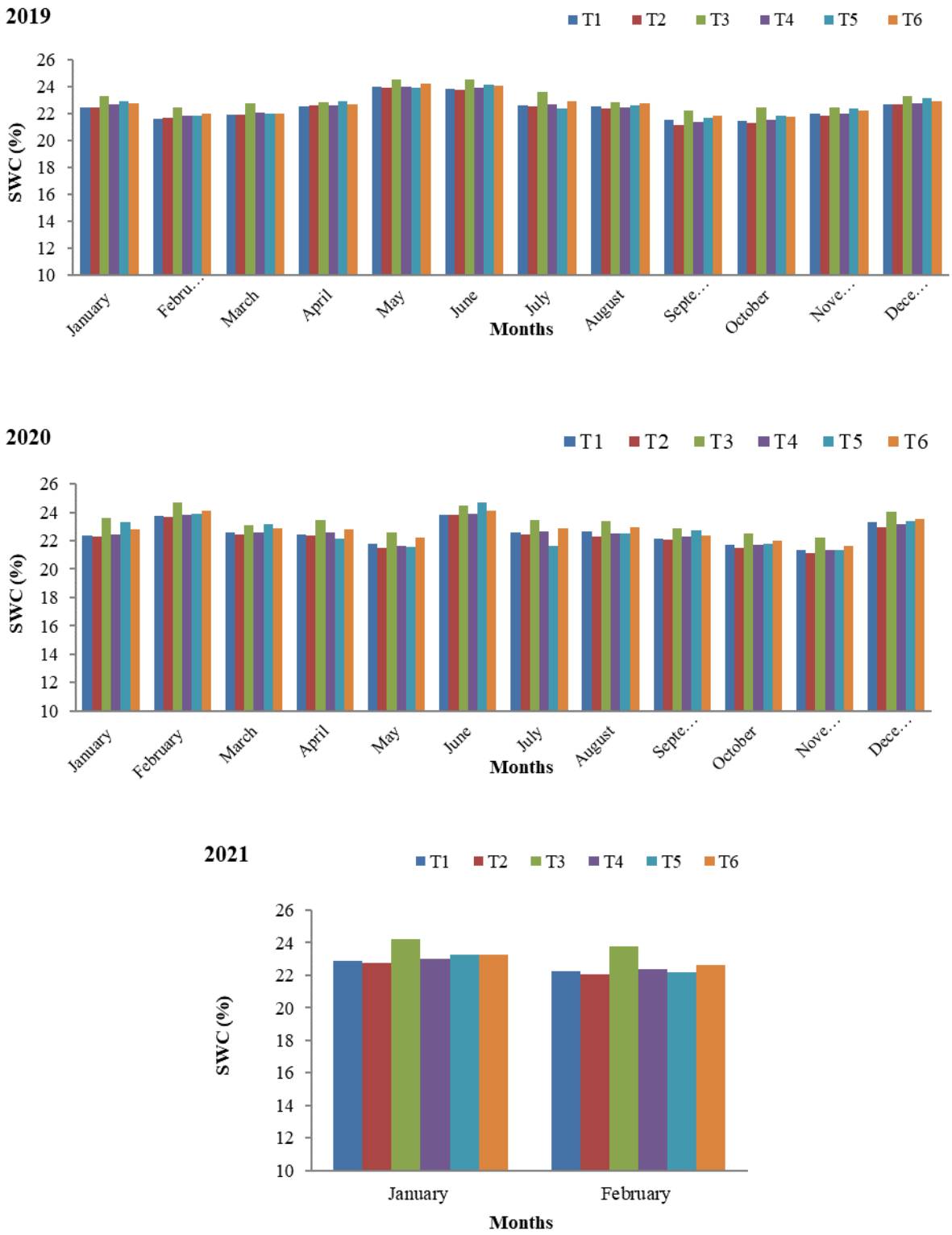


Fig. 29. Monthly average soil water content over three experimental years.

Mustard:

First, fourth and seventh crop mustard (variety: BARI Sharisha-14) was harvested from the experimental field during the year 2018-19, 2019-20 and 2020-21, respectively (Fig. 30a and 30b). Data on yield and yield components of mustard are analyzed and presented in Table 17. Different organic amendments significantly influenced the yield and yield contributing characters of mustard. Plant height, no. of pods/plant, no. of seeds/pod, 1000 seed weight was highest in T_3 treatment (Rice husk biochar @ 2 t/ha + 100% RF) and lowest in un-amended T_1 treatment. Moderate Plant height, no. of pods/plant, no. of seeds/pod, 1000 seed weight was obtained from 100% chemical fertilizer amended T_2 treatment. Similarly, the highest seed yield (1.45 t ha^{-1} in 2018-19, 1.52 t ha^{-1} in 2019-20 & 1.65 t ha^{-1} in 2020-21) was obtained from T_3 treatment (Rice husk biochar @ 2 t/ha + 100% RF) which was followed by T_5, T_4 and T_6 treatment.

Fig. 30a **Fig. 30b**

Fig. 30. Improvement of soil health in unfavourable eco-system (drought soil) with organic amendment for sustainable crop production (crop: mustard; Variety: BARI Sharisha-14)

Un-amended T_1 treatment yielded lowest seed yield (0.43 t ha^{-1} in 2018-19, 0.44 t ha^{-1} in 2019-20 &0.48 t ha^{-1}in 2020-21). Moderate seed yield (1.13 t ha^{-1} in 2018-19, 1.18 t ha^{-1} in 2019-20 &1.20 t ha^{-1} in 2020-21) was obtained from 100% chemical fertilizer amended T_2treatment. About 242.2%yield increase over un-amended T_1 treatment and 31.62% yield increase over 100% chemical fertilizer amended T_2treatment was recorded in T_3 treatment (Rice husk biochar @ 2 t/ha + 100% RF).

Table 24. Effects of different organic amendment on yield and yield contributing characters of mustard at Godagari during 2018-19, 2019-20 & 2020-21

Treatment	Plant height (cm)			No. of pods/plant		
	2018-19	2019-20	2020-21	2018-19	2019-20	2020-21
T_1 = Control (no fertilizer)	53.2b	54.9d	56.8d	61.2d	69.7d	74.3d
T_2 = 100% RF (Recommended Chemical Fertilizer)	68.3a	61.4cd	65.2c	74.4c	81.0c	85.2c
T_3 = Rice husk biochar @ 2 t/ha + 100% RF	79.2a	78.4a	82.4a	92.3a	103.6a	111.2a
T_4 = Poultry manure @ 3 t/ha + IPNS based inorganic fertilizer	75.4a	65.6bc	69.3bc	83.4abc	90.3b	98.4b
T_5 = Vermicompost @ 3 t/ha + IPNS based inorganic fertilizer	77.1a	71.6ab	75.2ab	86.2ab	93.3b	99.6b
T_6 = Organicfertilizer (Mazim) @ 3 t/ha + IPNS based inorganic fertilizer	76.5a	63.7c	68.2bc	81.6bc	89.0b	93.2bc

CV (%)	8.90	6.43	5.86	6.27	5.58	7.35

Table 24. Continued

Treatment	No. of seeds/pod			1000 seed weight (gm)		
	2018-19	2019-20	2020-21	2018-19	2019-20	2020-21
T_1 = Control (no fertilizer)	15.6d	19.5d	20.1d	2.96c	3.10b	3.20b
T_2 = 100% RF (Recommended Chemical Fertilizer)	22.3d	22.1cd	23.4cd	3.16bc	3.30ab	3.36ab
T_3 = Rice husk biochar @ 2 t/ha + 100% RF	30.7a	28.3a	30.1a	3.42a	3.60a	3.54a
T_4 = Poultry manure @ 3 t/ha + IPNS based inorganic fertilizer	26.4bc	25.6ab	27.1abc	3.20abc	3.34ab	3.46a
T_5 = Vermicompost @ 3 t/ha + IPNS based inorganic fertilizer	28.9ab	27.8ab	29.2ab	3.26ab	3.36ab	3.42ab
T_6 = Organicfertilizer (Mazim) @ 3 t/ha + IPNS based inorganic fertilizer	24.7c	24.8bc	25.9bc	3.18bc	3.32ab	1.38ab
CV (%)	9.21	6.98	8.32	6.33	5.81	6.62

Table 24. Continued

Treatment	Yield (t/ha)			% yield increase		
	2018-19	2019-20	2020-21	Average	over T_1 treatment	over T_2 treatment
T_1 = Control (no fertilizer)	0.43e	0.44e	0.48e	0.45	-	-
T_2 = 100% RF (Recommended Chemical Fertilizer)	1.13d	1.18d	1.20d	1.17	160.0	-
T_3 = Rice husk biochar @ 2 t/ha + 100% RF	1.45a	1.52a	1.65a	1.54	242.2	31.62
T_4 = Poultry manure @ 3 t/ha + IPNS based inorganic fertilizer	1.29bc	1.34bc	1.38bc	1.34	197.0	14.25
T_5 = Vermicompost @ 3 t/ha + IPNS based inorganic fertilizer	1.37ab	1.41ab	1.45b	1.41	213.3	20.51
T_6 = Organicfertilizer (Mazim) @ 3 t/ha + IPNS based inorganic fertilizer	1.22cd	1.25cd	1.32c	1.26	180.7	7.98
CV (%)	7.10	5.44	7.06	-	-	-

Boro

Second, fifth and eighth crop Boro (BRRI dhan 28) was harvested from the experimental field during the year 2019, 2020 and 2021, respectively (Fig. 31a and 31b). Data on yield and yield components of boro are analyzed and presented in Table 25. Different organic amendments significantly influenced the yield and yield contributing characters of Boro. Plant height, panicle length, no. of filled grain/panicle, 1000 grain weight and straw yield was highest in T_3 treatment (Rice husk biochar @ 2 t/ha + 100% RF) and lowest in un-amended T_1 treatment. Moderate plant height, panicle length, no. of filled grain/panicle, 1000 grain weight and straw yield was obtained from 100% chemical fertilizer amended T_2treatment. Similarly, the highest grain yield (6.91 t ha^{-1} in 2019, 7.08t ha^{-1} in 2020 &7.35 t ha^{-1} in 2021) was obtained from T_3 treatment (Rice husk biochar @ 2 t/ha + 100% RF) which was followed by T_5, $T_4$and T_6treatment. Un-amended T_1 treatment yielded lowest grain yield (3.03 t ha^{-1} in 2019, 3.12 t ha^{-1} in 2020 &3.24 t ha^{-1}in 2021). Moderate grain yield (4.92 t ha^{-1} in 2019, 5.14 t ha^{-1} in 2020 &5.33 t ha^{-1}in 2021) was obtained from 100% chemical fertilizer amended T_2treatment. About 127.3% yield increase over un-amended T_1 treatment and 38.66% yield increase over 100% chemical

fertilizer amended T_2treatment was recorded in T_3 treatment (Rice husk biochar @ 2 t/ha + 100% RF).

Fig. 31a **Fig. 31b**

Fig. 31. Improvement of soil health in unfavourable eco-system (drought soil) with organic amendment for sustainable crop production (crop: T. Aman; variety: BRRI dhan88)

Table 25. Effects of different organic amendment on yield and yield contributing characters of boro at Godagari during 2019, 2020 & 2021

Treatments	Plant height (cm)			Panicle length (cm)			Filled grain/Panicle		
	2019	2020	2021	2019	2020	2021	2019	2020	2021
T_1 = Control (no fertilizer)	76.5c	68.9b	82.2c	20.4a	20.7a	21.2b	85.1c	90.20d	94.10c
T_2 = 100% RF (Recommended Chemical Fertilizer)	83.3bc	85.1ab	89.5bc	21.5a	21.8a	21.8ab	93.4bc	96.23cd	98.87bc
T_3 = Rice husk biochar @ 2 t/ha + 100% RF	96.9a	92.9a	101.3a	22.8a	23.2a	23.8a	107.4a	113.2a	116.5a
T_4 = Poultry manur @ 3 t/ha + IPNS based inorganic fertilizer	90.2ab	88.3ab	94.5ab	22.1a	22.3a	22.5ab	100.8ab	101.4bc	104.5abc
T_5 = Vermicompost @ 3 t/ha + IPNS based inorganic fertilizer	93.2ab	89.3a	97.6ab	22.5a	22.9a	22.5ab	103.2ab	107.2ab	110.2ab
T_6 = Organic fertilizer (Mazim) @ 3 t/ha + IPNS based inorganic fertilizer	86.4ab	88.6ab	92.1abc	21.9a	22.2a	22.4ab	96.1abc	98.90bcd	99.27bc
CV (%)	6.53	9.02	6.35	7.21	7.39	6.41	6.80	5.90	7.73

Table 25. Continued

Treatments	1000 grain weight (gm)			Straw yield (t ha^{-1})		
	2019	2020	2021	2019	2020	2021
T_1 = Control (no fertilizer)	20.59a	21.10c	20.19a	4.03c	4.26d	4.48c
T_2 = 100% RF (Recommended Chemical Fertilizer)	21.09a	21.75bc	21.31a	5.96b	6.38c	8.10b
T_3 = Rice husk biochar @ 2 t/ha + 100% RF	22.27a	22.50a	22.73a	8.48a	8.74a	9.18a
T_4 = Poultry manur @ 3 t/ha + IPNS based inorganic fertilizer	21.62a	21.95ab	21.74a	7.62a	7.73ab	8.59ab
T_5 = Vermicompost @ 3 t/ha + IPNS based inorganic fertilizer	22.11a	22.42ab	22.05a	8.07a	8.27a	9.01ab
T_6 = Organic fertilizer (Mazim) @ 3 t/ha + IPNS based inorganic fertilizer	21.34a	21.90ab	21.45a	6.53b	6.92bc	8.46b
CV (%)	7.26	5.74	6.68	7.94	8.56	7.01

Table 25. Continued

Treatments	Grain yield (t ha^{-1})				% yield increase	
	2019	2020	2021	Average	over T_1 treatment	over T_2 treatment
T_1 = Control (no fertilizer)	3.03d	3.12d	3.24d	3.13	-	-
T_2 = 100% RF (Recommended Chemical Fertilizer)	4.92c	5.14c	5.33c	5.13	63.9	-
T_3 = Rice husk biochar @ 2 t/ha + 100% RF	6.91a	7.08a	7.35a	7.11	127.3	38.66
T_4 = Poultry manur @ 3 t/ha + IPNS based inorganic fertilizer	6.24ab	6.42ab	6.46b	6.37	103.6	24.24
T_5 = Vermicompost @ 3 t/ha + IPNS based inorganic fertilizer	6.56a	6.86a	7.01a	6.81	117.6	32.75
T_6 = Organic fertilizer (Mazim) @ 3 t/ha + IPNS based inorganic fertilizer	5.69bc	5.86bc	6.05b	5.87	87.4	14.36
CV (%)	8.28	6.89	6.22	-	-	-

T.Aman

Third, sixth and ninth crop T.Aman (BRRI dhan88) was harvested from the experimental field during the year 2019, 2020 and 2021, respectively (Fig. 32). Data on yield and yield components of T.Aman are analyzed and presented in Table 19. Different organic amendments significantly influenced the yield and yield contributing characters of T.Aman. Plant height, panicle lengt, no. of filled grain/panicle, 1000 grain weightand straw yield was highest in T_3 treatment (Rice husk biochar @ 2 t/ha + 100% RF) and lowest in un-amended T_1 treatment. Moderate plant height, panicle length, no. of filled grain/panicle, 1000 grain weightand straw yield was obtained from 100% chemical fertilizer amended T_2treatment. Similarly, the highest grain yield (4.06 t ha^{-1} in 2019 &4.32 t ha^{-1} in 2020) was obtained from T_3 treatment (Rice husk biochar @ 2 t/ha + 100% RF) which was followed by T_5, $T_4$and T_6treatment. Un-amended T_1 treatment yielded lowest grain yield (3.33 t ha^{-1} in 2019 &3.54 t ha^{-1}in 2020). Moderate grain yield (3.76 t ha^{-1} in 2019 &3.82 t ha^{-1}in 2020) was obtained from 100% chemical fertilizer amended T_2treatment. About 21.80% yield increase over un-amended T_1 treatment and 10.55% yield increase over 100% chemical fertilizer amended T_2 treatment was recorded in T_3 treatment (Rice husk biochar @ 2 t/ha + 100% RF).

Table 26. Effects of different organic amendment on yield and yield contributing characters of T.Aman at Godagari during 2019, 2020 & 2021

Treatments	Plant height (cm)		Panicle length (cm)		Filled grain/Panicle	
	2019	2020	2019	2020	2019	2020
T_1 = Control (no fertilizer)	85.6b	90.1a	20.2b	18.4b	79.9b	82.1c
T_2 = 100% RF (Recommended Chemical Fertilizer)	99.8a	102.2a	21.8ab	23.5a	83.9ab	90.4bc
T_3 = Rice husk biochar @ 2 t/ha + 100% RF	109.2a	107.1a	23.9a	24.4a	94.7a	103.7a
T_4 = Poultry manur @ 3 t/ha + IPNS based inorganic fertilizer	104.5a	106.0a	22.8ab	24.0a	88.4ab	94.9ab
T_5 = Vermicompost @ 3 t/ha + IPNS based inorganic fertilizer	106.1a	106.9a	23.1ab	24.2a	93.2a	97.2ab
T_6 = Organic fertilizer (Mazim) @ 3 t/ha + IPNS based inorganic fertilizer	103.2a	104.8a	22.4ab	23.9a	86.8ab	92.6b
CV (%)	7.16	7.81	7.40	6.76	8.23	5.43

Table 26. Continued

Treatments	1000 grain weight (gm)		Straw yield (t ha^{-1})	
	2019	2020	2019	2020
T_1 = Control (no fertilizer)	20.74a	20.92a	4.62b	4.90c
T_2 = 100% RF (Recommended Chemical Fertilizer)	20.98a	21.03a	5.02ab	5.19bc
T_3 = Rice husk biochar @ 2 t/ha + 100% RF	21.69a	22.27a	5.45a	5.79a
T_4 = Poultry manur @ 3 t/ha + IPNS based inorganic fertilizer	21.22a	21.66a	5.15ab	5.37abc
T_5 = Vermicompost @ 3 t/ha + IPNS based inorganic fertilizer	21.54a	21.94a	5.21ab	5.48ab
T_6 = Organic fertilizer (Mazim) @ 3 t/ha + IPNS based inorganic fertilizer	21.12a	21.18a	5.06ab	5.28abc
CV (%)	8.11	6.29	7.83	6.76

Table 26. Continued

Treatments	Grain yield (t ha^{-1})			% yield increase	
	2019	2020	Average	over T_1 treatment	over T_2 treatment
T1 = Control (no fertilizer)	3.33b	3.54b	3.44	-	-
T_2 = 100% RF (Recommended Chemical Fertilizer)	3.76ab	3.82ab	3.79	10.17	-
T_3 = Rice husk biochar @ 2 t/ha + 100% RF	4.06a	4.32a	4.19	21.80	10.55
T_4 = Poultry manur @ 3 t/ha + IPNS based inorganic fertilizer	3.86ab	3.97ab	3.92	13.81	3.30
T_5 = Vermicompost @ 3 t/ha + IPNS based inorganic fertilizer	3.94ab	4.07ab	4.01	16.42	5.67
T_6 = Organic fertilizer (Mazim) @ 3 t/ha + IPNS based inorganic fertilizer	3.83ab	3.85ab	3.84	11.63	1.32
CV (%)	9.69	8.19	-	-	-

Fig. 32. Improvement of soil health in unfavourable eco-system (drought soil) with organic amendment for sustainable crop production (crop: T. Aman)

Total rice (system) yield

Total rice (system) yield as influenced by different organic amendment has been presented in Table 20. Highest total rice (system) yield of 14.38 t $ha^{-1}yr^{-1}$ was obtained from T_3 treatment (Rice husk biochar @ 2 t/ha + 100% RF). Lowest total rice (system) yield of 7.47 t $ha^{-1}yr^{-1}$ was obtained from un-amended T_1 treatment.

Table 27. Average yield, rice equivalent yield and total rice (system) yield (t $ha^{-1}yr^{-1}$) of Mustard-Boro-T.Aman

Treatment	Average yield of crops in the pattern			Rice equivalent yield of crops in the pattern	Total rice (system) yield
	Mustard	Boro	T.Aman	Mustard	
T_1	0.45	3.13	3.44	0.90	7.47
T_2	1.17	5.13	3.79	2.34	11.26
T_3	1.54	7.11	4.19	3.08	14.38
T_4	1.34	6.37	3.92	2.68	12.97
T_5	1.41	6.81	4.01	2.82	13.64
T_6	1.26	5.87	3.84	2.52	12.23

Price : 1 kg mustard= Tk. 50, 1 kg Boro = Tk. 25, 1 kg T.Aman = Tk. 25

Apparent Nutrient balance in mustard-boro-T.Aman

Apparent nutrient balance in mustard-boro-T.Aman are presented in Fig. 33 & 34. Nitrogen, potassium and S balance was found negative while phosphorus balance was found positive. After computing actual nutrient balance, more nitrogen, potassium and sulphur will be added in the cropping system.

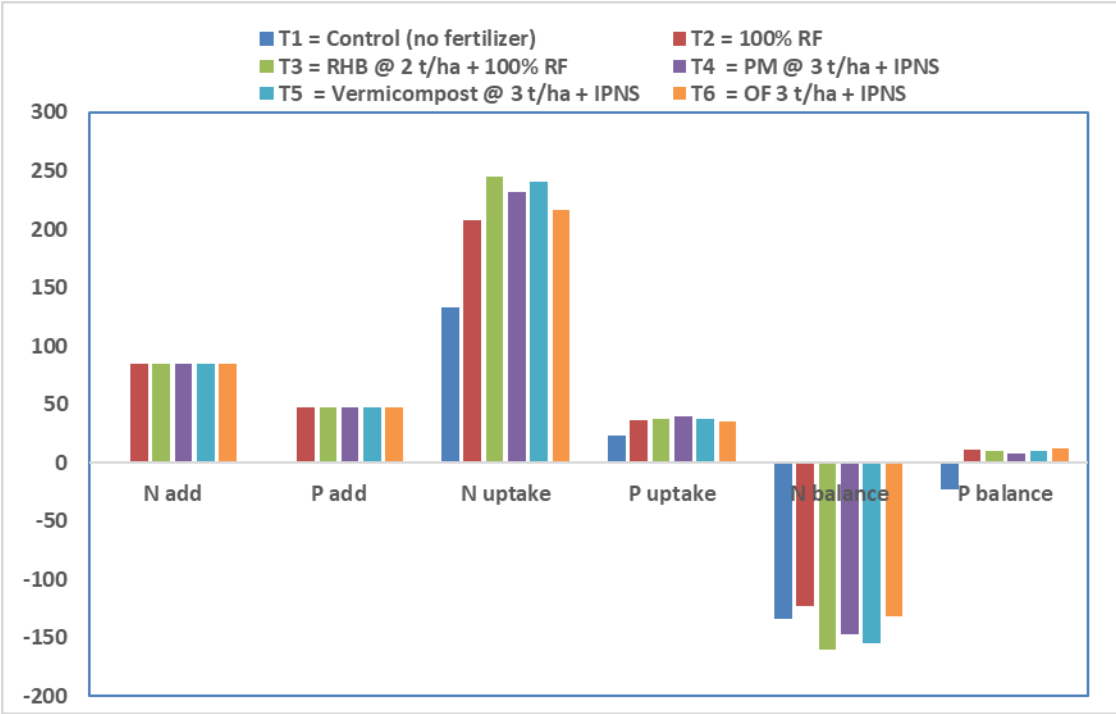


Fig. 33. Nitrogen & Phosphorus balance in mustard-boro-T.Aman at drought prone soil of Godagari (average of 3 year)

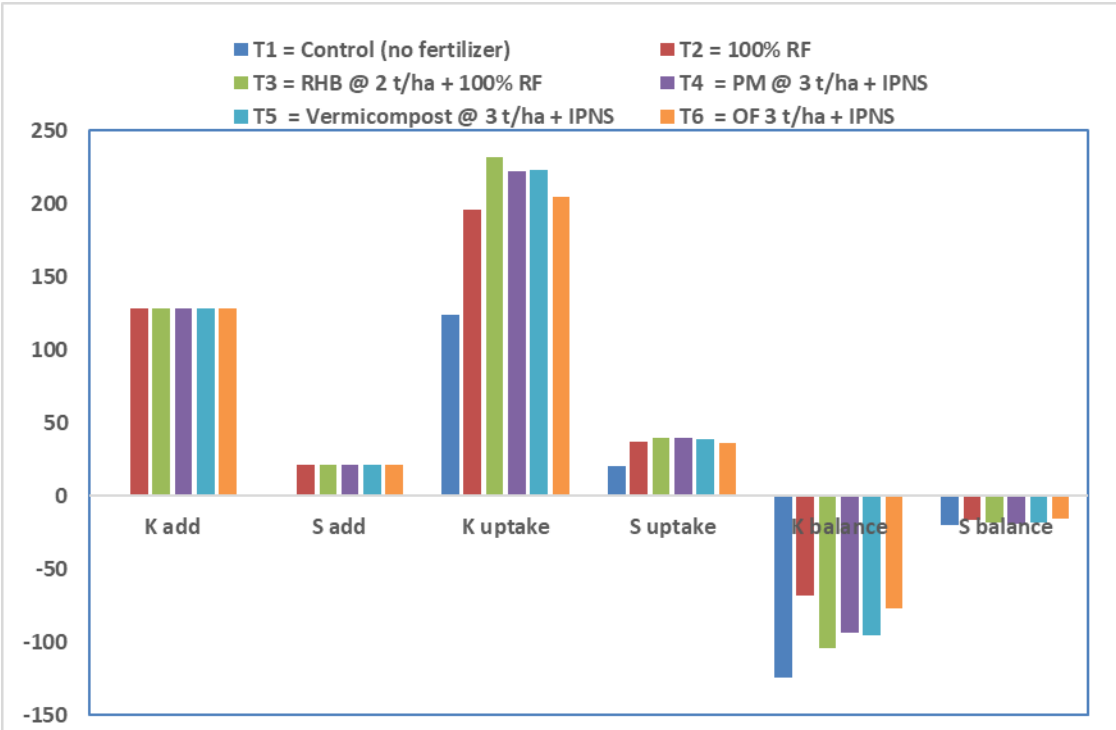


Fig. 34. Potassium & Sulphur balance in mustard-boro-T.Aman at drought prone soil of Godagari (average of 3 year)

E. Field experiments on saline soil (Dumuria)

During the three experimental years, the average rainfall from March 2018 to February 2021 was 203.08 mm (Fig. 35). Approximately 95% of the precipitation during the rainy season from April to October of the respective year, which indicated that the water requirement of saline land T.aman well synchronized with the rainy season.

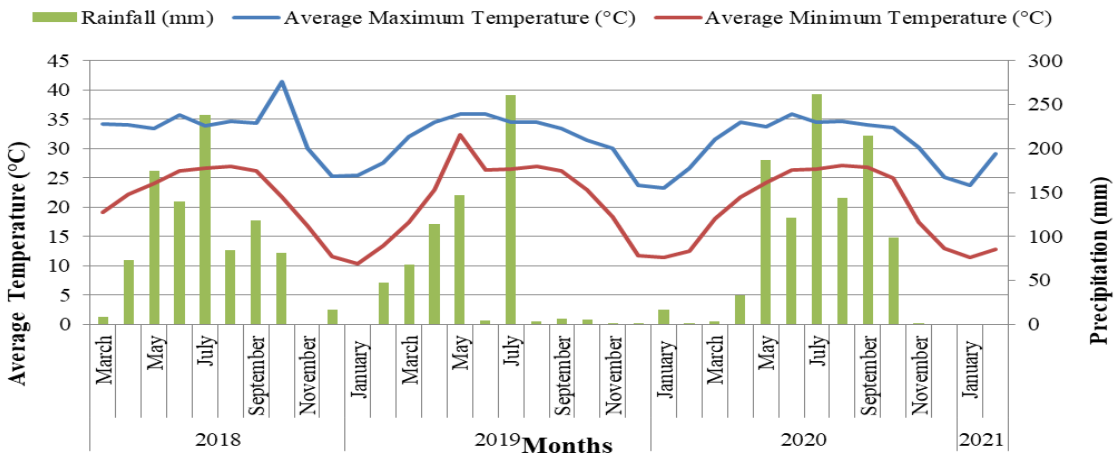


Fig. 35. Monthly average temperature and precipitation over three experimental years

Soil salinity of experimental soil of Dumuria during rabi season of 20218-19, 2019-20, 2020-21 was described in Fig. 36, 37 and 38, respectively. Irrespective of treatment, salinity increase upto the end of March and declined thereafter. Among the all treatments, lowest salinity was recorded in T_3 treatment (RH biochar 2 t/ha + 100% RF) and highest was obtained from T_1 (control) and T_2 treatment (100% RF). RH biochar acts as a much and there by reduces soil moisture evaporation. As a result, salt in ground water cannot come out through capillary rise.

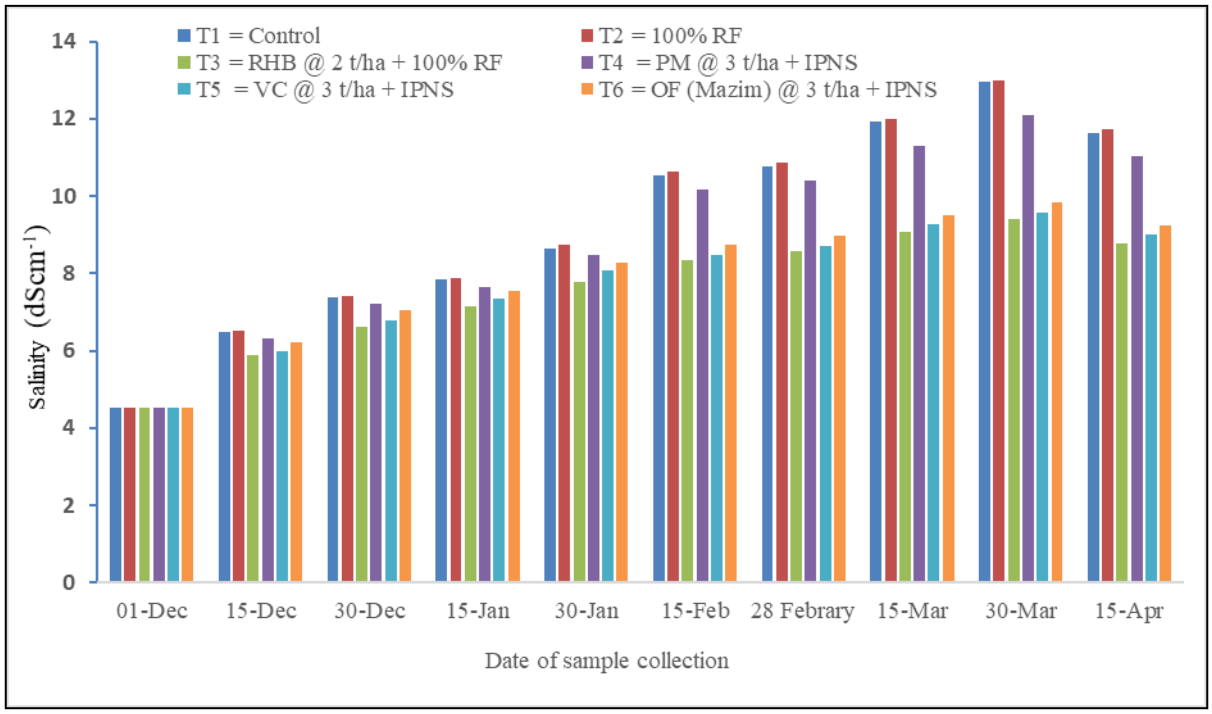


Fig. 36. Salinity levels (dS m^{-1}) of soil in sweet gourd field during 2018-2019

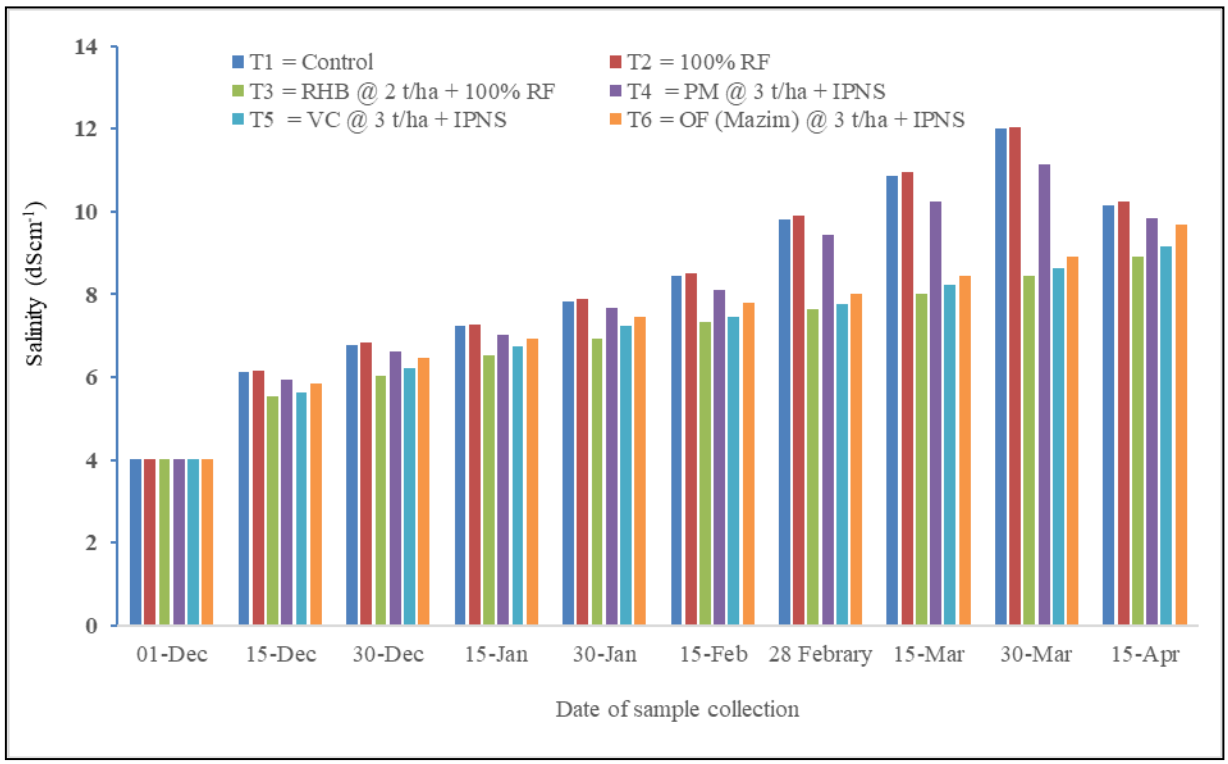


Fig. 37. Salinity levels (dS m^{-1}) of soil in sweet gourd field during 2020-2021

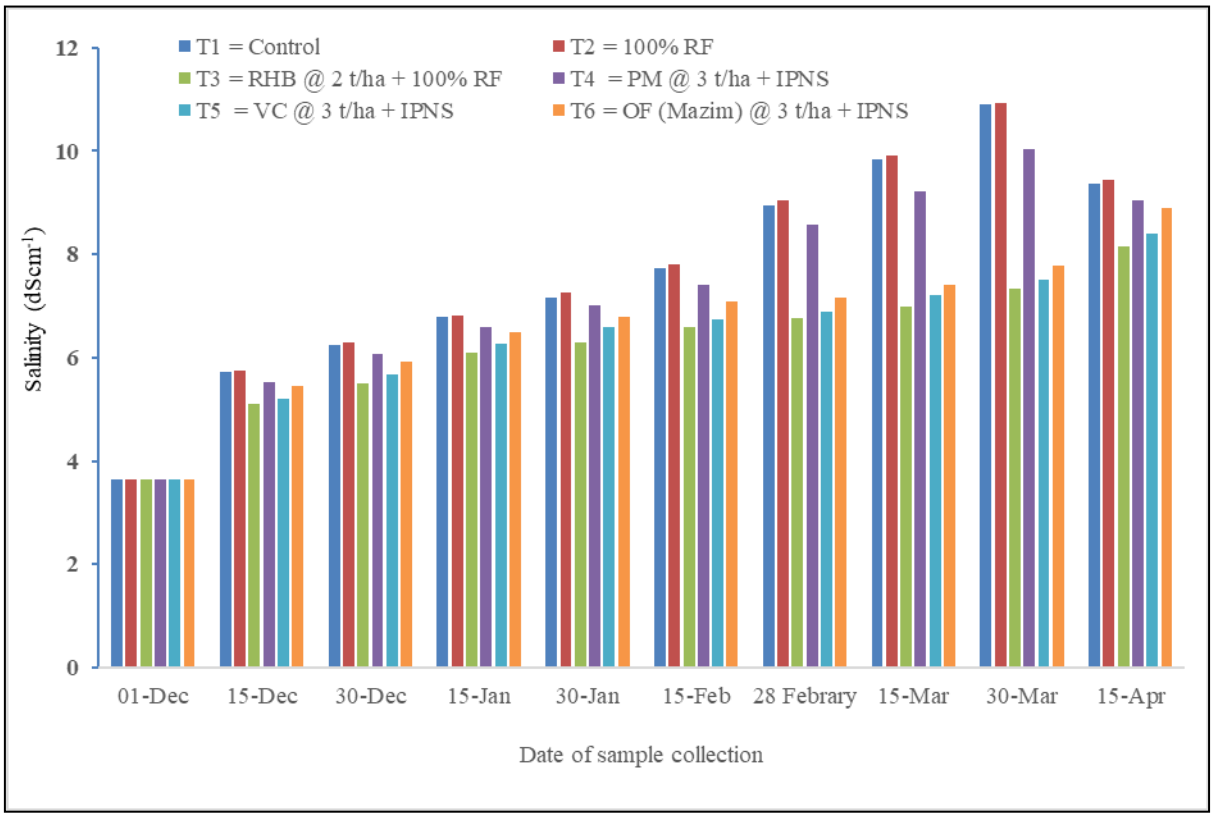


Fig. 38. Salinity levels (dS m^{-1}) of soil in sweet gourd field during 2021-2022

Three field experiments were conducted on saline soil at Dumuria, Khulna. Initial soil nutrient status of Dumuria experimental field is presented in Table 21.

Table 28. Analytical data of the experimental soils of Dumuria (Initial soil)

Location	pH	OM%	Ca	Mg	K	Total N %	P	S	B	Cu	Fe	Mn	Zn
			meq 100g^{-1}				µg g^{-1}						
Shahosh, Dumuria	7.1	1.55	12.3	4.1	0.14	0.25	22	18	0.21	3.1	11	5.4	0.8
Critical Level	-	-	2.0	0.5	0.12	-	10	10	0.20	0.2	4	1	0.6

Sweet gourd:

First, third and fifth crop sweet gourd (variety: Maxima) was harvested from the experimental field during the year 2019, 2020 and 2021, respectively (Fig. 39). Data on yield and yield components of sweet gourd are analyzed and presented in Table 28. Different organic amendments significantly influenced the yield and yield contributing characters of sweet gourd. No. of fruits/plant, fruit diameter, flash thickness and individual fruit weight was highest in T_3 treatment (Rice husk biochar @ 2 t/ha + 100% RF) and lowest in un-amended T_1 treatment and chemically amended T_2 treatment. Moderate no. of fruits/plant, fruit diameter, flash thickness and individual fruit weight was obtained from poultry manure @ 3 t/ha + IPNS based inorganic fertilizer amended T_4treatment. Similarly, the highest fruit yield (10.84t/ha in 2019, 12.41t/ha in 2020 &15.78t/ha in 2021) was obtained from T_3 treatment (Rice husk biochar @ 2 t/ha + 100% RF) which was followed by $T_5$and T_6 treatment. Due to severe soil salinity sweet gourd plant grown in T_1 and T_2 treatment died and no yield was recorded. Moderate fruit yield (4.06t/ha in 2019, 5.46t/ha in 2020 &9.92t/ha in 2021) was obtained from poultry manure @ 3 t/ha + IPNS based inorganic fertilizer amended T_4treatment. About 100.8%yield increase over poultry manure @ 3 t/ha + IPNS based inorganic fertilizer amended T_4treatment was recorded in T_3 treatment (Rice husk biochar @ 2 t/ha + 100% RF).

Fig. 39. Field experiment on saline soil of Dumuria on Sweet gourd applying different organic amendments.

Table 29. Effects of different organic amendment on yield and yield contributing characters of sweet gourd at Dumuria during 2019, 2020 & 2021

Treatment	No. of fruits/plant			Fruit diameter (cm)		
	2019	2020	2021	2019	2020	2021
T_1 = Control (no fertilizer)	-	-	-	-	-	-
T_2 = 100% RF (Recommended Chemical Fertilizer)	-	-	-	-	-	-
T_3 = Rice husk biochar @ 2 t/ha + 100% RF	2.03a	2.27a	2.61a	18.2a	20.4a	23.8a
T_4 = Poultry manure @ 3 t/ha + IPNS based inorganic fertilizer	1.13b	1.45b	1.78c	15.2a	16.8a	19.9c
T_5 = Vermicompost @ 3 t/ha + IPNS based inorganic fertilizer	1.67a	2.19a	2.41a	17.7a	18.9a	22.4ab
T_6 = Organic fertilizer (Mazim) @ 3 t/ha + IPNS based inorganic fertilizer	1.27b	1.82b	2.10b	16.9a	18.9a	21.3bc
CV (%)	21.62	9.15	8.97	18.63	10.85	6.99

Table 29. Continued

Treatment	Flash thickness (cm)			Individual fruit weight (kg)		
	2019	2020	2021	2019	2020	2021
T_1 = Control (no fertilizer)	-	-	-	-	-	-
T_2 = 100% RF (Recommended Chemical Fertilizer)	-	-	-	-	-	-
T_3 = Rice husk biochar @ 2 t/ha + 100% RF	3.83a	3.88a	4.21a	2.63a	2.74a	3.22a
T_4 = Poultry manure @ 3 t/ha + IPNS based inorganic fertilizer	2.87c	2.92c	3.67c	1.77c	1.84c	2.63c
T_5 = Vermicompost @ 3 t/ha + IPNS based inorganic fertilizer	3.57ab	3.65ab	4.09ab	2.37ab	2.45ab	2.98b
T_6 = Organic fertilizer (Mazim) @ 3 t/ha + IPNS based inorganic fertilizer	3.17bc	3.26bc	3.82bc	2.07bc	2.11bc	2.86b
CV (%)	11.29	8.26	6.58	15.62	8.99	6.16

Table 29. Continued

Treatment	Fruit yield (t/ha)				% yield increase over T_4 treatment
	2019	2020	2021	Average	
T_1 = Control (no fertilizer)	-	-	-	-	-
T_2 = 100% RF (Recommended Chemical Fertilizer)	-	-	-	-	-
T_3 = Rice husk biochar @ 2 t/ha + 100% RF	10.84a	12.41a	15.78a	13.01	100.8
T_4 = Poultry manure @ 3 t/ha + IPNS based inorganic fertilizer	4.06c	5.46c	9.92d	6.48	-
T_5 = Vermicompost @ 3 t/ha + IPNS based inorganic fertilizer	8.81ab	10.32b	13.94b	11.02	70.11
T_6 = Organic fertilizer (Mazim) @ 3 t/ha + IPNS based inorganic fertilizer	7.99b	9.57b	13.01c	10.09	57.25
CV (%)	22.36	6.21	6.81	-	-

T. Aman:

Second and fourth crop T.Aman (BRRI dhan78) was harvested from the experimental field during the year 2019, 2020 and 2021, respectively (Fig. 40a and 40b). Data on yield and yield components of T.Aman are analyzed and presented in Table 30. Different organic amendments significantly influenced the yield and yield contributing characters of T.Aman. Plant height, panicle length, no. of filled grain/panicle, 1000 grain weightand straw yield was highest in T_3 treatment (Rice husk biochar @ 2 t/ha + 100% RF) and lowest in un-amended T_1 treatment. Moderate plant height, panicle length, no. of filled grain/panicle, 1000 grain weightand straw yield was obtained from 100% chemical fertilizer amended T_2treatment. Similarly, the highest grain yield (3.60 t ha^{-1} in 2019 &3.96 t ha^{-1} in 2020) was obtained from T_3 treatment (Rice husk biochar @ 2 t/ha + 100% RF) which was followed by T_5, $T_4$and T_6treatment. Un-amended T_1 treatment yielded lowest grain yield (2.74 t ha^{-1} in 2019 & 2.92 t ha^{-1}in 2020). Moderate grain yield (3.18 t ha^{-1} in 2019 &3.43 t ha^{-1}in 2020) was obtained from 100% chemical fertilizer amended T_2 treatment. About 33.57% yield increase over un-amended T_1 treatment and 14.20% yield increase over 100% chemical fertilizer amended T_2 treatment was recorded in T_3 treatment (Rice husk biochar @ 2 t/ha + 100% RF).

Table 30. Effects of different organic amendment on yield and yield contributing characters of T. Aman at Godagari during 2019, 2020 & 2021

Treatments	Plant height (cm)		Panicle length (cm)		Filled grain/Panicle	
	2019	2020	2019	2020	2019	2020
T_1 = Control (no fertilizer)	91.2b	94.2b	16.2a	17.1b	57.1d	64.1c
T_2 = 100% RF (Recommended Chemical Fertilizer)	98.9ab	99.6ab	17.3a	18.2ab	65.8c	72.8bc
T_3 = Rice husk biochar @ 2 t/ha + 100% RF	103.2a	108.2a	19.5a	20.7a	80.2a	87.3a
T_4 = Poultry manur @ 3 t/ha + IPNS based inorganic fertilizer	100.8ab	104.3ab	19.1a	19.5ab	73.2abc	79.3ab
T_5 = Vermicompost @ 3 t/ha + IPNS based inorganic fertilizer	102.3a	106.9a	19.1a	19.8ab	75.8ab	83.1ab
T_6 = Organic fertilizer (Mazim) @ 3 t/ha + IPNS based inorganic fertilizer	99.4ab	102.4ab	18.5a	19.0ab	71.0bc	76.4ab
CV (%)	8.48	6.28	9.94	9.52	6.47	8.65

Table 30. Continued

Treatments	1000 grain weight (gm)		Straw yield (t ha^{-1})	
	2019	2020	2019	2020
T1 = Control (no fertilizer)	20.56b	20.74b	3.55e	3.81e
T_2 = 100% RF (Recommended Chemical Fertilizer)	21.19ab	21.35ab	4.17d	4.46d
T_3 = Rice husk biochar @ 2 t/ha + 100% RF	21.88a	22.13a	5.04a	5.49a
T_4 = Poultry manur @ 3 t/ha + IPNS based inorganic fertilizer	21.72a	21.79a	4.51c	4.98bc
T_5 = Vermicompost @ 3 t/ha + IPNS based inorganic fertilizer	21.36ab	21.96a	4.78b	5.22ab
T_6 = Organicfertilizer (Mazim) @ 3 t/ha + IPNS based inorganic fertilizer	21.31ab	21.62ab	4.42c	4.69cd
CV (%)	5.41	5.62	6.83	7.32

Table 30. Continued

Treatments	Grain yield (t ha^{-1})			% yield increase	
	2019	2020	Average	over T_1 treatment	over T_2 treatment
T1 = Control (no fertilizer)	2.74c	2.92c	2.83	-	-
T_2 = 100% RF (Recommended Chemical Fertilizer)	3.18b	3.43b	3.31	16.78	-
T_3 = Rice husk biochar @ 2 t/ha + 100% RF	3.60a	3.96a	3.78	33.57	14.20
T_4 = Poultry manur @ 3 t/ha + IPNS based inorganic fertilizer	3.32ab	3.65ab	3.49	23.14	5.29
T_5 = Vermicompost @ 3 t/ha + IPNS based inorganic fertilizer	3.44ab	3.76ab	3.60	27.21	8.76
T_6 = Organic fertilizer (Mazim) @ 3 t/ha + IPNS based inorganic fertilizer	3.27ab	3.53b	3.40	20.14	2.72
CV (%)	7.10	6.38	-	-	-

Fig.40a

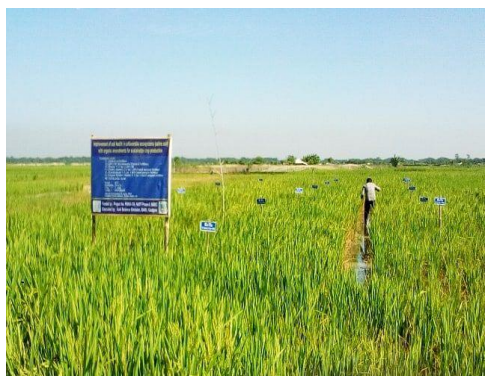


Fig. 40b

Fig. 40. Improvement of soil health in unfavourable eco-system (saline soil) with organic amendment for sustainable crop production (crop: T. Aman; BRRI dhan-78)

Total rice (system) yield

Total rice (system) yield as influenced by different organic amendment has been presented in Table 24. Highest total rice (system) yield of 14.19 t $ha^{-1}yr^{-1}$ was obtained from T_3 treatment (Rice husk biochar @ 2 t/ha + 100% RF). Lowest total rice (system) yield of 2.83 t $ha^{-1}yr^{-1}$ was obtained fromun-amended T_1 treatment.

Table 31. Average yield, rice equivalent yield and total rice (system) yield (t $ha^{-1}yr^{-1}$) of Mustard- Boro-T.Aman

Treatment	Average yield of crops in the pattern		Rice equivalent yield of crops in the pattern	Total rice (system) yield
	Sweet gourd	T.Aman	Sweet gourd	
T_1	0	2.83	0	2.83
T_2	0	3.31	0	3.31
T_3	13.01	3.78	10.41	14.19
T_4	6.48	3.49	5.18	8.67
T_5	11.02	3.60	8.82	12.42
T_6	10.09	3.40	8.07	11.47

Price : 1 kg sweet gourd = Tk. 20, 1 kg T.Aman = Tk. 25

Apparent nutrient balance in sweet gourd-fallow-T. Aman

Apparent nutrient balance in sweet gourd-fallow-T.Aman are presented in Fig. 41 & 42. Nitrogen, balance was found negative while phosphorus, potassium and sulphur balance was found positive. Due to two crop grown in a year, nutrient balance is much better than acidic soil of belabo and drought prone soil of Godagari where three crop grown in a year. After computing actual nutrient balance, more nitrogen will be added in the cropping system

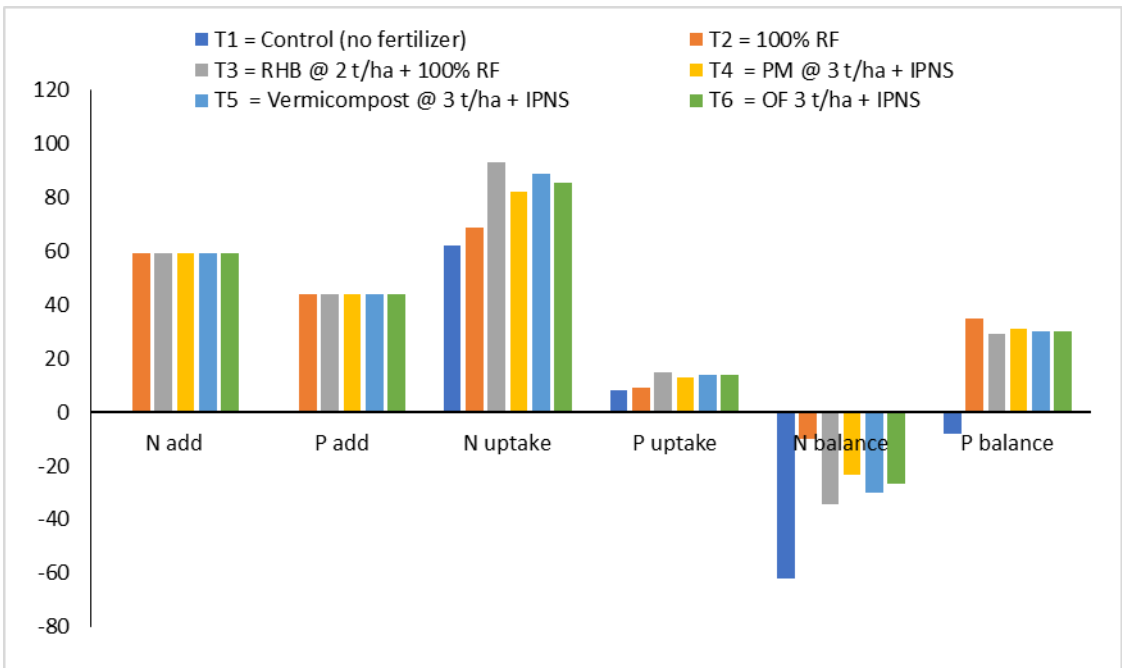


Fig. 41. Nitrogen & Phosphorus balance in Sweet gourd-Fallow-T.Aman at saline soil of Dumuria (average of 3 year)

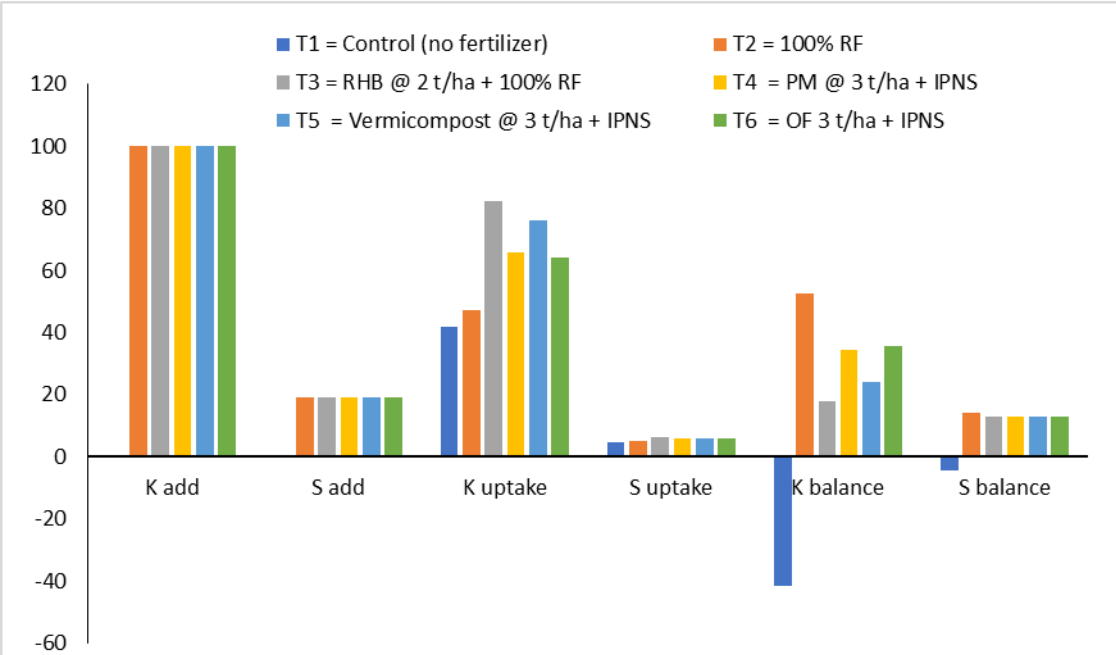


Fig. 42. Potassium & sulphurs balance in Sweet gourd-Fallow-T.Aman at saline soil of Dumuria (average of 3 year)

Effect of organic compound on soil properties and fertility characteristics

Naturally rapid mineralization of soil organic matter is a limitation on the practical application of organic fertilizers, despite the application having positive effect in enhancing soil fertility (Yun and Ro, 2009). Thus, the repeated application at high dose of organic materials can cause significant contribution to global warming, plant toxicity, accumulation in plants of heavy metals, and ground and surface water pollution of nutrients leaching. Recently some studies have indicated that the simultaneous application of BC and compost resulted in enhanced soil fertility, water holding capacity, crop yield and C sequestration benefit (Agegnehu et al., 2015). Schulz and Glaser (2012) found that the overall plant growth and soil fertility decreased in the order compost > BC + compost > mineral fertilizer + BC > mineral fertilizer > control. Combination of BC with mineral fertilizer further increased plant growth during one vegetation period but led also to accelerate BC degradation during a second growth period. In this studies, the results suggested that the effect of adding RHB treatment significantly increased TC, TP, C/N ratio, K, Na, and Ca, but no negative impact on mixed-soil.

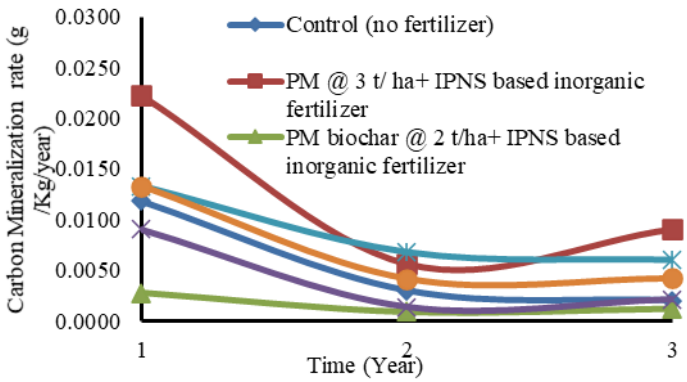


Fig. 43. Soil organic carbon mineralization rate under acidic soil (Narsingdi)

Soil Total Organic Carbon (TOC).

Results showed that application of biochar and other organic sources increased soil TOC contents in acidic, saline and drought areas soils (Figure 43-45). However, no significant differences were found among the TOC contents of the amended soils. Additionally, Trupiano et al. (2017) found that application of compost and biochar, alone or in combination, increased soil TOC content than that in the unamended soils, which is indicative that biochar and/or compost applications to soils can enhance C accumulation and sequestration. The total SOC content in experimental fields gradually decreased with time. The SOC contents of initial soil were 9.83, 8.96 and 10.98 g/kg in three locations, respectively. After using poultry biochar @ 2t/ha at Narsingdi soil, SOC was increased 9.9% and 1% SOC loss at the end of the experiment. But, at the same field it was increased 12.95 % and 2% loss over time. Rajshahi soil SOC was increased 8.19% and at the end of the experiment it was 5.87%. The SOC was increased up to 8.37% by using @ 2t/ha RHB and 1.79% decreased over time. On the other hand OF, vermicompost, poultry manure increase the SOC and almost it was loss at the end of the experiment of respective location. Over all the SOC content of experimental fields increased with biochar application.

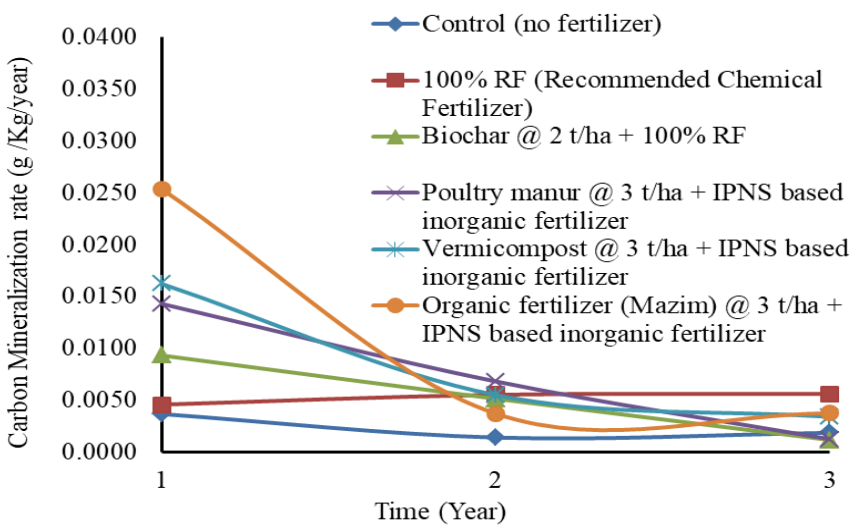


Fig. 44. Soil organic carbon mineralization rate under drought soil (Rajshahi)

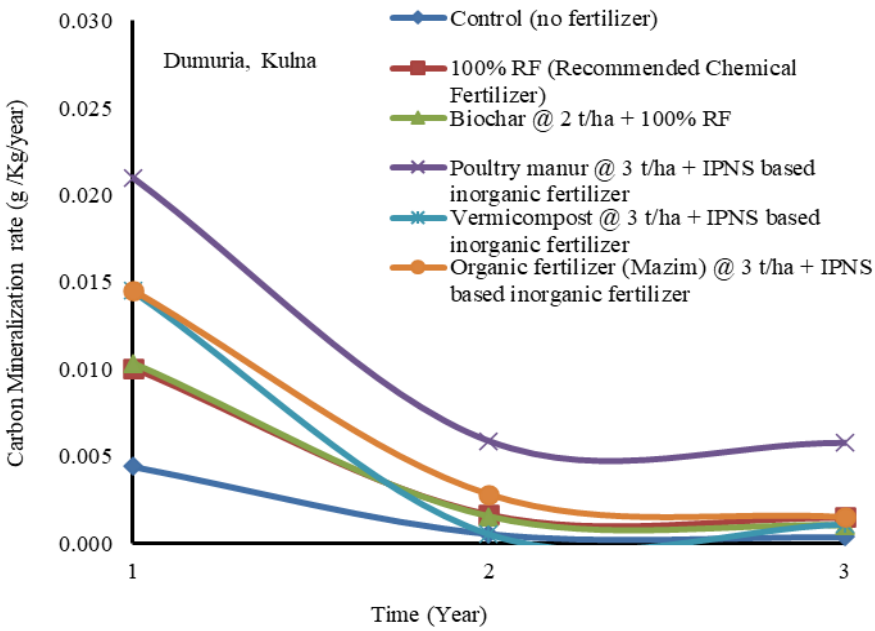


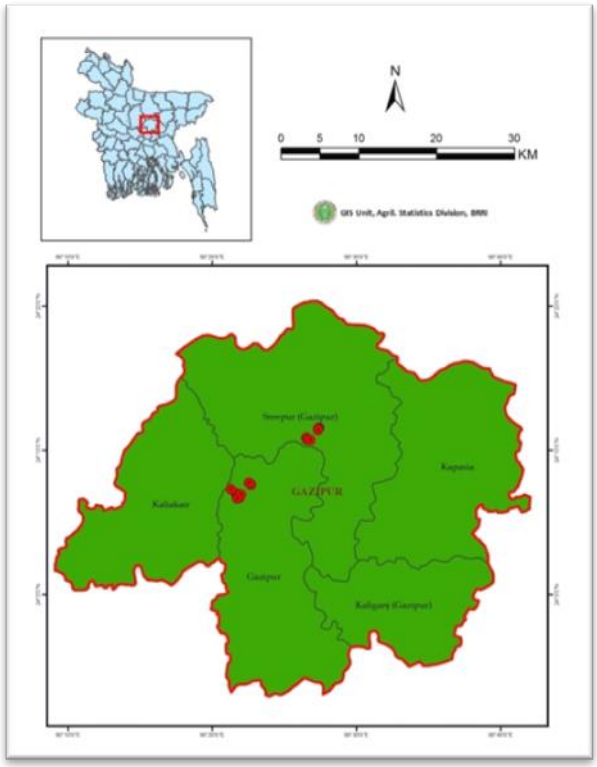
Fig. 45. Soil organic carbon mineralization rate under saline areas (Kulna)

BRRI Component

Activity 1: Benchmark survey to characterize bio-physicochemical properties of the soil of Sripur-Gazipur areas

Summary

The rice soils of Sripur, Mirzapur and Pirojali were irrigated with polluted industrial water and soils of Mirzapur and Pirojali remained under polluted water for 5-7 months in a year. A benchmark survey was done with 30 rice soil samples with the objective to characterize the biochemical properties of heavy metal polluted industrial area of Sripur-Gazipur. We found soils of Mirzapur and Pirujali were acidic in nature and pH ranged from 4.95 to 5.88 and 4.42 to 6.0, respectively. Soils of the studied area contained high organic matter (>2.5%), total N (0.15-0.20%), available K (0.16-0.22 meq /100 g soil), high level of Fe (87 to 838 ppm), Pb (44 to169 ppm), and Cd (0.63 to 4.38 ppm). However, the mean concentrations of Ni (31 ppm), Cu (4.2 ppm) and Cr (26.2 ppm) in the studied area were still below the toxic limit recommended by world health organization (WHO). Zn (3-65 ppm) status is found significantly higher than the flood plain soil of other AEZs. Total bacteria population ranged from 7.7×10^7 to 2.2×10^5 cfu g^{-1} dry soil respectively. The free- living N_2 fixing (NFB) and phosphate solubilizing bacteria (PSB) population were very low ranging from 1.2×10^7 to 1.1×10^3 cfu g^{-1} dry soil in NFB and 1.3×10^6 to 2.2×10^5 cfu g^{-1} dry soil in PSB respectively. Fungus and actinomycetes populations were also very low and most of the cases missing. Average biomass carbon ranged from 100 to 123 mg/kg. Furthermore, total and beneficial microbial populations were lower than any other healthy agricultural soil. In general, rice soils of Sripur, Mirzapur and Pirujali were acidic in nature, rich in organic matter and contaminated with iron, lead and cadmium.



Map showing the benchmark survey area of Gazipur and Sripur

Bio-chemical properties of studied soil: Physiographically the studied areas are located under Madhupur tract and are underlain by the Pleistocene Dupitilla formation. In general, the dominant soil texture of the studied areas is silt clay and land type was medium high land. The bulk density (g/cm^3) of soils for Sripur, Mirzapur and Pirujali were 0.50, 0.57 and 0.54, respectively.

Soil chemical properties:

The soil pH of industrial area ranged from 4.42 to 7.95, which indicates soils of most of the area are mostly moderately acidic to neutral in nature. Soil organic C status was above the critical level and varies from 1.0 to 3.63%. Total N ranges from 0.11% to 0.32%. The exchangeable K (0.09 to 0.35 meq/100g soil) and P (3.5 to 34 ppm) were mostly in sufficient level, exchangeable Na and Ca ranges from 0.02 to 0.06% and 0.02 to 0.16%, respectively. The chemical properties of soil are stated in Table 32.

Table 32. Chemical properties of the rice soils of Sripur and Gazipur industrially polluted area

Location	pH	OC (%)	OM (%)	N (%)	Avail. P (ppm)	*K	Na (%)	Ca (%)	Mg (ppm)
Sripur	7.18	1.31	2.26	0.11	11.35	0.14	0.03	0.08	39
Sripur	7.95	2.59	4.47	0.24	13.3	0.23	0.03	0.16	40
Sripur	7.4	0.92	1.59	0.11	4.215	0.12	0.02	0.03	43
Sripur	7.73	1.16	2.00	0.11	32	0.10	0.02	0.03	42
Sripur	6.82	1.21	2.09	0.16	34.05	0.32	0.05	0.05	43
Sripur	7.21	1.02	1.76	0.15	13	0.33	0.06	0.03	41
Sripur	6.49	1.31	2.26	0.16	9.45	0.34	0.06	0.05	42
Sripur	6.58	1.18	2.03	0.14	19.8	0.22	0.04	0.02	40
Sripur	6.94	1.18	2.03	0.18	14.15	0.21	0.03	0.02	42
Sripur	6.31	1.45	2.50	0.14	11.45	0.21	0.04	0.02	41
Pirojali	5.46	2.22	3.82	0.26	6.15	0.20	0.03	0.05	43
Pirojali	5.17	1.53	2.65	0.18	8.35	0.20	0.03	0.03	43
Pirojali	5.16	1.98	3.41	0.21	4.3	0.21	0.04	0.03	43
Pirojali	5.41	1.93	3.32	0.21	10.9	0.27	0.03	0.06	41
Pirojali	5.37	0.77	1.32	0.10	5.65	0.09	0.02	0.02	38
Pirojali	5.06	1.64	2.82	0.17	8.95	0.16	0.03	0.02	37
Pirojali	5.16	1.60	2.76	0.14	3.5	0.16	0.03	0.03	43
Pirojali	5.32	3.53	6.09	0.32	5.6	0.20	0.04	0.05	44
Pirojali	5.44	3.53	6.09	0.27	28	0.22	0.04	0.05	44
Pirojali	4.95	3.63	6.26	0.28	11.2	0.25	0.05	0.05	44
Pirojali	5.09	1.60	2.76	0.19	12.85	0.16	0.03	0.04	44
Pirojali	5.11	1.13	1.94	0.16	10.4	0.13	0.02	0.04	42
Pirojali	5.88	1.02	1.76	0.17	10.25	0.11	0.02	0.02	40
Mirzapur	6.11	1.20	2.07	0.25	18.95	0.09	0.03	0.02	40
Mirzapur	5	1.11	1.92	0.18	21.75	0.10	0.02	0.02	41
Mirzapur	4.7	1.72	2.97	0.20	14.65	0.28	0.05	0.04	44
Mirzapur	5.46	1.33	2.29	0.14	12.25	0.08	0.02	0.02	35
Mirzapur	4.47	2.62	4.51	0.20	27	0.35	0.06	0.05	44
Mirzapur	4.38	2.29	3.95	0.19	9.15	0.11	0.03	0.02	40
Mirzapur	4.42	2.55	4.40	0.25	4.95	0.14	0.03	0.03	43

***K meq/100 g soil)**

Micro nutrient status:

Total concentration of Fe of the studied area ranged from 87- 838 ppm (Fig 46a) whereas it has been observed that the Fe concentration ranging 44- 484 ppm in floodplain soil (Sarkar et al 2018). Hussain (1992) reported that the soils of Madhupur tract contained high amount of iron and aluminium, which are in agreement with our study. Conversely, Fe has never been reported to be deficient in this soil (Islam et al. 1992). The maximum permissible limit of Fe in soil 50000 ppm recommended by WHO and FAO (Chiroma et al., 2014), however in the studied area soil Fe concentration was in the above permissible level. The rice field remains inundated under contaminated canal's water most of the crop growing period and reduced condition Fe^{3+} ion converts to Fe^{2+} ion causing Fe toxicity in the plant. Moreover, presence of relatively high organic matter content in the soil increases the solubility of Fe^{2+} (Tisdle et al., 1995). It is reported that rice suffers Fe toxicity at the Fe^{2+} concentration higher than 300-500 ppm (Bode et al.1995).

Total Mn concentration varied from 7 to 150 ppm in soil of studied area (Fig 1b) which is more or less similar to the Mn (3- 141 ppm) status recorded in floodplain soil (Sarkar et al., 2018). In most acidic soils at low pH (<5.5) and an increased redox potential manganese oxide can be easily reduced in the soil exchange sites (Kogelmann and Sharpe, 2006),

increasing the concentration of soluble Mn^{2+}, which is the predominant Mn form in the soil solution. The maximum permissible limit of Mn in soil is 2000 ppm and for crop production, the permissible limit is 500 ppm (Chiroma et al., 2014). The present Mn status of the studied area is within the range.

The concentration Zn in soil the studied areas ranged from 3-65 ppm (Fig 46b) which is greater to Zn (0.62- 4.21 ppm) status recorded in floodplain soil (Sarkar et al., 2018) of other orner of our country. FAO (1986) reported that most of the flood plain soils contain more than 40 ppm Zn. The maximum acceptable concentration of Zn was 150 ppm for crop production (Kabata-Pendias and Pendias, 1992). According to WHO, the maximum permissible limit of Zn in soil is 300 ppm (Chiroma et al., 2014). The values of our study area were within the permissible limit recommended by WHO.

The concentration of Cu of the studied area varied from 1 to 7 ppm (Fig 1b). The level of Cu in the soils was less than the maximum acceptable concentration of 100 ppm for crop production (Kabata-Pendias and Pendias, 1992). According to WHO, the maximum permissible limit of Cu in soil is 100 ppm (Chiroma et al., 2014). The values of our study area were below the permissible limit recommended by WHO.

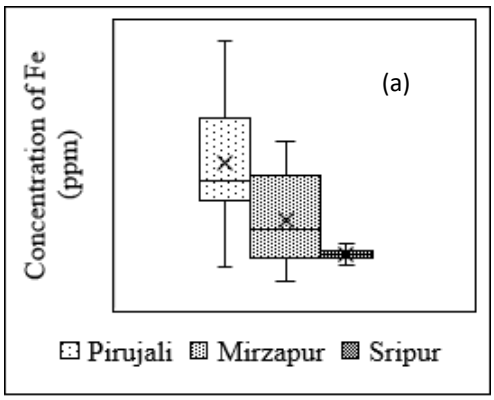


Fig. 46a. The concentration of soil Fe (PPM) of Sripur and Gazipur industrially polluted rice soil.

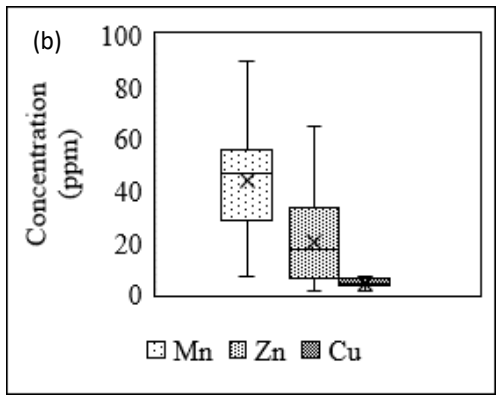


Fig. 46b. The concentration of Mn, Zn, Cu in Sripur and Gazipur industrially polluted rice soil.

The concentration of Pb was found 44 ppm to 169 ppm having the mean value of 117.97 ppm (Fig 2) in the industrially polluted rice soil of Gazipur Sadar and Sripur Upazilla which is comparatively higher than the other reported research works in Bangladesh such as Jahiruddin et al, 2000, Zakir et al., 2015. Vandana et al. (2011) observed the concentration of Pb ranging from 42.9 to 1835.0 ppm in hazardous waste disposal site of Hyaderabad, India. According to WHO, the maximum acceptable concentration of Pb in an unpolluted soil is 85 ppm (WHO, 1996) and for crop production is 50 ppm (Kabata-Pendias and Pendias, 1992). The values of our finding are higher than the permissible limit recommended by WHO.

The investigation revealed that the concentration of Ni varies from 0.63 ppm to 62.5 ppm having the mean value of 31 ppm in the agricultural farmland soil adjacent the studied industrial area (Fig 47). Iqbal et al. (2011) observed the concentration of Ni ranging from 32.1 to 94 ppm in the agricultural land irrigated with industrial effluent in Pakistan. According to WHO, the desirable maximum concentration for Ni in an unpolluted soil is 35 ppm (WHO, 1996). The mean value of Ni concentration in the studied area was still below the acceptable limit recommended by WHO.

The study revealed that the concentration of Cr ranging from 0.63 ppm to 102.5 ppm with a mean value of 26.2 ppm of the studied industrial area (Fig 47). Zakir et al., (2015) also found Cr concentration 29.21 ppm in the soil of Gazipur industrial area which is quite similar to our finding. According to WHO, the maximum permissible concentration of Cr in soil is 100 ppm (WHO, 1996). Most of the values were below to the permissible limit recommended by WHO.

The study investigated that the concentration of Cd ranging from 0.63 ppm to 4.38 ppm with a mean value of 2.96 ppm (Fig 47WW). The concentration of Cd is comparatively lower than the concentration of other heavy metals due to its low adsorptive nature in soil (Mido and Satake, 2003). Previously the mean concentration of Cd has been recorded 0.41 ppm in the soil of Gazipur industrial area which was comparatively lower than the concentration recorded in our study (Zakir et al 2015). Bharti et al. (2013) recorded that the mean concentration of Cd was 1.927 ppm in the soil irrigated with effluent of textile in Panipath city of India. WHO (1996) stated that the maximum permissible limit of Cd in an unpolluted soil was 0.8 ppm. The mean value exceeds the standards recommended by WHO.

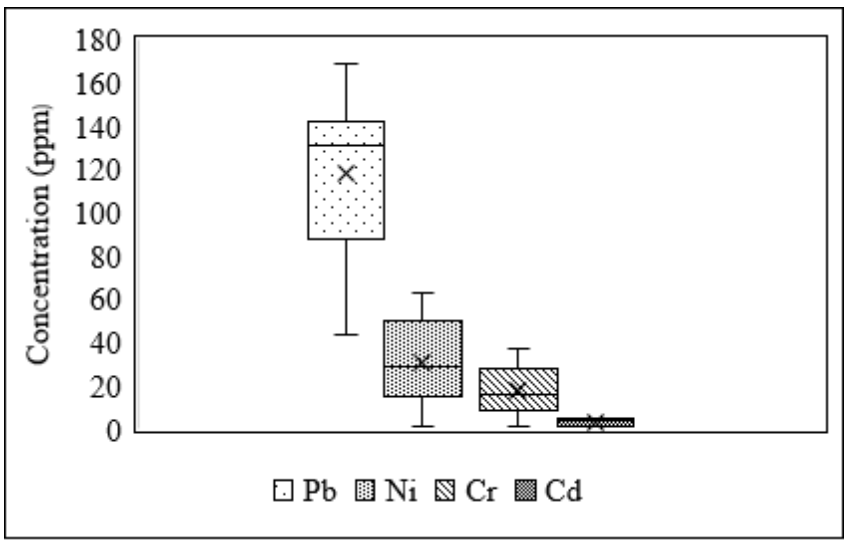


Fig. 47. The concentration of heavy metals (Pb, Ni, Cr and Cd) in the Sripur and Gazipur industrially polluted rice soil.

Soil microbial population:

The total bacterial population was quite lower compared to any other healthy rice soil showing the ranges of 7.7×10^7 to 2.2×10^5 cfu g^{-1} dry soil respectively (Fig. 48). Hiruki (1992) observed the decrease of total bacterial population in heavy metal contaminated rice field which agrees the findings of our study. The free-living N_2 fixing bacteria (FNB) population was also recorded low having ranges from 1.2×10^7 to 1.1×10^3 cfu g^{-1} dry soil respectively. Heavy metals such as Cd, Cr etc were reported to inhibit the growth, morphology and activities of symbiotic N_2 fixers (Stan et al., 2011). The phosphate solubilizing bacteria (PSB) population was higher than free-living N_2 fixing bacteria and it varies from 1.3×10^6 to 2.2×10^5 cfu g^{-1} dry soil respectively. But the PSB population is generally lower than the unpolluted agricultural soil. PSB such as *Bacillus sp.* are sensitive to high concentration of Pb and Cr (Shao et al., 2019). In the studied area the Cr concentration is also recorded relatively high. The findings of Shao et al., (2019) is in agreement with our present findings.

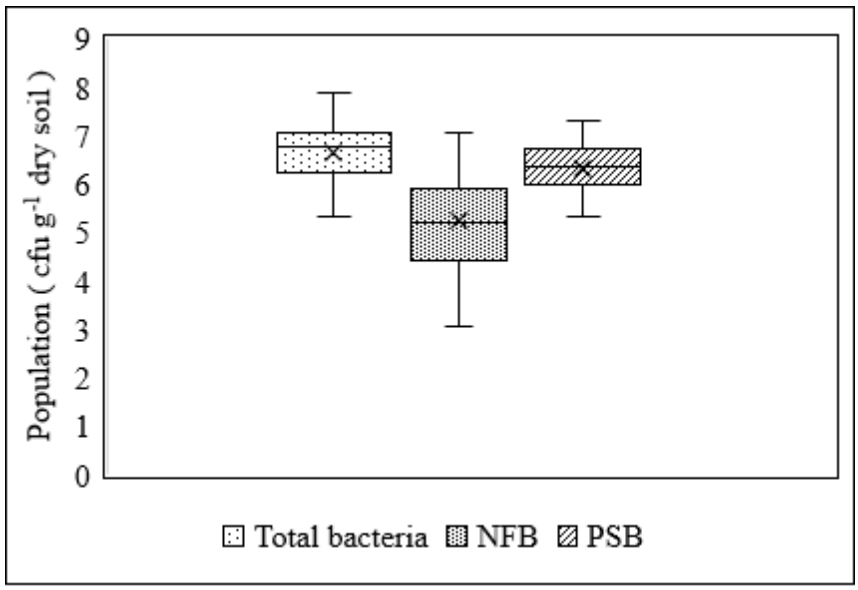


Fig. 48. The population of total bacteria, free living N_2 fixing bacteria (NFB) and phosphate solubilizing bacteria (PSB) in the Sripur and Gazipur industrially polluted rice soil.

The fungus population was very low and it ranges from 1.1×10^4 to 6.6×10^4 cfu g^{-1} dry soil in Sripur and in the sample of Pirujali and Mirzapur no fungal population was found (Fig 49 (a & b). Chen et al., 2014 observed significant decrease in the abundance of fungi in the paddy field with long term contaminated with heavy metal (Cd, Cr, Pb and Zn) which was similar to the result of our study. The actinomycetes population was also recorded very low ranging from $2.4\times10^3$to 1.3×10^2 cfu g^{-1} dry soil in Sripur, 5×10^2 to 2×10^2cfu g^{-1} dry soil in Pirujali and from 1×10^2 to 2.2×10^4cfu g^{-1} dry soil in Mirzapur (Fig 4). Vítězová (2013) observed that the increased concentration of Cd, Pb and Zn can hamper the growth of actinomycetes population which completely agrees with our findings in the polluted rice soil of Sripur-Gazipur industrial area.

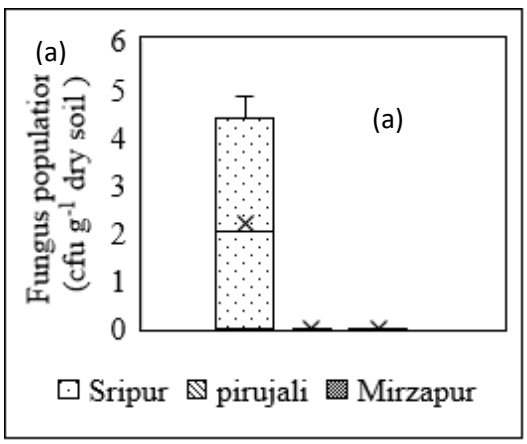


Fig. 49a. The population of total fungus in the Sripur and Gazipur industrially polluted rice soil.

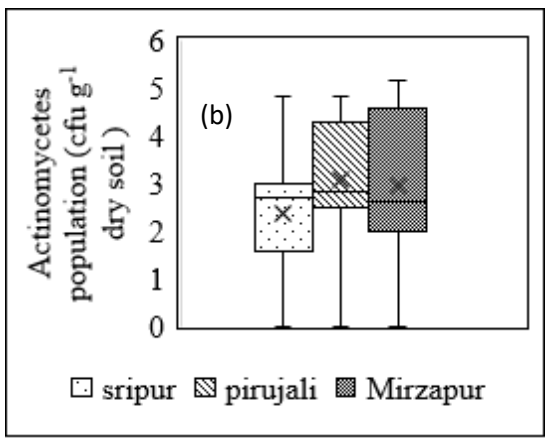


Fig 49b. The population of total actinomycetes in the Sripur and Gazipur industrially polluted rice soil.

Fig. 49a and 49b the fungi and actinomycetes population (cfu g^{-1} dry soil) in industrially polluted rice soil in Gazipur. The biomass C of Sripur soil ranged from 100 to 400 mg C/kg soil with an average value of 168.49 mg C/ kg soil. The average biomass C of Mirzapur soil was 166.84 mg C/ kg soil and it ranged from 95.94 to 287.82 mg C/ kg soil. The biomass C

of Pirujali soil ranged from 95.94 to 204.33 mg C/ kg soil with an average value of 123 mg C/ kg soil.

Conclusions:

In this benchmark study, we concluded that soils of Gazipur -Sripur industrial area were acidic in nature. Organic matter and biomass C is high. Soil bulk density ranged from 0.50, 0.57 gm/cm^3. The concentration of Fe, Zn, Cu, Mn were higher than sufficiency level. However, Pb and Cd concentration were in toxic level according to WHO permissible limit for agricultural soil. Biomass carbon ranged from 100 to 123 mg/kg soil. Culturable microbial populations were lower than un-polluted soil. Beneficial bacteria such as free-living N_2 fixing and phosphate solubilizing bacteria populations were also low.

Picture: Contaminated water is adding in irrigation channel from factory wall at Sripur

Activity 2: Study of the mineralization rate of nutrient after organic amendment in the industrial polluted soil under continuous standing water conditions (incubation study)

Summary

Different organic sources may have effect on nutrient mineralization. Laboratory incubation study on nutrient mineralization is important to know the nutrient release pattern. An incubation study was performed at laboratory to determine mineralization of organic materials (vermicompost, biochar) and evaluate the effect of organic materials for amelioration of heavy metal pollution in Sripur. Study result showed that irrespective of soils, higher amount of C, N and P accumulation was found in vermicompost applied treatment. Vermicompost application significantly increased C mineralization rate among the treatments and slightly higher (k =0.081) trend was found in the polluted soil. The highest amount of K mineralization was recorded in the both biochar and vermicompost added treatment. Application of organic matter increased Zn mineralization in the unpolluted soil, however application of vermicompost significantly increased Zn mineralization in the both soil. Applications of treatments were not able to reduce soil Cd and Pb concentration below the toxic limit. Application of biochar significantly increased Mn concentration in both soils. Biochar application slightly reduced Fe^{++}, Pb and Cd concentration but still remain at toxic level. Microbial population was slightly higher in the un-polluted soil compared to polluted soil. Application of biochar and vermicompost with chemical fertilizer significantly increased microbial population in the un-polluted soil.

Effect of organic amendments on nutrient mineralization:

Ammonium-N: In the polluted soil, significantly high NH_4-N mineralization was observed in the biochar amended soil followed by vermicompost treatment (Fig 50a). The lowest NH_4-N mineralization was found in the control treatment. In this soil, initial NH_4-N concentration was high (277 ppm) in the vermicompost followed by biochar (156 ppm) applied treatment. Rapid NH_4-N mineralization was started immediate after incubation in all of the treatments and the highest (415ppm) NH_4-N released in biochar at 7 days of incubation. In the vermicompost applied treatment the highest 302 ppm NH_4-N was recorded at 21day of incubation. The highest 139 ppm NH_4-N concentration was found in the chemical fertilized treatment. After 21 day of incubation NH_4-N concentration was sharply decreased in all of the treatments (Fig. 50a). In the un-polluted soil, the highest NH_4-N concentration was found in the vermicompost followed by chemical fertilizer treatment. Alike polluted soil the initial NH_4-N concentration was high in the vermicompost treatment compared to biochar and only chemical fertilizer treatments. The highest NH_4-N (403 ppm) was found in the vermicompost treatment at 7 days of incubation. After 21 days of incubation NH_4-N mineralization decreased sharply (Fig.5b).

NO_3-N mineralization: There were no significant differences found in NO_3-N mineralization for both polluted and un-polluted soils. Initially NO_3-N concentration was high and after 3 days it maintained a linear pattern during the whole incubation period for both the soil (Table 33).

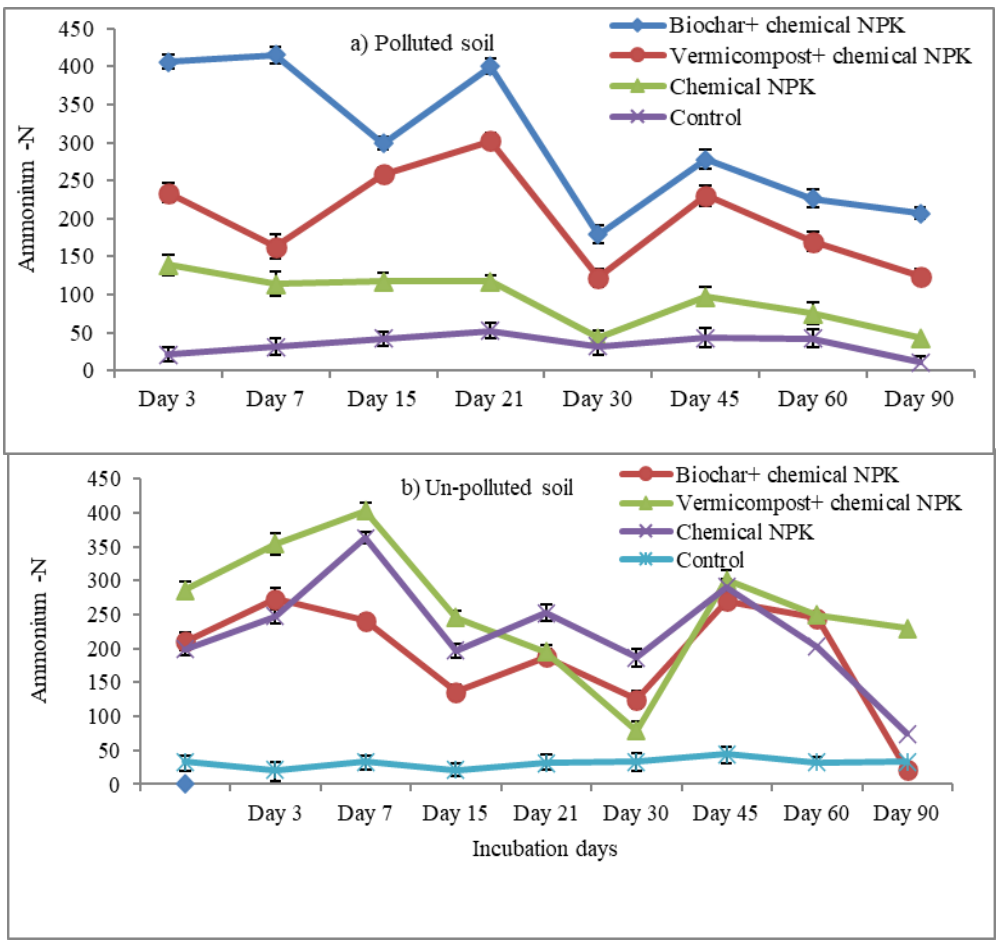


Fig. 50 (a & b) Effect of different organic amendments and chemical fertilizer on NH_4-N mineralization in the polluted and un-polluted soils of Sripur Gazipur

Table 33. Effect of different organic amendment and chemical fertilizer on NO_3-N mineralization in the industrial effluent polluted and un-polluted soil

Treatment	Initial		Day 3		Day 7		Day 15		Day 21		Day 30		Day 45		Day 60		Day 90	
	S_1	S_2	S_1	S_2	S_1	S_2	S_1	S_2	S_1	S_2	S_1	S_2	S_1	S_2	S_1	S_2	S_1	S_2
Biochar+ chemical NPK	31.1 ±1.2	31.7 ±2.1	11 ±0.4	10.9 ±0.6	21.3 ±2.1	11 ±0.2	10.7 ±0.7	20.9 ±3.1	21.6 ±1.1	11.1 ±2.3	22.4 ±3.1	11.4 ±0.7	11.1 ±1.1	11.2 ±0.2	10.8 ±0.3	11.1 ±0.1	5.4 ±0.5	5.3 ±0.4
Vermicompost+ chemical	32 ±3.1	31.8 ±2.1	11.2 ±0.3	11.1 ±0.9	21.7 ±1.1	11.2 ±0.3	21.5 ±2.2	10.7 ±0.1	22.4 ±2	11.4 ±0.4	11.1 ±0.2	11.3 ±0.6	10.9 ±0.5	11.2 ±0.2	10.6 ±0.3	11.3 ±0.2	5.6 ±0.3	5.7 ±0.4
Chemical fertilizer	31. ±1.5	31.4 ±2.1	10.7 ±0.5	10.8 ±0.6	10.4 ±0.6	11 ±0.3	21.3 ±0.5	10.4 ±0.3	10.7 ±0.4	11 ±0.2	32.3 ±2.1	11 ±0.7	10.7 ±0.4	10.8 ±0.5	10.7 ±0.1	10.7 ±0.4	5.4 ±0.1	5.3 ±0.1
Control	30.7 ±3.1	10.3 ±0.1	10.5 ±0.3	5.3 ±0.1	20.4 ±1.1	10.9 ±0.2	10.4 ±0.6	10.7 ±0.5	20.9 ±2.1	10.3 ±0.4	10.5 ±0.3	11 ±0.5	10.7 ±0.7	11 ±0.2	10.5 ±0.4	10.7 ±0.2	5.3 ±0.3	5.5 ±0.1

Here, S_1= polluted soil, S_2= Un-polluted soil

Organic carbon and mineralization rate: Application of organic material significantly increased carbon content in the soil (Fig. 51a). The highest C content was found in the vermicompost applied treatment in both soils. However, in the polluted soil higher C content was found in the control treatment followed by the chemical fertilizer applied treatment. The lowest C content was recorded in the biochar applied treatment. The highest C (3.08%) was recorded at day 7 in the control treatment followed by chemical fertilizer treatment (2.73% C) at 15 day of incubation. After that C content was gradually decreased over time.

In the un-polluted soil, initial C content was also high in the vermicompost applied soil. The highest C content (3.19%) was recorded in the vermicompost at day 3 and with increased of incubation day, C content gradually decreased in all of the treatments. In comparison of the treatments, C content was higher in the control treatment (Fig. 51b).

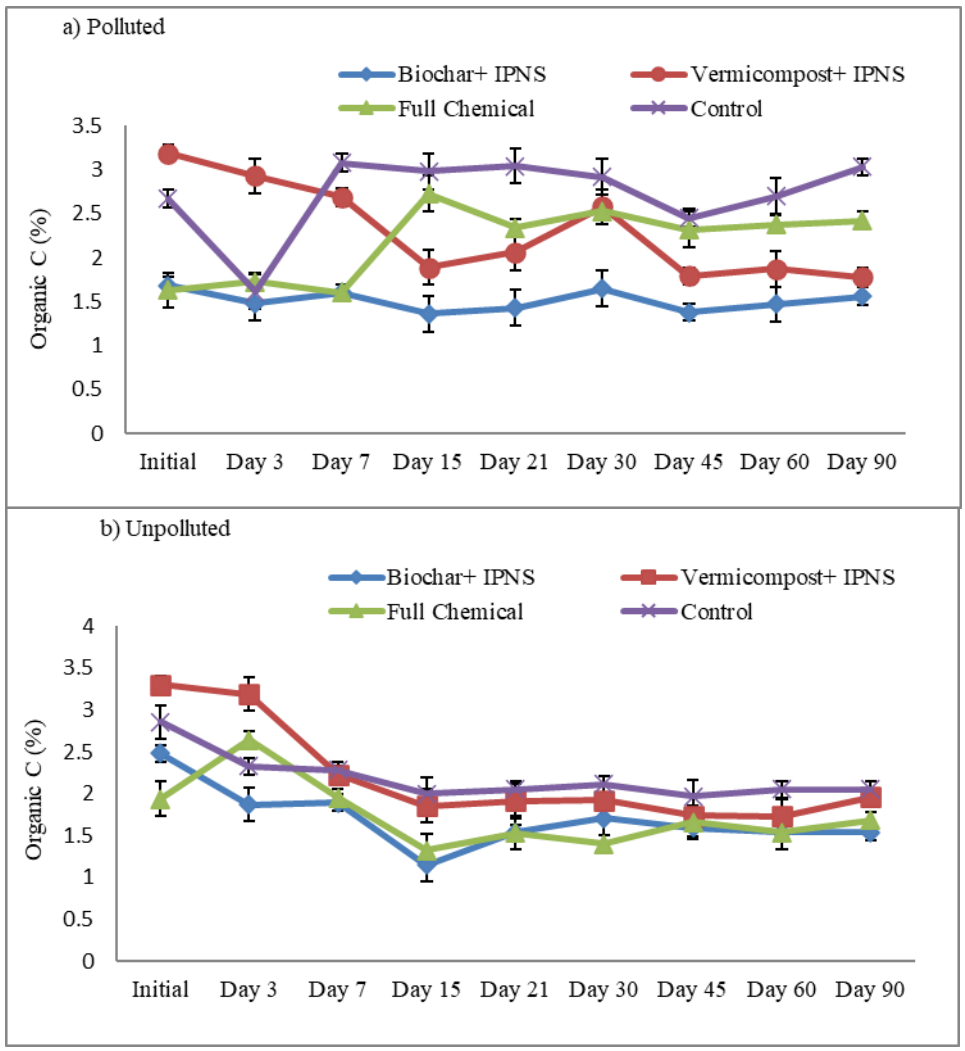


Fig. 51 (a & b) Effect of different organic amendments and chemical fertilizer on soil organic C content in the polluted and un-polluted soils of Sripur Gazipur.

Carbon mineralization rate:
Organic amendment increased C mineralization rate (*k*) in both of the soil especially in the vermicompost applied soil. However, the lowest C mineralization rate was found in the control soil. Vermicompost application significantly increased C mineralization rate among the treatments and slightly higher (*k* =0.08) trend was found in the polluted soil. In case of chemical fertilizer application, C mineralization rate was also higher (*k* = 0.007) in the polluted soil than un-polluted soil. In general C mineralization was high in the polluted soil compared to unpolluted soil (Fig.52 a & 52 b).

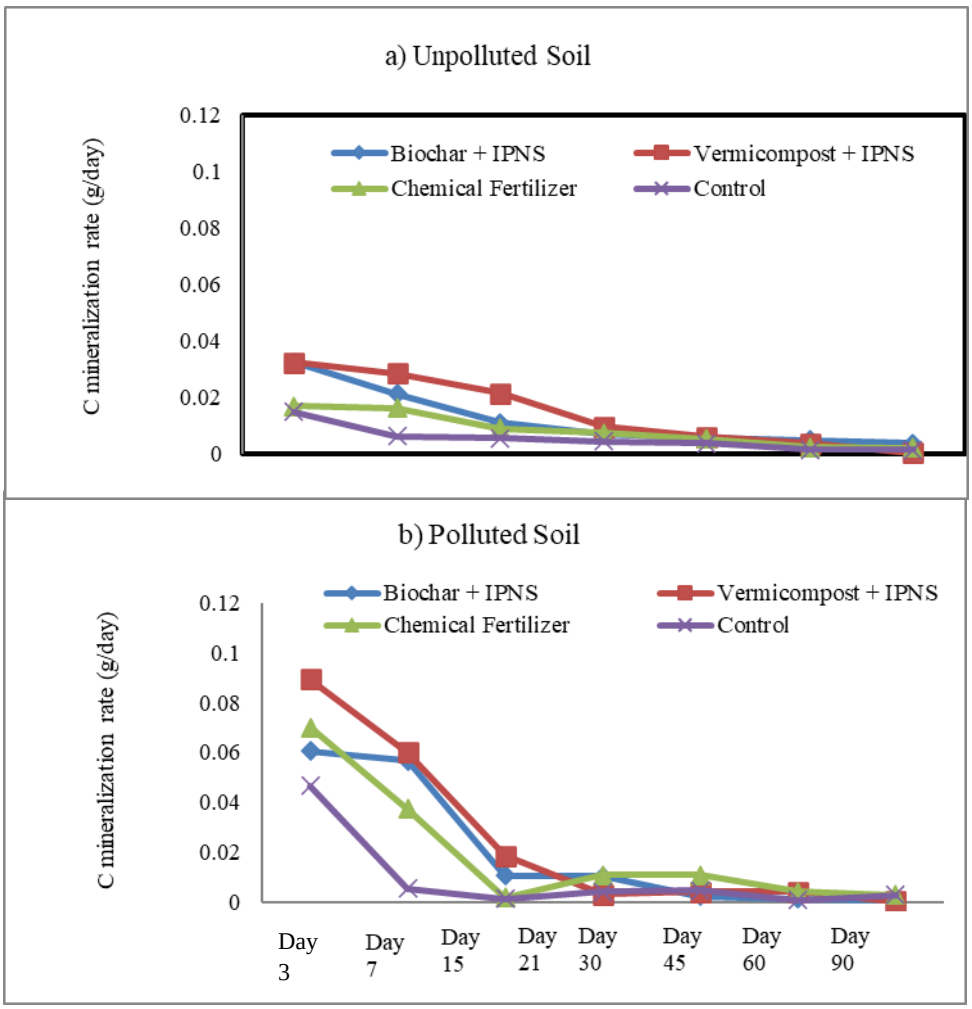


Fig. 52 (a & b) Effect of different organic amendments and chemical fertilizer on soil organic C mineralization rate (*k)* in the polluted and unpolluted soils of Sripur Gazipur.

Available P: Mineralization of P was followed the similar pattern for both of the soils (Fig. 53a & 53b). Significantly the highest amount of available P was found in the vermicompost applied treatment in both polluted and un-polluted soil followed by biochar applied treatments. The lowest concentration of P was found in the control soil. At one month of incubation the highest 325 ppm P was found in the polluted and 261 ppm P in the un-polluted vermicompost amended soil. P mineralization decreased after 1 month of incubation.

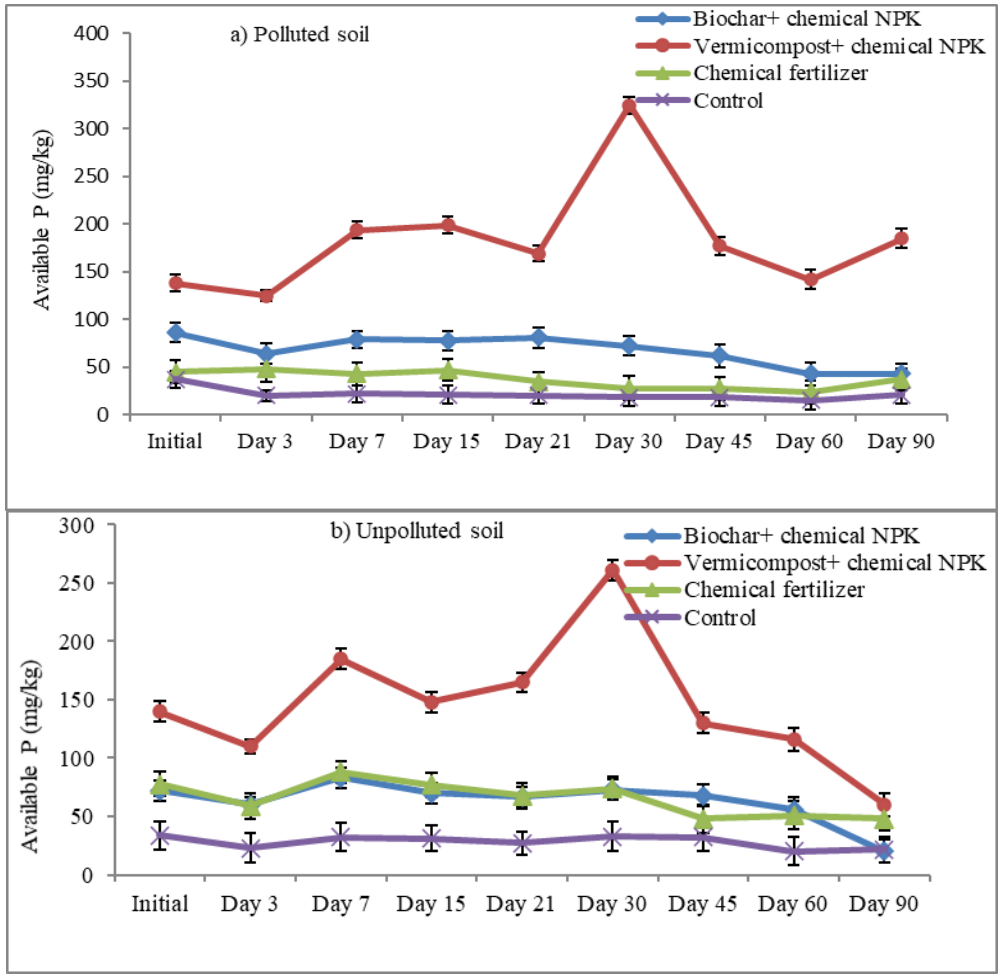


Fig. 53 (a & b) Effect of different organic amendments and chemical fertilizer on soil available P mineralization in the polluted and un-polluted soils of Sripur Gazipur.

Exchangeable K: Initially exchangeable soil K was higher in the vermicompost and biochar applied soil compared to chemical fertilizer treatment. In the polluted soil, the highest amount of exchangeable K was found in the vermicompost (5.3 meq/100gm soil) at 30 day of incubation (Fig. 54a). In the unpolluted soil the highest exchangeable K (5.7 meq/100gm soil) was found in the vermicompost at 21 day of incubation followed by biochar and chemical fertilizer treatment. The lowest amount of K was recorded in the control treatment

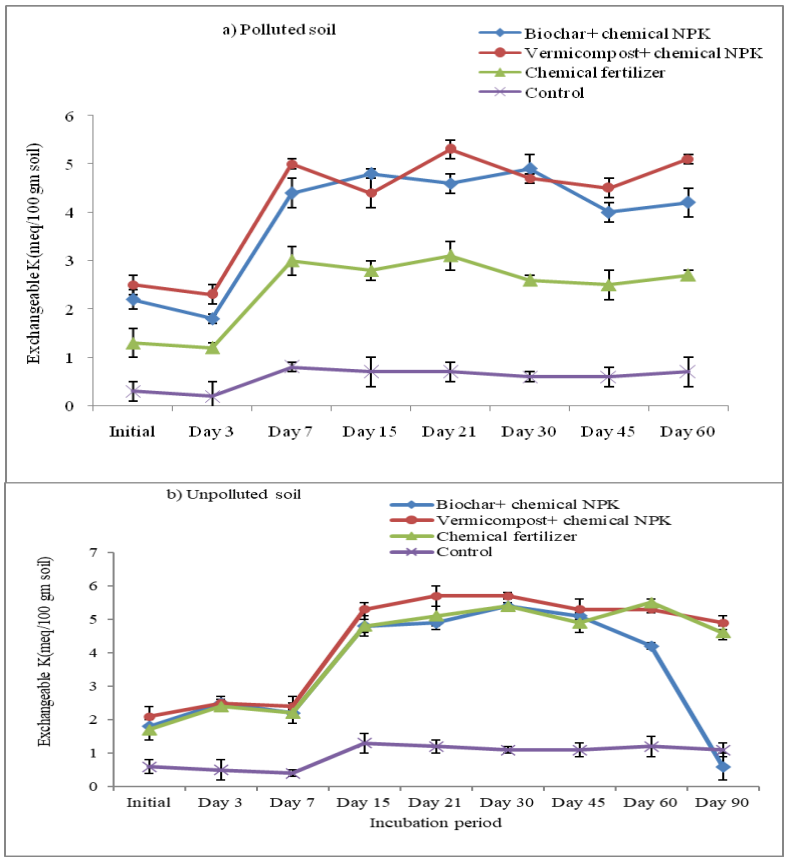


Fig. 54 (a & b) Effect of different organic amendments and chemical fertilizer on soil exchangeable K mineralization in the polluted and un-polluted soils of Sripur Gazipur.

Zinc (Zn): Application of organic matter increased Zn mineralization in the unpolluted soil, however application of vermicompost significantly increased Zn mineralization in the both soil (Fig. 55a & 55b). Initially total Zn concentration was higher in the vermicompost applied soil compared to biochar and chemical fertilizer treatment in both polluted and unpolluted soil and the trend remained until 90 days. In unpolluted soil the highest concentration of Zn (29.705 ppm) was found in the vermicompost treatment at the 21 days of incubation followed by biochar and chemical fertilizer treatment. Similarly, Zn concentration (31.42 ppm) increased in vermicompost applied soil at the 21 days of incubation. In unpolluted soil, Zn concentration showed higher trend in vermicompost followed by chemical fertilizer and biochar applied soil. In the polluted soil biochar treatment showed lower trend than control soil up to day 30.

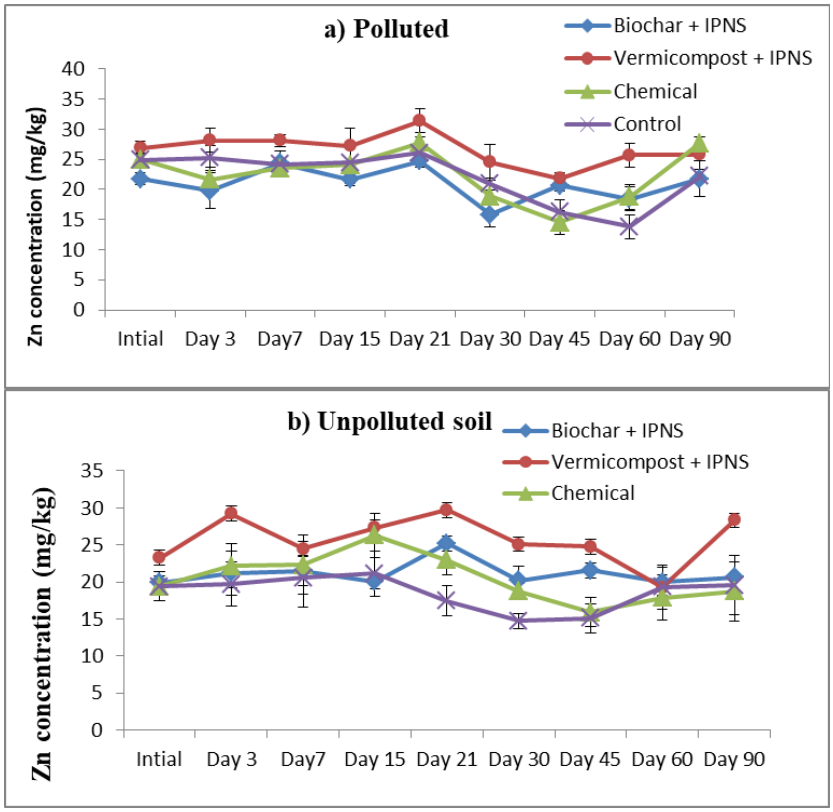


Fig. 55 (a & b) Effect of different organic amendments and chemical fertilizer on Zn mineralization in the polluted and un-polluted soils of Sripur, Gazipur.

Copper (Cu): Copper concentration was higher in vermicompost treated soil compared to chemical fertilizer application and control treatment in the un-polluted soil. Biochar applied soil showed the lowest concentration initially. In polluted soil, Cu concentration was higher in chemical fertilizer applied soil followed by vermicompost, control and biochar treatment (Fig. 56a). The maximum concentration of Cu (18.505 ppm) was recorded in vermicompost applied soil at 21 days of incubation in un-polluted soil (Fig. 56b). Likewise, the maximum concentration of Cu (16.795 ppm) was observed in chemical fertilizer applied fertilizer at 90 days of incubation in the polluted soil.

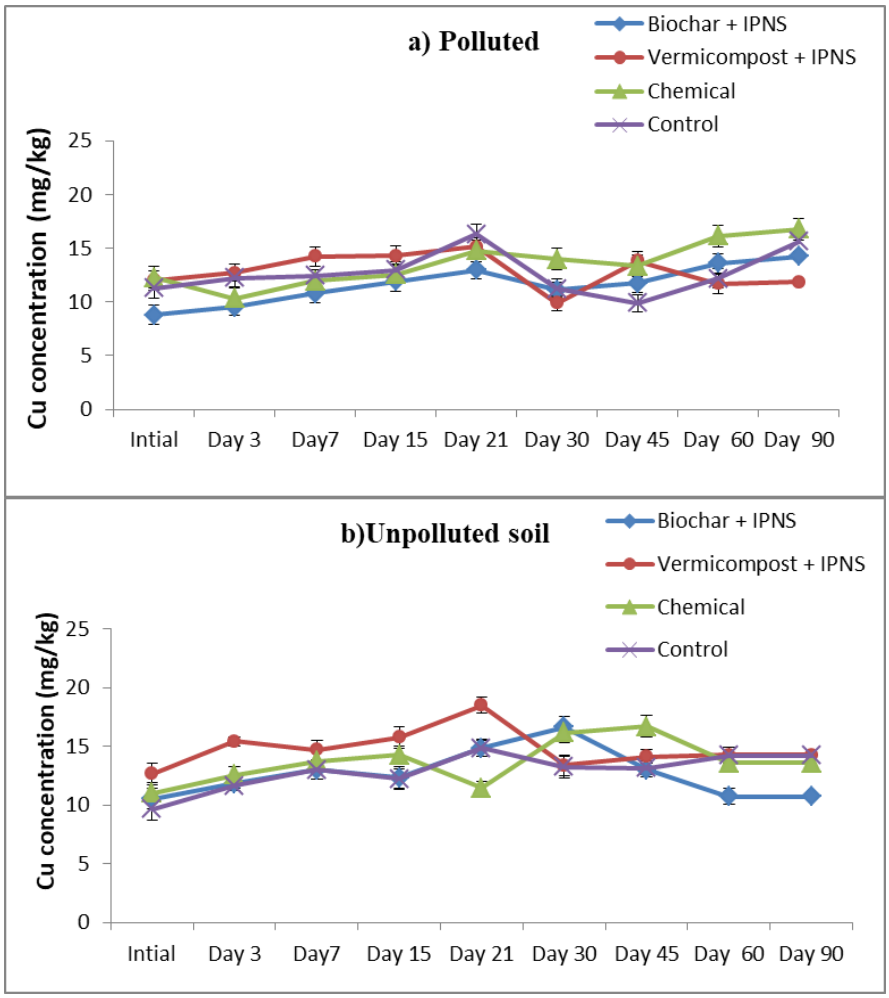


Fig. 56 (a & b) Effect of different organic amendments and chemical fertilizer on Cu mineralization in the polluted and un-polluted soils of Sripur, Gazipur.

Manganese (Mn): Application of biochar significantly increased Mn concentration in the both soils. In the unpolluted soil, the maximum concentration was recorded in biochar treated soil (97.625 ppm) at the 21 days of incubation and in the polluted soil, the maximum concentration (111.29 ppm) was found in the same day (Fig. 57a). The lowest Mn concentration was found in the control treatment at polluted soil, however in the un-polluted soil the lowest concentration was in the chemical fertilizer treated soil (Fig. 57 a & b).

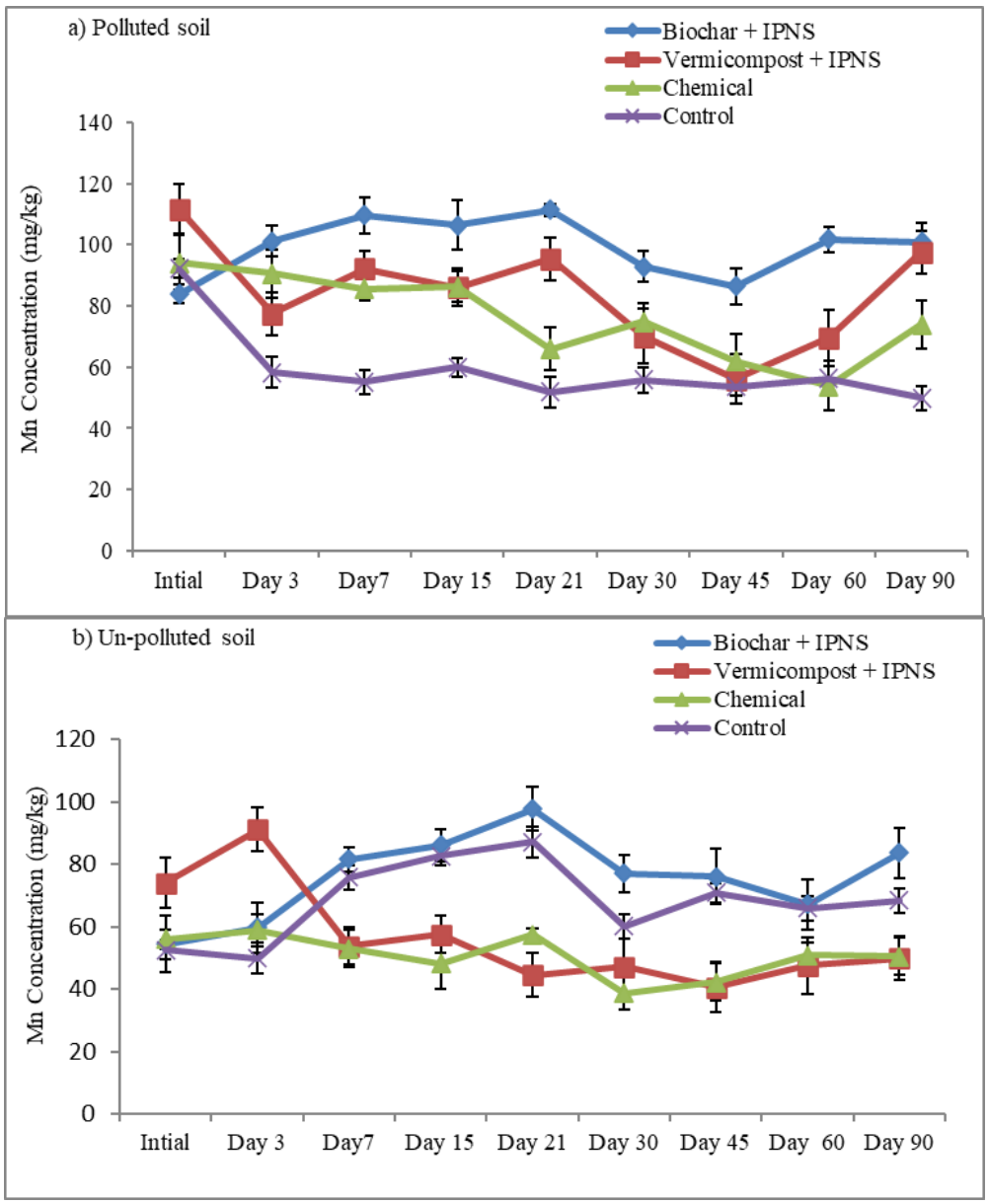


Fig. 57 (a & b) Effect of different organic amendments and chemical fertilizer on Mn mineralization in the polluted and un-polluted soils of Sripur, Gazipur.

Iron (Fe^{++}): In the unpolluted soil, biochar application increased Fe^{++} concentration up to 3 days and after this it was comparable with other treatments. In the polluted soil initial Fe^{++} concentration was higher in the control soil, however application of biochar slightly reduced Fe^{++} concentration but still remain above the sufficiency level (Fig. 58 a & b).

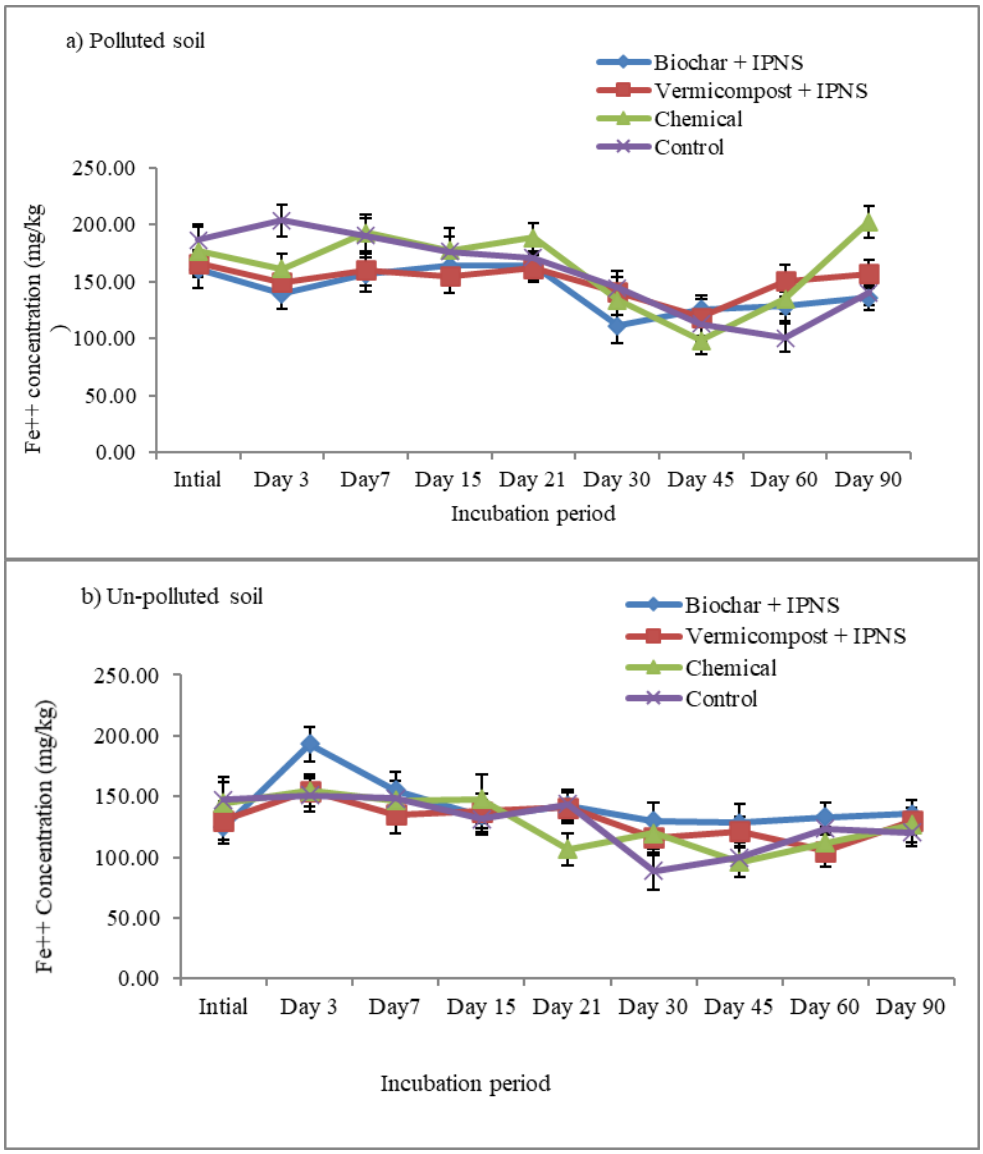


Fig. 58 (a & b) Effect of different organic amendments and chemical fertilizer on Fe^{++} mineralization in the polluted and un-polluted soils of Sripur, Gazipur.

Lead (Pb): In the unpolluted soil application of treatment significantly reduced Pb content except day 15 and the lowest Pb was found in the chemical fertilizer applied treatment. In the polluted soil vermicompost increased Pb concentration (86.45 ppm) at day 3 and after this it decreased. Application of biochar decreased Pb concentration and it remained slightly under toxic level (Fig. 59 a & b).

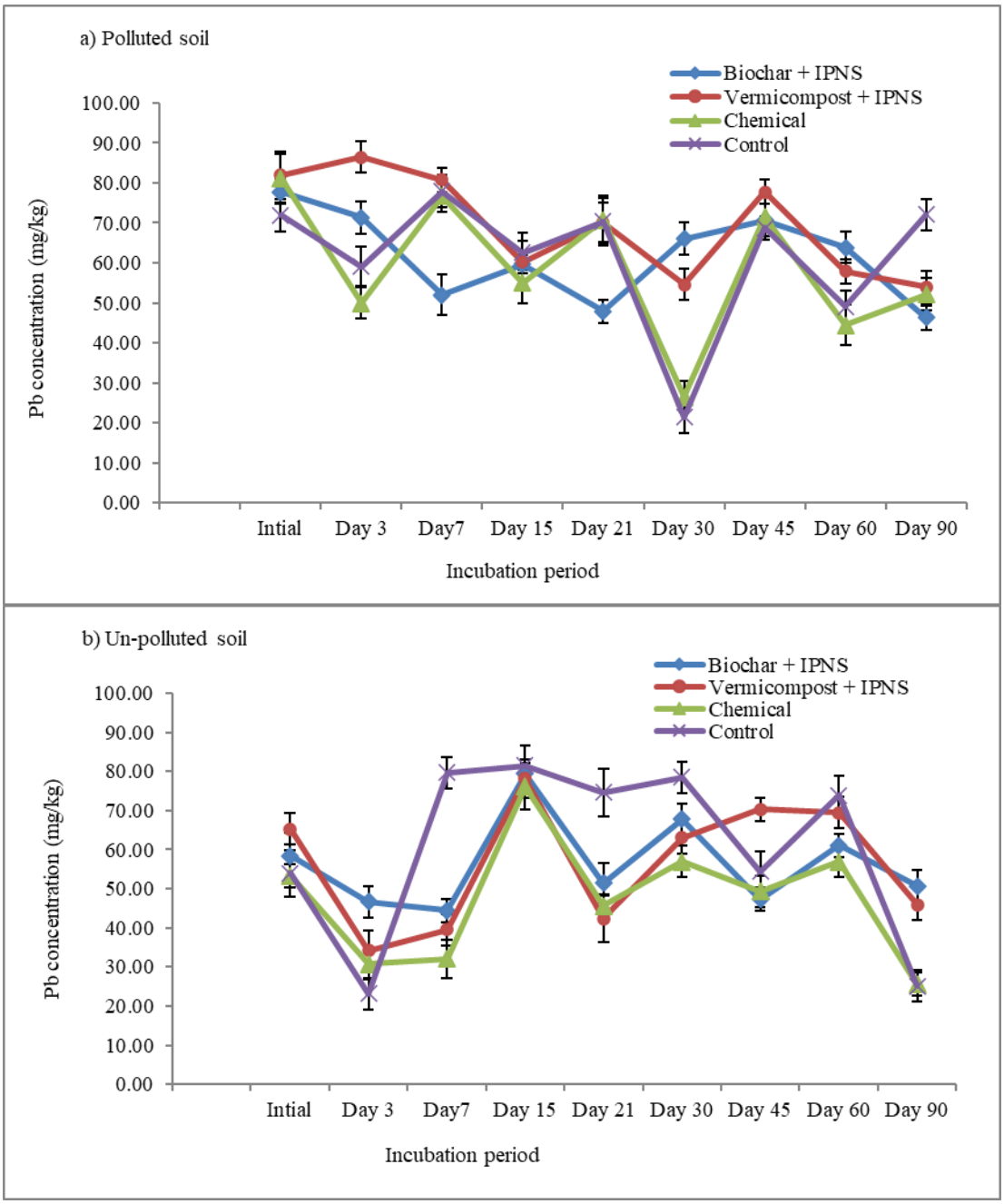


Fig. 59 (a & b) Effect of different organic amendments and chemical fertilizer on Pb mineralization in the polluted and un-polluted soils of Sripur, Gazipur.

Cadmium (Cd): In the unpolluted soil, application of chemical fertilizer and biochar increased Cd concentration compared to vermicompost treatment. In this soil the maximum concentration of Cd (0.25 ppm) found in the chemical fertilizer treatment at 21 day followed by biochar (0.23 ppm) at 15 day and vermicompost (0.20) at 30 day of incubation. In the polluted soil application of chemical fertilizer increased Cd concentration (0.36 ppm) at 30 day followed by biochar (0.30 ppm) at 21 day. Application of treatments decreased Cd concentration in the polluted soil and the lowest Cd concentration was found in the biochar treatment (Fig.15 a & b).

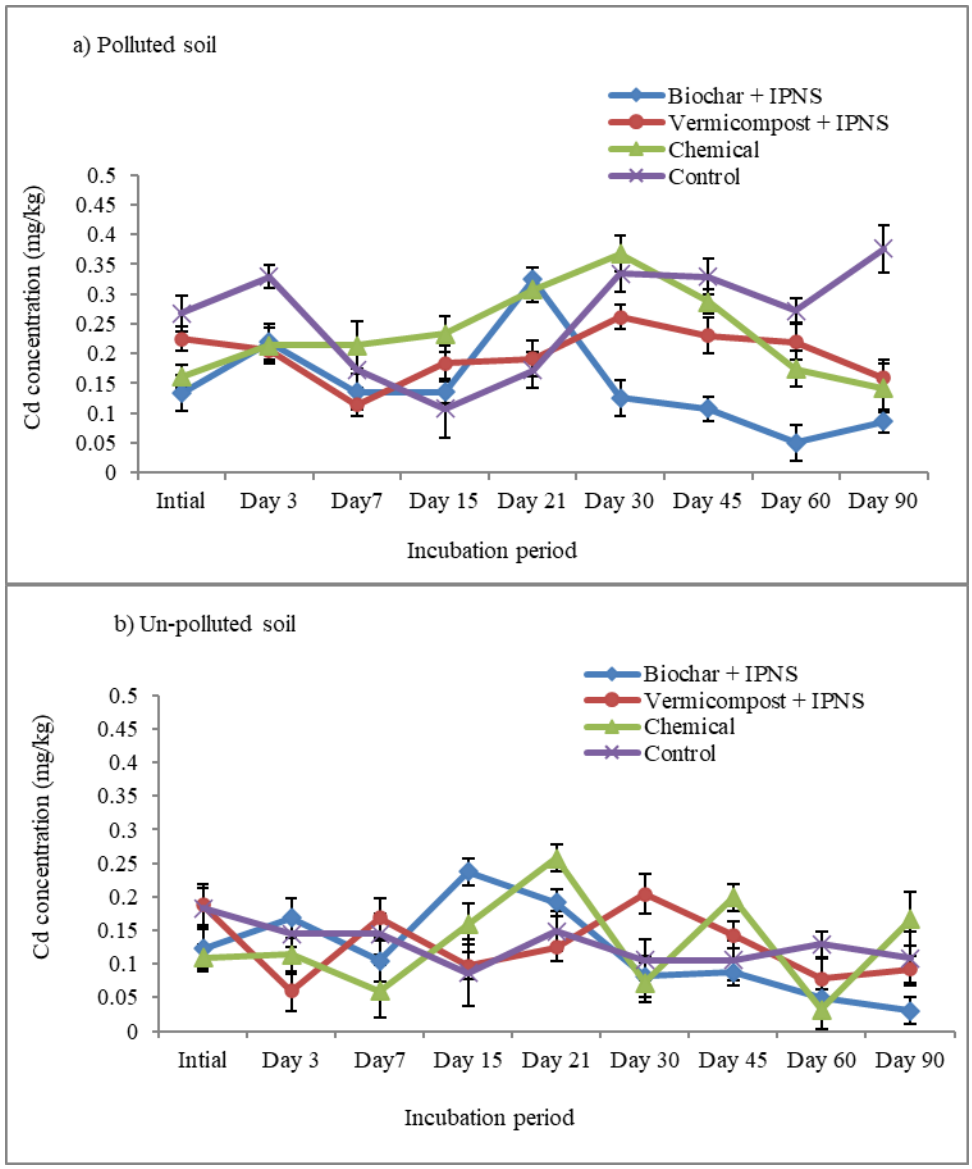
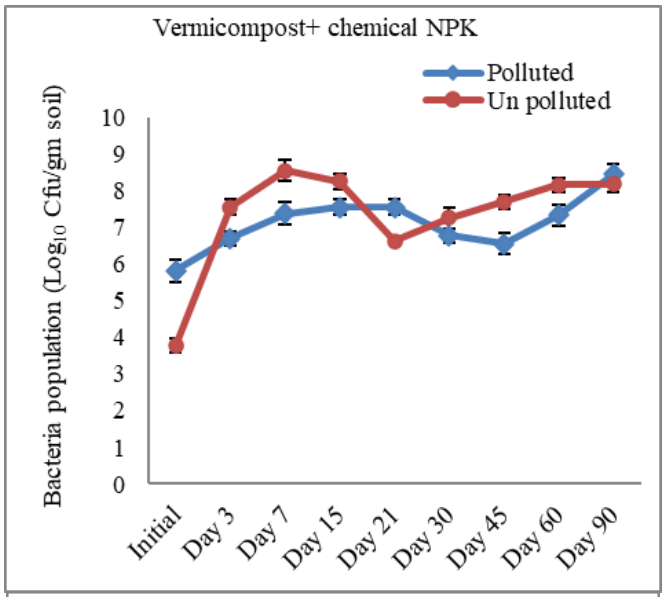


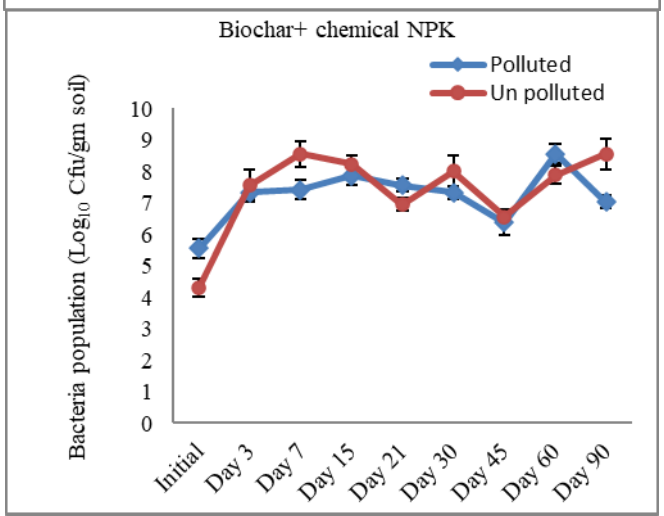
Fig. 60 (a & b) Effect of different organic amendments and chemical fertilizer on Cd mineralization in the polluted and un-polluted soils of Sripur, Gazipur.

Microbial population: Microbial population was slightly higher in the un-polluted soil. Application of biochar, vermicompost and chemical fertilizer affected bacterial growth in the polluted soil. Application of biochar and vermicompost with chemical fertilizer significantly increased microbial population in the un-polluted soil (Fig.61 a & b). The significantly highest population (8.55 Log Cfu/gm soil) appeared in vermicompost and biochar added soil at 7 day of incubation whereas highest population appeared in chemical fertilizer and control soil at 21 day of incubation (Fig. 61 c & d). Bacteria population gradually decreased with increased incubation time in all of the treatment.

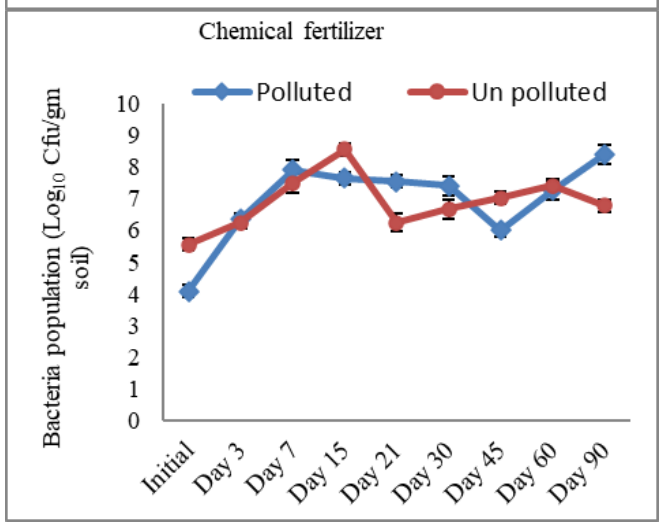
a


Vermicompost+ chemical NPK
Polluted
Un polluted
Bacteria population (Log10 Cfu/gm soil)
0
1
2
3
4
5
6
7
8
9
10
Initial
Day 3
Day 7
Day 15
Day 21
Day 30
Day 45
Day 60
Day 90

b


Biochar+ chemical NPK
Polluted
Un polluted
Bacteria population (Log10 Cfu/gm soil)
0
1
2
3
4
5
6
7
8
9
10
Initial
Day 3
Day 7
Day 15
Day 21
Day 30
Day 45
Day 60
Day 90

c


Chemical fertilizer
Polluted
Un polluted
Bacteria population (Log10 Cfu/gm soil)
0
1
2
3
4
5
6
7
8
9
10
Initial
Day 3
Day 7
Day 15
Day 21
Day 30
Day 45
Day 60
Day 90

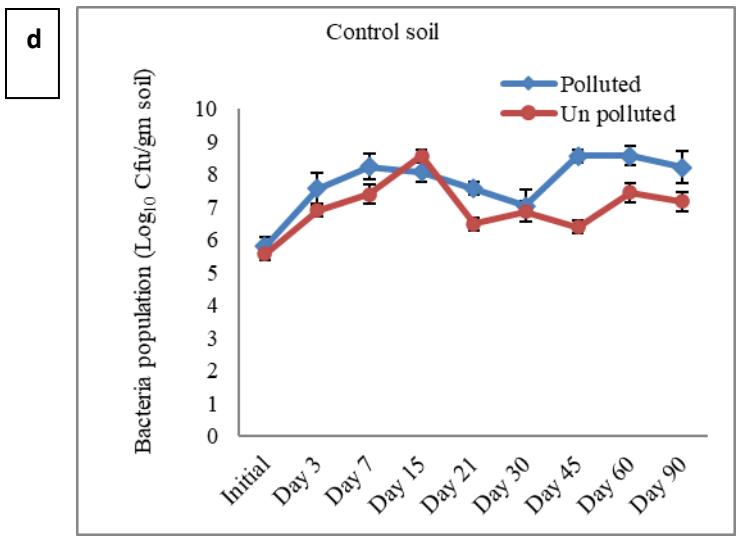


Fig. 61 (a, b, c & d) Effect of different organic amendments and chemical fertilizer on soil bacteria population in the polluted and un-polluted soils of Sripur Gazipur.

Conclusion

Biochar increased N mineralization in the polluted soil, while in unpolluted soil N mineralization increased due to vermicompost. C mineralization rate (*k*) was higher in unpolluted soil, however application of vermicompost increased C mineralization rate in polluted soil. Application of biochar reduced carbon mineralization in polluted soil. Vermicompost application increased P and K mineralization in both polluted and un-polluted soil and behaviour of P and K was almost similar for both soil. Biochar application slightly reduced Fe, Cd and Pd concentration however not below the toxic limit. Microbial population was higher in un-polluted soil. Application of treatments increased microbial activity in un-polluted soil compared to polluted soil.

Activity 3: Improvement of industrial polluted soil health with organic amendments for sustainable crop production

Summary

A number of total 12 experiments were conducted at Mirzapur, Pirojali and Sripur during 2018-20 with the objective to ameliorate heavy metal polluted soil and improve rice yield by organic amendment. Soils of Mirzapur and Pirujali were inundated during T. Aman season, so only one experiment was conducted at Sripur farmer's field in T.Aman 2019. Vermicompost, biochar, poultry manure, organic fertilizer and bacteria inoculum were applied as organic source along with chemical fertilizer as IPNS basis. Organic matter application rate was 2ton ha^{-1} except bacteria inoculum. The results of 11 experiments were incorporated in this report and one experiment could not harvest due to some unusual circumstances. In the field experiments, there was little or no significant positive effect found on grain yield of rice due to application of biochar, vermicompost, bacteria inoculum and chemical fertilizer in the soils of Sripur, and Pirujali. However, significant negative effect of vermicompost + chemical application found in Mirzapur site. The studied soils contained high organic matter and Fe^{+2}, and after 45 days of transplanting severe Fe toxicity appeared in rice plant. There was a positive relationship (r = 0.80) found between soil organic matter and Fe content of the study areas. The higher the organic matter of the soils, the more intensive accumulation of Fe^{2+} in flooded soil which might be the possible cause of Fe

toxicity. There were abundant nutrients due to application of organic amendments but their impact on grain yield was suppressed by Fe toxicity.

Picture: Fe toxicity developed after 35 day of transplanting

Chemical properties of the applied organic materials:

Organic products were locally made. Biochar was prepared from chitta dhan at BRRI glasshouse, Poultry manure and other organic fertilizer were collected from local bazar. The nutrient content was given in Table 34. According to the treatments nutrients were applied as IPNS basis with chemical fertilizer.

Table 34. Chemical composition of organic materials used in the study during 2018-2020

Parameters	Chitta dhan Biochar	Poultry manure	Organic fertilizer	Vermicompost	Bacteria inoculum (1 g /40 l)
pH	7.9	7.8	6.67	7.11	7.1
OC (%)	40	16	17.3	18.65	-
N (%)	0.98	2.5	3.07	1.92	2.8
P (%)	0.28	4.8	1.50	1.95	
K (ppm)	0.44	1.2	1.01	0.83	-
Ca (ppm)	3.1	905	201	347	-
Mg (ppm)	0.85	1400	1490	1580	-
Na (ppm)	0.22	0.4	-	-	-
Fe (ppm)	1.5	350	0.32	0.33	-
Cu (ppm)	-	4.05	0.01	0.01	-
Zn (ppm)	180	18.5	0.02	0.02	-
Mn	-	-	0.03	0.03	-

Nutrient content of the irrigation water channel:

In the month of May and December water samples were collected from the irrigation channels of three different locations. Study result showed that irrigation water contained high carbon (2.1 to 2.5 %) and considerable amount of P, K and Fe (Table 35) Water pH ranged from 7.5 to 7.9. High amount of Ca, Zn, Mn, Cu, Pb, Ni, Cd and Cr were also found in the irrigation water at both May and December. Among the heavy metals; Cr was in the borderline of FAO toxic permissible limit, however, Mn, Cu and Cd were above the permissible limit (Table 35). Crop production by using such irrigation water may increase human health rick and deteriorate soil health.

Picture: Pirujali and Mirzapur irrigation water source

Picture: Sripur irrigation water source

Table 35. Nutrient concentration of water of the nearest irrigation channel of sampling areas

Location	Season	pH	C	N	P	K	Na	Ca	Zn	Mn	Fe	Cu	Pb	Ni	Cd	Cr
			(%)		(mg/kg)											
Mirzapur	December	7.8	2.1	0.04	0.10	0.55	9.34	40	0.4	0.7	4	0.2	0.1	0.01	0.01	0.1
	May	7.9	2.2	0.05	0.10	0.56	10	39	0.8	0.4	4	0.8	0.4	0.05	0.02	0.1
Pirujali	December	7.5	2.2	0.04	0.11	0.66	2.95	75	0.5	0.6	3	0.0	0.2	0.02	0.01	0.1
	May	7.6	2.3	0.05	0.12	0.67	4	79	0.1	0.2	2	0.4	0.4	0.03	0.01	0.1
Sripur	December	7.6	2.4	0.05	0.14	0.77	2.95	144	0.2	0.2	2	0.5	0.2	0.04	0.01	0.1
	May	7.7	2.5	0.04	0.15	0.77	4	150	0.3	0.5	3	0.4	0.3	0.04	0.02	0.2
***FAO permissible limit (ppm)**		-	-	-	-	-	-	**-**	**2**	**0.2**	**5**	**0.2**	**5**	**0.2**	**0.01**	**0.1**

*Ayers R.S and D. W. Westcot.1985. Water quality for agriculture, FAO. Irrigation and drainage 29 (Rev.), FAO. Rome. pp:174

Field experiments conducted at Sripur and Gazipur in the Boro 2018-19:

A number of total 8 field experiments were conducted at three different locations of Mirzapur, Pirojali and Sripur in Boro 2018-19.

Location: Sripur

Season: Boro 2018-2019

Experimental details: There were four experiments were conducted in the Sripur. Soil chemical properties of the three experimental sites were given in Table 36- (site 1), Table 37 (site 2) and Table 38 (site 3). The top soil (0-15 cm) pH was ranged from 5.54 to 6.94. Soil organic matter ranged from 2 to 3% and soils having sufficient N, P and K content. However, Fe concentration was very high and it ranged from 96 ppm to 245 ppm. The concentration of Mn, Zn, Cu, Ni, and Cr were also in considerable limit. However according to FAO and WHO permissible limit for agricultural soil, the concentration Pb and Cd concentration were above toxic level. After harvest soil samples were collected from each treatment and no significant changes were recorded for nutrient concentration (Table 36, Table 37 and Table 38). Plant grown in these sites showed Fe toxicity form seedling stage and become more severe at maximum tillering stage, except experiment site 2. The experiment site 1 was nearby (5 m) to the contaminated irrigation channel and experiment site 3 was also nearby to the contaminated irrigation channel (10 m, but 500 m far from contamination source). Experiment site 2 was established 500 m far from irrigation channel and farmer used ground water to irrigate this plot. The treatments were as; **T_1-**Vermicompost 3 ton/ha + IPNS (N-P-K-S @40-0-48-10), **T_2-**Biocher 2 ton/ha + Chemical fertilizer (N-P-K-S @100-20-80-10), **T_3-**Mazim OF 3 ton/ha + (N-P-K-S @ 40-0-35-10), **T_4-** Chemical fertilizer (N-P-K-S @100-20-80-10) and **T_5-** No Fertilizer. Each plot size was 5 m x 6 m. BRRI dhan29 was grown as test crop. The design of the experiment was RCBD with three replications.
Another field experiment was conducted at nearby factory effluent (3m) and treatments were as **T_1=** Biochar 2 ton/ha + 80 kg/ha K, **T_2=** 100 kg/ha k, **T_3=** Biochar 2 ton/ha, **T_4=** Chemical fertilizer (N-P-K-S @100-20-80-10), **T_5=** No Fertilizer. There was no soil plow pan of that field and soil sample was not analysed.

Grain yield of Boro 2018-19:

The soils of the experimental sites of Sripur contained high organic matter. However, there was little or no effect found on grain yield of added organic matter (Table 39). In the study site 1(5 M distance from contaminated irrigation channel), grain yield was very low and it was 3.88 t/ha in chemical fertilized (T_4) applied plot which was statistically similar to vermicompost (T_1) and biochar (T_2) applied treatment. The lowest grain yield was recorded in the organic fertilizer (T_3) and control (T_4) treatment. In the study site 3, which had distance 10 m from contaminated irrigation channel, but 500 m far from contamination source also produce same grain yield (average 4.0 t/ha). At a glance there was no effect of added organic matter or biochar found in the experiment site 1 and 3. A slightly different scenario of yield was observed in the study site 2 which was not irrigated by the polluted water and 500 m far from contaminated irrigation channel. The average yield was 5 t/ha and there was also no significant treatment effect found in this study site. At the study site-4, lowest yield was found at chemical fertilizer applied treatment and it was similar to control treatment. There was significant effect found for biochar and K amendment (Table 40).

Experiment Location: Sripur (site 1)

Experiment Location: Sripur (site 2)

<

Experiment Location: Sripur (site 3)

Table 36. Initial soil properties of experimental field at Sripur site 1. Field nearby (5 m) to the polluted irrigation channel

Treatment	pH	OC (%)	N (%)	Avil.P (ppm)	*K	Na (ppm)	Ca (ppm)	Mg (ppm)	Fe (ppm)	Mn (ppm)	Zn (ppm)	Cu (ppm)	Pd (ppm)	Cd (ppm)	Cr (ppm)	Ni (ppm)
T_1	6.75	1.78	0.18	9.8	0.27	0.07	0.05	45	175	40.5	5.18	4.52	85.2	3.5	20	27.8
T_2	6.85	1.73	0.17	9.6	0.29	0.06	0.05	40	186	44.8	4.95	4.30	88.5	3.2	26	26.5
T_3	6.90	1.75	0.18	9.7	0.28	0.07	0.04	38	215	45.5	5.25	4.49	91.5	3.8	18	25.5
T_4	6.77	1.74	0.16	9.5	0.25	0.05	0.03	42	198	46.7	5.14	4.05	80.5	2.6	19	24.8
T_5	6.86	1.69	0.15	9.3	0.22	0.06	0.04	41	178	45.2	5.05	4.15	75.8	2.4	23	23.5
Initial	6.94	1.72	0.14	9.5	0.29	0.05	0.03	44	205	43.6	4.71	4.01	81.3	2.5	15	26.3
Permissible limit for crop production (WHO)									50000	500	150	100	50	0.08	100	35

Table 37. Initial soil properties of experimental field at Sripur, Site 2. Field nearby 10 m to the polluted irrigation channel but 500 m far from polluted source.

Treatment	pH	OC (%)	N (%)	Avil.P (ppm)	*K	Na (ppm)	Ca (ppm)	Mg (ppm)	Fe (ppm)	Mn (ppm)	Zn (ppm)	Cu (ppm)	Pd (ppm)	Cd (ppm)	Cr (ppm)	Ni (ppm)
T_1	5.7	1.75	0.17	7.4	0.26	0.06	0.08	45	210	33	3.50	3.85	82.4	5.2	25.4	42.5
T_2	5.6	1.70	0.16	7.5	0.28	0.07	0.07	48	234	35	3.25	3.28	80.5	5.0	23.3	40.5
T_3	5.8	1.78	0.18	7.2	0.26	0.07	0.08	41	225	40	3.85	4.15	79.8	4.2	21.4	36.4
T_4	5.9	1.65	0.16	7.3	0.24	0.04	0.05	46	201	48	3.50	3.80	75.5	4.8	19.5	35.5
T_5	5.7	1.62	0.15	6.8	0.21	0.04	0.05	39	218	45	3.18	3.05	70.5	4.5	17.5	30.6
Initial	5.6	1.68	0.10	6.2	0.26	0.05	0.06	40	245	48	3.15	2.84	68.8	3.5	14.5	31.3
Permissible limit for crop production (WHO)									50000	500	150	100	50	0.08	100	35

Table 38. Initial soil properties of experimental field at Sripur, site 3: Field 500 m far from irrigation channel and crop irrigated by underground water

Treatment	pH	OC (%)	N (%)	Avil.P (ppm)	*K	Na (ppm)	Ca (ppm)	Mg (ppm)	Fe (ppm)	Mn (ppm)	Zn (ppm)	Cu (ppm)	Pd (ppm)	Cd (ppm)	Cr (ppm)	Ni (ppm)
T_1	6.22	1.27	0.13	8.1	0.26	0.08	0.09	46	130	66	1.15	2.98	110	4.8	45.6	25.6
T_2	6.30	1.25	0.12	8.3	0.27	0.09	0.09	47	124	60	1.30	3.05	115	4.5	47.5	27.8
T_3	6.25	1.30	0.13	8.4	0.24	0.08	0.07	49	120	72	1.20	3.35	120	4.9	44.5	30.5
T_4	6.04	1.21	0.12	8.0	0.25	0.06	0.07	45	115	63	1.08	3.40	110	4.2	38.9	24.5
T_5	6.15	1.16	0.11	7.7	0.21	0.05	0.06	40	102	65	1.25	3.50	108	4.1	35.8	22.5
Initial	6.12	1.22	0.10	7.8	0.22	0.06	0.07	42	96	59	1.07	3.03	106	4.4	36.9	19.5
Permissible limit for crop production (WHO)									50000	500	150	100	50	0.08	100	35

***K (meq/100 g soil)**

Table 39. Effect of organic amendments and chemical fertilizer on the grain and straw yield of BRRI dhan29 at Sripur (site-1, site-2, site-3).

Treatments	Grain and Straw yield t/ha					
	Site -1		Site -2		Site -3	
	Grain	Straw	Grain	Straw	Grain	Straw
T_1 =Vermicompost 3 ton/ha + IPNS (N-P-K-S @40-0-48-10)	3.59a	4.21ab	5.02	4.72	4.40a	4.69a
T_2 =Biocher 2 ton/ha + Chemical fertilizer (N-P-K-S @100-20-80-10)	3.72a	4.25ab	5.18	5.31	3.62a	4.13bc
T_3 =Mazim OF 3 ton/ha + (N-P-K-S @ 40-0-35-10)	3.35b	4.03b	4.92	4.87	3.89a	4.21b
T_4 = Chemical fertilizer (N-P-K-S @100-20-80-10)	3.88a	4.60a	5.25	5.09	3.73a	3.96bc
T_5 = No Fertilizer	3.13 b	3.52c	4.86	4.48	3.22b	3.75c
CV	11.81	5.61	12.88	10.03	10.60	5.72

Table 40. Effect of chemical fertilizer and biochar application on grain and straw yield of Hira (Hybrid) at Sripur (site-4).

Treatments	Yield t/ha	
	Grain	Straw
T_1 =Biochar 2 ton/ha + 80 kg/ha K	5.37 ab	4.91
T_2 = 100 kg/ha k,	5.07 abc	5.09
T_3 =Biochar 2 ton/ha	5.69 a	4.91
T_4 = Chemical fertilizer (N-P-K-S @100-20-80-10)	4.67 c	4.59
T_5 = No Fertilizer	4.77 bc	5.01
CV	6.68	11.58

Nutrient uptake in grain and straw (Boro 2018-19)

In the experiment site 1, application of chemical fertilizer significantly reduced plant N uptake and increased Fe and Cd uptake (Table 41). However other macro nutrients (P, K, S) and heavy metal uptakes were varied among the treatments. In the study site 2, application of treatments significantly increased N uptake in the grain and straw compared to control (Table 42). Application of chemical fertilizer significantly increased Fe uptake. In this site, significantly high Cr uptake found in the vermicompost, organic fertilizer and in the control treatment. In the site 3, there was no significant effect of organic amendments found for macro nutrients uptake, however application of chemical fertilizer significantly increased Fe uptake (Table 43). Vermicompost application significantly increased Pb, Cd and Cr uptakes. However significant high amount of Cr uptake also observed in the control and organic fertilizer treatment. In general, application of chemical fertilizer increased Fe uptake in the Sripur compared to other treatments.

Table 41. Application of organic amendments and chemical fertilizer on grain and straw nutrient uptakes. Site 1: Nearby (5 m) to the polluted irrigation channel

	Total nutrient uptake										
Treatment	N (kg/ha)	P (kg/ha)	K (kg/ha)	S (kg/ha)	Zn (kg/ha)	Cu (kg/ha)	Mn (kg/ha)	Fe (kg/ha)	Pb (g/ha)	Cd (g/ha)	Cr (g/ha)
T_1	51a	25a	63abc	10.4a	0.23a	0.19bc	1.84d	1.98c	96ab	7.2b	7.9a
T_2	48a	23ab	70a	11.9a	0.21a	0.20ab	2.81ab	2.40b	101ab	6.6b	5.4b
T_3	48a	20bc	57bc	16.5a	0.16b	0.19b	2.47bc	1.86c	93b	6.7b	8.4a
T_4	63b	25a	64ab	12.2a	0.20ab	0.22a	3.04a	4.19a	110a	8.1a	5.6b
T_5	51a	19c	51c	9.1a	0.16b	0.17c	2.21cd	2.58b	88b	6.4b	7.6a
$LSD_{0.05}$	9	3	12	9.4	0.04	0.02	0.45	0.31	15	0.9	1.0
CV(%)	10	7	11	41.6	12.30	6.29	9.68	6.23	8	7.1	9.4

Table 42. Application of organic amendments and chemical fertilizer on grain and straw nutrient uptakes, site 2: field, Nearby 10 m to the polluted irrigation channel but 500 m far from polluted source

	Total nutrient uptake										
Treatment	N (kg/ha)	P (kg/ha)	K (kg/ha)	S (kg/ha)	Zn (kg/ha)	Cu (kg/ha)	Mn (kg/ha)	Fe (kg/ha)	Pb (g/ha)	Cd (g/ha)	Cr (g/ha)
T_1	71a	26a	165a	10.1ab	0.22a	0.21b	2.27c	2.16c	111a	8.3a	9.0a
T_2	66a	29a	163a	11.8a	0.26a	0.25a	3.71a	2.99b	128a	8.4a	6.8b
T_3	71a	25a	144a	10.0ab	0.21a	0.24ab	3.24ab	2.27c	120a	8.2a	10.2a
T_4	73a	26a	165a	10.4ab	0.21a	0.24ab	3.52ab	4.64a	125a	9.2a	6.4b
T_5	51b	27a	139a	9.6b	0.21a	0.21b	3.18a	3.34b	116a	8.3a	9.9a
$LSD_{0.05}$	11	4	67	2.0	0.05	0.04	0.52	0.71	17	1.9	1.7
CV(%)	9	9	23	10.2	12.94	8.77	8.61	12.19	8	12.0	10.6

Table 43. Application of organic amendments and chemical fertilizer on grain and straw nutrient uptakes, field 500 m far from irrigation channel and crop irrigated by underground water

	Total nutrient uptake										
Treatment	N (kg/ha)	P (kg/ha)	K (kg/ha)	S (kg/ha)	Zn (kg/ha)	Cu (kg/ha)	Mn (kg/ha)	Fe (kg/ha)	Pb (g/ha)	Cd (g/ha)	Cr (g/ha)
T_1	58a	22a	70ab	10.5a	0.23a	0.21a	2.45c	2.19c	112a	8.1a	8.8a
T_2	57a	18ab	52b	8.9b	0.16bc	0.20a	2.80ab	2.27c	98b	6.4b	5.2b
T_3	62a	21a	86a	10.7a	0.19b	0.21a	2.91a	1.95c	102ab	7.0b	8.8a
T_4	47a	20ab	67ab	9.1b	0.17bc	0.20ab	2.88a	3.60a	100b	7.1b	4.9b
T_5	45a	15b	55b	7.4c	0.13c	0.18b	2.49bc	2.71b	92b	6.8b	8.0a
$LSD_{0.05}$	24	5	27	0.9	0.04	0.02	0.33	0.35	11	0.7	0.9
CV(%)	24	15	22	5.1	11.02	5.35	6.43	7.28	6	5.1	6.5

Season T. Aman 2019:

Experimental details: In the T. Aman season, an experiment was conducted at Sripur (500m) far from polluted channel to find the effect of biochar and organic inoculant on plant growth and crop yield. Treatments were as T_1- control, T_2 -Inoculum + Chemical Fertilizer (kg/ha) @ NPKS: 80-15-50-10, T_3-Chemical fertilizer, T_4- Biochar + Chemical Fertilizer (kg/ha) @ NPKS: 80-15-50-10. Mixed plant growth promoting bacterial (PGPB) inoculum was applied (g/40L) in each treatment at maximum tillering stage.

Grain and straw yield of BRRI dhan 49 at T. Aman 2019

Study result showed that soil amendments increased grain yield although it was not statistical significant (Table 44). Bacteria inoculum gave slightly higher yield as these bacteria produces siderophore and effective for mitigation of Fe toxicity.

Table 44. Yield and yield attributes of BRRI dhan 49 in T. Aman 2019 at Sripur

Treatment	Tiller/m^2	Panicle/m^2	Grain yield (t/ha)	Straw yield (t/ha)
Control	275	260	3.84	4.52
Inoculum + Chemical Fertilizer	315	297	4.38	5.11
Chemical Fertilizer	280	261	4.19	5.07
Biocher + Chemical Fertilizer	295	286	4.23	4.88
CV	8	8	11.65	6.81
LSD0.05	49	43	0.97	0.66

Season: Boro 2019-2020

Experiment details: In the Boro 2019-2020 one experiment was conducted in the Sripur at the near (50 m) polluted irrigation channel. Treatments were as T_1 –Inoculum + full chemical fertilizer (kg/ha) @ N-P-K-S: 100-20-80-10, T_2- Biochar + full chemical fertilizer (kg/ha) @

N-P-K-S: 100-20-80-10, T_3 - Vermicompost + IPNS based chemical fertilizer (N-P-K-S @40-0-48-10), T_4-Full chemical fertilizer, T_5 – Control.

Grain and straw yield

In the Sripur, insignificant effect was found due to application of soil amendments over chemical fertilizer treatment for the number of tiller, panicle, grain and straw yield of BRRI dhan89. However, a little higher grain yield (4.67 t ha^{-1}) was recorded when PGPB inoculum was applied with chemical fertilizer compared to other treatment. The lowest grain yield was found in the control treatment (Table 45).

Table 45. Effect of different organic amendments and chemical fertilizer on plant growth and yield of BRRI dhan89 in the industrial polluted soil of Sripur.

Treatment	Tiller no/m^2	Panicle no/m^2	Grain yield (t ha^{-1})	Straw yield (t ha-^{1})
Inoculum + Full CF	277a	263a	4.67a	5.17a
Biochar + Full CF	283a	264a	4.33a	4.95a
Vermicompost + IPNS based CF	236a	222a	4.47a	5.02a
Full Chemical Fertilizer	269a	258a	4.34a	4.71a
Control	230a	218a	3.25b	3.90b
CV (%)	15	15	8.94	8.32

Different letters used within the column denote significant differences ($p<0.05$) between the treatments according to ANOVA and LSD Test.

Grain and straw nutrient uptake:

Application of chemical fertilizer alone and Vermicompost (IPNS) gave statistically similar N uptake followed by chemical fertilizer along with biochar application (Table 18). The lowest N uptake was recorded in the control treatment. Among the heavy metals the lowest Pb uptake was found in the biochar (T_2) applied treatment followed by Inoculum treatment (T_1). Conversely, the highest Cd uptake was found in the Biochar (T_2) and lowest in the chemical fertilizer applied treatment (T_4).

Table 46 Effect of different organic amendments and chemical fertilizer on nutrient uptake of BRRI dhan89 in the industrial polluted soil of Sripur during Boro 2019-2020

	Total Nutrient Uptake											
Treat.	N (kg/ha)	P (kg/ha)	K (kg/ha)	S (kg/ha)	Zn (kg/ha)	Cu (kg/ha)	Mn (kg/ha)	Fe (kg/ha)	Pb (g/ha)	Cd (g/ha)	Cr (g/ha)	Ni (g/ha)
T1	59b	18a	75b	11.4ab	0.57a	0.16a	5.03a	4.22a	37bc	1.2cd	39.2a	2.2ab
T2	62ab	17ab	90a	10.6b	0.48ab	0.15a	5.41a	3.26b	37c	2.5a	26.4bc	2.3a
T3	69a	20a	72b	12.6a	0.51ab	0.16a	4.75a	2.68b	50ab	1.6bc	35.4ab	2.3a
T4	69a	18ab	58c	10.7ab	0.57a	0.15a	4.73a	2.72b	56a	1.0d	22.0c	2.0ab
T5	42c	13b	63bc	7.7c	0.38b	0.11b	3.25b	2.91b	59a	1.9b	9.4d	1.8b
LSD0.05	8	5	12	1.9	0.14	0.04	0.77	0.89	13	0.5	11.3	0.5
CV (%)	7	15	9	9.6	14.30	13.04	8.86	14.91	15	15.6	22.8	13.0

Location: Mirzapur

Season: Boro 2018-19

Experimental details: There were two field experiments in the Mirzapur union. Soil chemical properties of experimental sites were given in Table 47 (site1) and Table 48 (site 2). The top soil (0-15 cm) pH was 4.38 and 4.42, respectively, which showed soil was acidic in nature. Soil organic matter ranged from 4.01 to 4.8% and soils having sufficient N, P and K content. However, Fe concentration was very high in site 1 (522 ppm) and in site 2, it was 87 ppm. Plant grown in the site 1 showed Fe toxicity form seedling stage and become more severe at maximum tillering stage. According to the WHO toxicity level for agricultural soil, the soils of the both sites were toxic with Pb and Cd. The experiment no. 1 was established 200 m far from contaminated irrigation channel and experiment no 2 was 400 m far from contaminated irrigation channel. The treatments were as; **T_1**-Vermicompost 3 ton/ha + IPNS (N-P-K-S @40-0-48-10), **T_2**-Biochar 2 ton/ha + Chemical fertilizer (N-P-K-S @100-20-80-10), **T_4**-Mazim OF 3 ton/ha + (N-P-K-S @40-0-35-10), **T_4**- Chemical fertilizer (N-P-K-S @100-20-80-10) and **T_5**- No Fertilizer. Each plot size was 5m x 6m. BRRI dhan29 was grown as test crop. The design of the experiment was RCBD with three replications.

Table 47. Initial soil properties of experimental field at Mirzapur. Site 1: about 200 m far from polluted irrigation channel

Treatment	pH	OC (%)	N (%)	Avil.P (ppm)	*K	Na	Ca	Mg	Fe	Mn	Zn	Cu	Pd	Cd	Cr	Ni
T_1	4.48	2.28	0.20	10.2	0.13	0.03	0.04	45	330	21	8.50	4.15	175	4.5	35.0	17.5
T_2	4.51	2.26	0.18	9.5	0.14	0.03	0.04	40	325	35	8.24	3.52	184	4.6	36.5	20.5
T_3	4.45	2.28	0.19	10.2	0.12	0.03	0.03	51	285	29	8.05	3.85	189	4.7	37.8	21.8
T_4	4.42	2.25	0.17	9.4	0.11	0.02	0.02	42	305	27	7.90	3.15	185	4.4	31.2	14.8
T_5	4.40	2.24	0.16	9.1	0.10	0.02	0.02	47	320	25	8.05	4.02	146	4.1	35.5	17.5
Initial	4.38	2.29	0.19	9.2	0.11	0.03	0.02	40	300	19	8.29	3.32	168	4.4	34.4	15.5
Nutrient permissible limit for crop production (WHO)									50000	500	150	100	50	0.08	100	35

Table 48. Initial soil properties of experimental field at Mirzapur. Site 2: about 400 m far from polluted irrigation channel

Treatment	pH	OC (%)	N (%)	Avil.P (ppm)	*K	Na	Ca	Mg	Fe	Mn	Zn	Cu	Pd	Cd	Cr	Ni
T_1	4.46	2.60	0.26	8.7	0.18	0.05	0.04	48	530	32	7.50	4.01	150	6.5	14.5	16.5
T_2	4.27	2.58	0.25	8.2	0.19	0.06	0.04	47	520	29	7.25	3.90	156	7.2	15.2	15.2
T_3	4.26	2.62	0.26	8.9	0.17	0.05	0.04	50	495	25	8.05	3.85	162	6.2	14.8	14.8
T_4	4.40	2.42	0.24	7.6	0.15	0.04	0.03	45	480	28	7.65	3.52	140	5.8	12.9	14.2
T_5	4.35	2.35	0.23	7.4	0.15	0.03	0.03	44	510	31	7.20	3.35	137	5.5	13.5	13.9
Initial	4.42	2.55	0.25	7.9	0.14	0.03	0.03	43	545	22	8.29	4.05	144	5.2	13.1	14.5
Nutrient permissible limit for crop production (WHO)									50000	500	150	100	50	0.08	100	35

***K (meq/100 g soil)**

Grain and straw yield of Boro 2018-19:

The soils of the experimental sites of Mirzapur contained high organic matter. There was little or no effect of organic matter found on grain yield (Table 49). In the both study sites average yield was 6 t/ha. There no statistical yield difference found between control and applied treatments.

Table 49. Effect of organic amendments and chemical fertilizer on grain and straw yield of BRRIdhan29 at Mirzapur during Boro 2018-2019.

Treatments	Grain and straw (yield t/ha)			
	Site-1		Site -2	
	Grain	Straw	Grain	Straw
T_1=Vermicompost 3 ton/ha + IPNS (N-P-K-S @40-0-48-10)	6.25	7.01	6.13	6.82
T_2=Biocher 2t/ha +Chemical fertilizer (N-P-K-S @100-20-80-10)	6.40	7.01	6.28	6.68
T_3=Mazim OF 3 ton/ha + (N-P-K-S @40-0-35-10)	6.32	7	6.02	6.48
T_4= Chemical fertilizer (N-P-K-S @100-20-80-10)	6.29	7.2	5.66	6.25
T_5= No Fertilizer	6.31	6.08	6.32	6.15
CV	9.45	8.56	9.6	5.66

Nutrient uptake in the grain and straw:

Although there was no significant grain yield observed within the treatments, however nutrient uptake differed within the treatment. In the site 1, there was no statistical difference found for N uptake within the applied treatments except control (T_5) (Table 50), and the lowest N uptake was found in the control treatment. In the site 2, the highest N uptake was recorded in the vermicompost applied treatment (T_1) (Table 51). In the both sites Fe uptake increased with organic amendments. However, Pb uptake decreased due to vermicompost application. In the site 1, the highest Cd uptake observed in the control treatment and in the site 2, the highest Cd uptake recorded in the biochar treatment (T_2).

Table 50. Effect of organic amendments and chemical fertilizer on nutrient uptake of BRRI dhan29 in Mirzapur, Boro 2018-19. Site 1: 200 m far from polluted irrigation channel

	Total nutrient uptake										
Treatment	N (kg/ha)	P (kg/ha)	K (kg/ha)	S (kg/ha)	Zn (kg/ha)	Cu (kg/ha)	Mn (kg/ha)	Fe (kg/ha)	Pb (g/ha)	Cd (g/ha)	Cr (g/ha)
T_1	77ab	33a	155a	12.3b	0.41a	0.30ab	5.18a	9.12a	41d	4.79ab	26.74a
T_2	84a	32a	152ab	13.9ab	0.34bc	0.30ab	4.73ab	8.85a	56bc	5.06ab	25.50ab
T_3	79a	35a	157a	16.1a	0.35b	0.31ab	4.11b	9.80a	53c	4.20b	21.05bc
T_4	81a	35a	164a	15.6a	0.29cd	0.35a	5.02a	7.51b	64b	5.30a	23.86abc
T_5	71b	28a	117b	13.4ab	0.25d	0.26b	4.78ab	6.88b	75a	4.38ab	19.88c
$LSD_{0.05}$	7	7	38	3.0	0.05	0.07	0.80	1.18	11	1.10	4.51
CV(%)	5	11	14	11.0	8.63	12.53	8.90	7.44	10	12.30	10.24

Table 51. Effect of organic amendments and chemical fertilizer on nutrient uptake of BRRI dhan29 in Mirzapur, Boro 2018-19. Site 2: 400 m far from polluted irrigation channel

	Total nutrient uptake										
Treatment	N (kg/ha)	P (kg/ha)	K (kg/ha)	S (kg/ha)	Zn (kg/ha)	Cu (kg/ha)	Mn (kg/ha)	Fe (kg/ha)	Pb (g/ha)	Cd (g/ha)	Cr (g/ha)
T_1	97 a	40a	181b	13.1a	0.40a	0.29a	5.05a	8.97a	113c	4.7ab	26.1a
T_2	104a	37a	167c	14.0a	0.39ab	0.29a	4.42ab	8.46a	131bc	4.9a	24.4a
T_3	75b	36a	174bc	15.2a	0.39ab	0.27a	3.75b	9.26a	132bc	3.9b	19.5b
T_4	64b	36a	193a	14.3a	0.38ab	0.30a	4.37ab	6.66b	143ab	4.7ab	20.7b
T_5	68b	34a	139d	21.7a	0.29b	0.26a	4.76a	7.02b	156a	4.4ab	20.1b
$LSD_{0.05}$	17	6	10	10.2	0.11	0.06	0.73	0.92	19	0.9	3.6
CV(%)	11	9	3	34.6	15.65	10.73	8.66	6.04	8	10.6	8.7

Experiment location: Mirzapur (site1)

Experiment location: Mirzapur (site2)

Season: Boro 2019-20

Grain and straw yield:

At Mirzapur, BRRI dhan74 was cultivated. The significant highest amount of grain yield (5.45 t ha^{-1}), tillier number m^2 (305) panicle number m^2 (291) was obtained in the inoculum + full dose of chemical fertilizer treatment though it was statistical similar to the biochar + full dose of chemical fertilizer (5.41 t ha^{-1}) and only full dose of chemical fertilizer (5.27 t ha^{-1}) treatment. The negative impact of vermicompost + chemical fertilizer application was found on grain yield (4.81 t ha^{-1}). The lowest grain yield was recorded in the control treatment (Table 52).

Table 52. Effect of different organic amendments and chemical fertilizer on plant growth and yield of BRRI dhan74 in the polluted area of Purbo Duguri, Mirzapur.

Treatment	Tiller no/m^2	Panicle no/m^2	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})
Inoculum + Full CF	305a	291a	5.45a	5.70a
Biochar + Full CF	289ab	278a	5.41a	5.22bc
Vermicompost + IPNS based CF	289ab	279a	4.81b	4.99c
Full Chemical Fertilizer	290ab	278a	5.27a	5.48ab
Control	246b	235a	3.31c	3.61d
CV (%)	10	11	4.08	4.92
LSD0.05	56	58	0.37	0.46

Different letters used within the column denote significant differences ($p<0.05$) between the treatments according to ANOVA and LSD Test.

Nutrient uptake in the grain and straw

Application of treatments increased N uptake in the grain and straw and the lowest N uptake was found in the control treatment (Table 53). Inoculum uptake increased P uptake along with chemical fertilizer application. Uptake of Fe, Pd and Cd increased due to chemical fertilizer application. However, the lowest Cd and Ni uptake found in the control treatment.

Table 53. Effect of organic amendments and chemical fertilizer application on nutrient uptakes in the grain and straw of BRRI dhan74 at Mirzapur during Boro 2019-20

	Total Nutrient Uptake											
Treat.	N (kg/ha)	P (kg/ha)	K (kg/ha)	S (kg/ha)	Zn (kg/ha)	Cu (kg/ha)	Mn (kg/ha)	Fe (kg/ha)	Pb (g/ha)	Cd (g/ha)	Cr (g/ha)	Ni (g/ha)
T1	78ab	35a	180a	11.2a	0.74ab	0.11a	3.98a	2.74b	134ab	10.2a	27.6a	4.5a
T2	77ab	23b	147b	11.4a	0.57c	0.09b	4.16a	2.21bc	129ab	9.0b	30.7a	3.8b
T3	70b	17b	156b	12.0a	0.66b	0.09b	4.19a	2.14c	123ab	9.4ab	21.2b	3.8b
T4	86a	25b	198a	12.5a	0.81a	0.11a	4.52a	4.54a	138a	10.2a	17.9b	4.8a
T5	45c	22b	100c	12.5a	0.44d	0.07c	2.75b	2.18bc	115b	6.7c	19.3b	2.6c
LSD (0.05)	13	8	21	6.2	0.09	0.02	0.96	0.58	20	1.1	5.1	0.4
CV(%)	10	17	7	27.9	7.21	8.41	13.05	11.24	8	6.5	11.7	5.5

Location: Pirojali

Season: Boro 2018-19

Experimental details: There were two experiments conducted at the Pirojali union. Soil chemical properties of experimental sites were given in Table 54 and Table 55. The top soil (0-15 cm) pH was 4.18 and 4.25 for the sites which showed soil was acidic in nature. Soil organic matter was high and it was 3.57 % at study site 1, and 3.88% in study site 2. Both of the soils had sufficient N, P and K content. However, Fe concentration was very high and plant grown in these sites showed Fe toxicity form seedling stage and become more severe at maximum tillering stage. The concentration of Pd and Cd were above the toxic level according to the WHO nutrient permissible level. The experiment no. 1 was nearby (5 m) to the polluted irrigation channel and experiment no. 2 was far from the polluted irrigation channel (10 m, but 500 m far from polluted source). The treatments were as; **T_1-** Vermicompost 3 ton/ha + IPNS (N-P-K-S @40-0-48-10), **T_2-**Biochar 2 ton/ha + Chemical fertilizer (N-P-K-S @100-20-80-10), **T_3-**Mazim OF 3 ton/ha + (N-P-K-S @40-0-35-10), **T_4-** Chemical fertilizer (N-P-K-S @100-20-80-10) and **T_5-** No Fertilizer. Each plot size was 5m x 6m. BRRI dhan29 was grown as test crop. The design of the experiment was RCBD with three replications.

Table 54. Initial soil properties of experimental field at Pirojali, Site 1: field experiment located 5 m nearby from the polluted irrigation channel

Treatment	pH	OC (%)	N (%)	Avil.P (ppm)	*K	Na	Ca	Mg	Fe	Mn	Zn	Cu	Pd	Cd	Cr	Ni
T_1	4.27	2.03	0.19	11.5	0.21	0.04	0.04	51	605	40	4.85	6.50	150	4.8	7.5	10.5
T_2	4.18	2.02	0.18	10.8	0.24	0.05	0.04	58	582	30	5.06	6.15	165	3.9	7.2	10.2
T_3	4.24	2.04	0.19	11.3	0.22	0.04	0.05	55	570	28	4.75	5.85	170	3.7	7.5	9.8
T_4	4.17	2.00	0.17	10.3	0.19	0.03	0.03	52	590	42	4.21	5.62	120	3.0	6.5	10.5
T_5	4.13	1.99	0.17	9.8	0.18	0.03	0.02	46	620	38	4.05	5.85	115	3.5	6.8	9.2
Initial	4.18	2.01	0.19	10.3	0.21	0.03	0.03	44	610	36	4.11	5.33	132	3.2	6.9	9.4
Nutrient permissible limit for crop production (WHO)									50000	500	150	100	50	0.08	100	35

Table 55. Initial soil properties of the experimental field at Pirojali, Site 2: field experiment located 10 m far from the polluted irrigation channel but 500 m far from polluted source.

Treatment	pH	OC (%)	N (%)	Avil.P (ppm)	*K	Na	Ca	Mg	Fe	Mn	Zn	Cu	Pd	Cd	Cr	Ni
T_1	4.15	2.21	0.22	12.5	0.24	0.05	0.04	65	575	45	30.25	3.95	205	4.5	11.5	14.5
T_2	4.40	2.19	0.19	11.8	0.25	0.04	0.05	60	610	48	31.30	4.80	180	4.3	12.3	13.4
T_3	4.13	2.23	0.22	12.6	0.22	0.05	0.05	55	590	42	29.45	4.25	175	4.2	11.8	11.5
T_4	4.17	2.15	0.19	11.5	0.21	0.03	0.03	48	670	38	24.50	5.15	156	3.6	10.9	13.8
T_5	4.14	2.09	0.18	11.2	0.19	0.04	0.02	50	610	34	27.26	4.50	160	3.8	10.8	13.1
Initial	4.25	2.18	0.20	12.2	0.22	0.04	0.03	44	565	36	28.11	3.23	149	3.9	10.5	12.1
Nutrient permissible limit for crop production (WHO)									50000	500	150	100	50	0.08	100	35

***K (meq/100 g soil)**

Grain yield of Boro 2018-19:

Pirujali: The soils of the experimental sites of Pirojali contained high organic matter. There was little or no effect of organic matter found on grain yield (Table 56). The highest yield (7.68 t/ha) was found in Mazim OF 3 ton/ha + (N-P-K-S @40-0-35-10) which was statistically similar to fertilizer control and other applied treatment. The lowest grain yield was recorded in vermicompost applied treatment (4.89 t/ha). In the study site 2, the highest yield obtained in the chemical fertilizer applied treatment (6.64 t/ha) and the lowest in the fertilizer control (4.71t/ha) treatment.

Table 56. Effect of organic sources and chemical fertilizer on grain and straw yield of BRRI dhan29 at Pirojali during Boro 2018-2019

Treatments	Grain and Straw yield (t/ha)			
	Site -1		Site -2	
	Grain	Straw	Grain	Straw
T_1=Vermicompost 3 ton/ha + IPNS (N-P-K-S @40-0-48-10)	4.89 c	4.73 b	5.42 bc	5.03 ab
T_2=Biocher 2 ton/ha + Chemical fertilizer (N-P-K-S @100-20-80-10)	7.30 a	6.72 a	5.16 bc	5.43 a
T_3=Mazim OF 3 ton/ha + (N-P-K-S @40-0-35-10)	7.68 a	6.87 a	5.95 ab	4.76 ab
T_4= Chemical fertilizer (N-P-K-S @100-20-80-10)	6.36 b	6.23 a	6.65 a	5.76 a
T_5= No Fertilizer	7.09 ab	6.17 a	4.70 c	4.12 b
CV	7.32	6.49	11.04	11.03

Experiment location: Pirujali (site1)

Experiment location: Pirujali (site 2)

Grain and Straw nutrient uptak

In the site 1, there was no significant difference of N uptake found in the site 1 except vermicompost treatment (Table 57). Application of vermicompost significantly reduced N, P, K, S, Fe, Cu, Mn, Pb, and Cd uptake. Significant lowest amount of Cr uptake recorded in the control treatment. Application of chemical fertilizer also reduced P uptake. In the site 2, application of chemical fertilizer increased N and P uptake followed by organic fertilizer and biochar treatment. Biochar and vermicompost application significantly reduced Pb uptake. The lowest amount of Cd uptake found in the organic fertilizer and chemical fertilizer treatment. However, the lowest amount of Cr uptake found in the control treatment (Table30).

Table 57. Nutrient uptake due to application of different organic sources and chemical fertilizer in BRRI dhan29 at Pirujali (Site 1) during Boro 2018-2019

	Total nutrient uptake										
Treatment	N (kg/ha)	P (kg/ha)	K (kg/ha)	S (kg/ha)	Zn (kg/ha)	Cu (kg/ha)	Mn (kg/ha)	Fe (kg/ha)	Pb (g/ha)	Cd (g/ha)	Cr (g/ha)
T_1	69b	29b	148b	12.3c	0.21b	0.19b	2.01d	2.92c	61d	10.0c	14.3c
T_2	104a	40a	218a	18.8a	0.32a	0.38a	3.54a	3.56ab	100c	13.4a	20.1a
T_3	106a	43a	209a	19.4a	0.33a	0.39a	3.17ab	3.74a	140a	10.4c	17.4b
T_4	88a	33b	194a	16.1b	0.33a	0.37a	2.58c	3.13bc	129b	12.1ab	15.2bc
T_5	102a	40a	201a	16.6b	0.35a	0.36a	2.87bc	3.08bc	137ab	11.2bc	8.7d
$LSD_{0.05}$	19	4	34	1.2	0.05	0.07	0.46	0.56	10	1.6	2.5
CV(%)	10.66	6.13	9.17	3.8	8.93	11.41	8.54	9.10	5	7.5	8.9

Table 58. Nutrient uptake due to application of different organic sources and chemical fertilizer in BRRI dhan29 at Pirujali (Site 2) during Boro 2018-2019

	Total nutrient uptake										
Treatment	N (kg/ha)	P (kg/ha)	K (kg/ha)	S (kg/ha)	Zn (kg/ha)	Cu (kg/ha)	Mn (kg/ha)	Fe (kg/ha)	Pb (g/ha)	Cd (g/ha)	Cr (g/ha)
T_1	82b	35ab	166abc	13.3a	0.21bc	0.21b	2.50ab	3.12a	67c	10.7a	15.2a
T_2	78ab	34ab	204a	14.0a	0.24ab	0.22b	3.09a	2.90a	74c	10.6a	16.1a
T_3	86ab	30ab	144bc	13.0a	0.19c	0.21ac	2.45ab	2.61ab	102b	7.4b	12.2b
T_4	99a	37a	189ab	14.8a	0.27a	0.27b	2.79ab	2.88a	126a	11.4a	14.2ab
T_5	70b	27b	129c	9.8b	0.18c	0.17c	2.06b	1.97b	91b	7.5b	5.7c
$LSD_{0.05}$	16	9	53	2.3	0.04	0.04	0.76	0.64	15	2.3	2.9
CV(%)	10	14	17	9.4	10.78	10.72	15.58	12.64	9	13.0	12.1

Season: Boro 2019-2020

Application of organic matter and PGPB along with chemical fertilizer have insignificant effect over chemical fertilizer for tiller, panicle, grain and straw yield of BRRI dhan28 at Pirujali, Mirzapur (Table 59). Application of full dose of chemical fertilizer yielded 7.21 t ha^{-1} grain though it was statistical similar with PGPB inoculum, biochar and vermicompost applied treatment. The lowest grain yield was recorded in the control treatment.

Table 59. Effect of different organic amendments and chemical fertilizer on plant growth and yield of BRRI dhan28 in the polluted soil of Pirujali, Mirzapur.

Treatment	Tiller no/m^2	Panicle no/m^2	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})
Inoculum + Full CF	389a	379a	6.99a	7.08ab
Biochar + Full CF	380ab	368ab	7.11a	6.50b
Vermicompost + IPNS based CF	391a	379a	7.10a	6.80b
Full Chemical Fertilizer	364ab	352ab	7.21a	7.49a
Control	334b	325b	3.71b	3.81c
CV (%)	7	7	3.97	4.94
LSD0.05	46	45	0.48	0.59

Different letters used within the column denote significant differences ($p<0.05$) between the treatments according to ANOVA and LSD Test.

Nutrient uptake Pirozali in Boro 2019-20

There was no effect of organic sources and chemical fertilizer on N, P S and K uptake. The lowest N, P, S and K uptake recorded in the control treatment. Application of treatment significantly increased Fe uptake over control. Chemical fertilizer increased Pb uptake, however application of biochar and inoculum significantly reduced Pb uptake. The lowest Cr and Ni uptake found in the control treatment (Table 60).

Table 60. Nutrient uptake due to application of different organic sources and chemical fertilizer in BRRI dhan28 at Pirujali during Boro 2019-2020

	Total Nutrient Uptake											
Treatment	N (kg/ha)	P (kg/ha)	K (kg/ha)	S (kg/ha)	Zn (kg/ha)	Cu (kg/ha)	Mn (kg/ha)	Fe (kg/ha)	Pb (g/ha)	Cd (g/ha)	Cr (g/ha)	Ni (g/ha)
T_1	96a	34a	258a	18.0a	1.46a	0.29a	4.72a	3.15a	119c	14.5a	28.1b	6.5a
T_2	102a	30a	223b	17.8a	1.36a	0.29a	4.36ab	3.22a	125c	13.2a	15.5c	4.3b
T_3	105a	34a	228ab	17.4a	1.25b	0.20b	3.64c	3.23a	143b	13.1a	26.1b	4.6b
T_4	109a	30a	215b	17.9a	1.46a	0.18b	4.11b	3.23a	157a	14.4a	34.1a	4.8b
T_5	51b	17b	127c	8.5b	0.60c	0.09c	1.88d	1.71b	83d	6.5b	18.4c	2.0c
LSD0.05	20	7	32	1.9	0.10	0.04	0.44	0.62	12	1.8	5.1	1.1
CV(%)	11	13	8	6.3	4.53	8.88	6.25	11.25	5	7.8	11.0	13.0

Pictures: Field trials in Sripur Gazipur during Boro 2019-2020

Effect of organic amendment on soil biochemical properties and grain yield:

There was no significant effect found on grain yield of rice due to application of biochar, vermicompost, poultry manure, organic fertilizer and PGPB inoculum over chemical fertilizer in the soils of Sripur, and Pirujali. However, significant negative effect of vermicompost found in Mirzapur site. The result of incubation study proved that biochar application along with chemical fertilizer increased NH_4-N, and vermicompost application increased available P, exch. K and microbial population in the polluted soil. Inherent organic carbon content was high in the control soil, and C mineralization rate became high due to vermicompost application in both contaminated and uncontaminated soil. Although the application of vermicompost along with chemical fertilizer gave higher nutrient mineralization but there was no significant effect found on crop growth and grain yield. This was due to high organic matter and Fe^{+2} content of that soil. The soil test report showed the soils contained very high (> 300 ppm) Fe^{+2} and after 45 days of transplanting severe Fe toxicity appeared in rice plant. The higher the organic matter of the soils, the more amorphous and crystalline Fe^{3+} compounds were used as electron acceptors and the more intensive is the accumulation of Fe^{2+} in flooded soil which might be the possible cause of Fe toxicity in such soil. There was a positive significant relationship (r = 0.80) found between soil organic matter and Fe content of the study areas (Fig. 62). The toxic effect of Fe^{+2} may hinder nutrient uptake and affected grain yield in such soil.

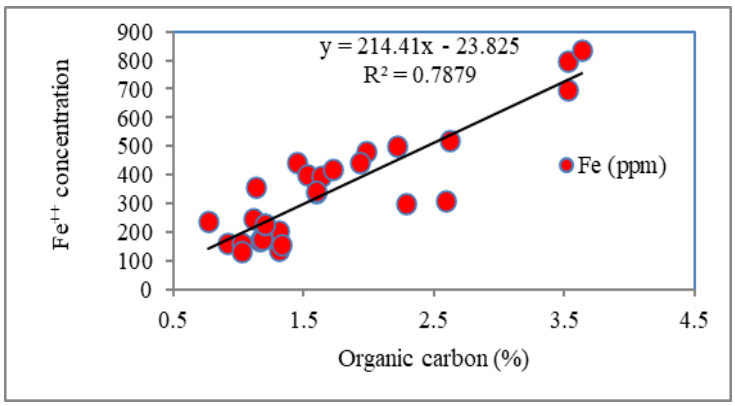


Fig. 62. Relationship between soil organic matter and soil Fe^{++} content at Sripur soil

Study result also proved that application of chemical fertilizer increased Fe^{++} uptake in the Sripur area. Besides Fe the soil contained high amount of Pb and Cd which is above the WHO agricultural soil permissible level. Nutrient uptake data showed presence of considerable heavy metal in the plant tissue. However, only organic amendment may not cure such soil. Further study need to reclaim the industrial polluted soil.

BINA Component

Experiment 1:

Benchmark survey to characterize biophysico- chemical properties of soil in the selected study areas

Results and Discussion

Soil texture: Based on the USDA system, particle size distribution and textural classes of the soils were determined and have been presented (Table 61). In the studied locations, sand, silt and clay particles varied from 2.73 – 25.22%, 68 – 87.49% and 6.59 – 18.28%, respectively. The highest sand particle of 25.22% was found in L-9 at Niamatpurupazila under Naogaon district and the lowest of 2.73% was recorded in L-7 at Niamatpurupazila of the same district. The highest silt particle of 87.49% was measured in L-7 at Niamatpurupazila under Naogon district and the lowest of 68.08% was recorded from L-17 location.

Table 61. Physical characterizations and geographical positions of soils at drought prone areas of Bangladesh

Sl. No.	Geographical position	Particle size analysis				Colour
		Sand (%)	Silt (%)	Clay(%)	Texture	
L-1	24^{0}41'543"N 88^{0}23'105"E	8.99	81.48	9.54	Silt	Brown
L -2	24^{0}41'549"N 88^{0}23'135"E	13.87	75.71	10.41	Silt loam	Brown
L -3	24^{0}42'658"N 88^{0}20'320"E	10.97	78.14	10.88	Silt loam	Brown
L -4	24^{0}43'726"N 88^{0}17'752"E	5.86	75.86	18.28	Silt loam	Black
L -5	24^{0}44'445"N 88^{0}19'917"E	11.47	79.17	9.36	Silt loam	Brown
L -6	24^{0}43'328"N 88^{0}21'941"E	10.34	77.67	11.98	Silt loam	Brown
L -7	24^{0}42'080"N 88^{0}22'074"E	2.73	87.49	9.79	Silt	Brown
L -8	24^{0}42'298"N 88^{0}24'010"E	22.41	71.00	6.59	Silt loam	Brown
L -9	24^{0}40'262"N 88^{0}26'498"E	25.22	61.09	13.69	Silt loam	Brown
L -10	24^{0}40'498"N 88^{0}28'832"E	7.81	79.09	13.10	Silt loam	Brown
L -11	24^{0}41'877"N 88^{0}28'648"E	17.52	73.20	9.27	Silt loam	Brown
L -12	24^{0}43'496"N 88^{0}28'780"E	18.93	70.06	11.00	Silt loam	Brown
L -13	24^{0}43'208"N 88^{0}27'301"E	9.03	76.53	14.43	Silt loam	Brown
L -14	24^{0}43'717"N 88^{0}26'205"E	4.84	80.80	14.36	Silt loam	Brown
L -15	24^{0}45'391"N 88^{0}26'451"E	3.87	83.39	12.74	Silt loam	Brown
L -16	24^{0}45'783"N 88^{0}27'399"E	13.10	79.09	7.82	Silt loam	Brown
L -17	24^{0}45'441"N 88^{0}28'668"E	21.91	68.08	10.01	Silt loam	Brown
L -18	24^{0}48'881"N 88^{0}26'305"E	7.68	80.97	11.36	Silt	Brown
L -19	24^{0}48'631"N 88^{0}24'115"E	6.39	78.78	14.83	Silt loam	Brown
L -20	24^{0}47'485"N 88^{0}24'077"E	9.96	79.01	11.04	Silt loam	Brown
L -21	24^{0}42'856"N 88^{0}25'175"E	9.29	80.00	10.69	Silt	Brown
L -22	24^{0}44'559"N 88^{0}25'688"E	7.79	80.01	12.13	Silt loam	Brown
L -23	24^{0}45'307"N 88^{0}24'522"E	3.64	83.05	13.31	Silt loam	Brown
L -24	24^{0}46'035"N 88^{0}22'620"E	10.43	76.06	13.49	Silt loam	Brown
L -25	24^{0}47'254"N 88^{0}20'644"E	11.69	71.81	16.50	Silt loam	Brown
L -26	24^{0}45'082"N 88^{0}21'638"E	9.86	81.16	8.98	Silt	Brown
L -27	24^{0}44'384"N 88^{0}20'826"E	10.06	78.03	11.89	Silt loam	Brown
L -28	24^{0}43'619"N 88^{0}21'324"E	10.50	79.29	10.19	Silt loam	Brown
L -29	24^{0}44'138"N 88^{0}22'410"E	12.00	79.11	8.89	Silt loam	Brown
L -30	24^{0}43'114"N 88^{0}22'519"E	10.00	80.09	9.90	Silt	Brown

The maximum clay particle of 18.28% was found in L-4 at Gomastapurupazila under Chapainawabganj district and the lowest of 6.59% from L-8 at Nacholeupazila under Chapainawabganj district. The textural class was silt loam in most soils and few of them were silt texture. Sand or loamy sand; loam, silt loam or silt and sandy clay, silty clay or clay are mentioned coarse, medium and fine textured soil, respectively. Among the soil textures,

silt loam textured soil holds the maximum amount of available water from 16.67 to 20.83 cm m^{-1} in soil. Silt loam is good for agricultural purpose. In this point of view all the studied soils are suitable for crop production if water availability is ensured the entire period of crop production.

Bulk density of soil

Bulk density of soil varied from 1.19 in L-25 and 1.57 g cm^{-3} in L-15 among the different locations of studied areas (Table 62). The average bulk density was noticed 1.40 g cm^{-3}.Bulk density reflects the soil's ability to function for structural support, water and solute movement, and soil aeration.

Table 62. Physical characterizations and geographical positions of soils at drought prone areas of Bangladesh

Sl. No.	Bulk density (g/cm^3)	Moisture (%)	Water holding capacity (%)	Porosity (%)	Void ratio	pH
L-1	1.32	20.24	55.75	50	1.00	7.78
L -2	1.25	32.02	56.93	53	1.13	7.68
L -3	1.44	21.37	48.30	45	0.83	7.62
L -4	1.36	27.57	66.57	49	0.94	7.59
L -5	1.40	28.19	49.82	47	0.89	7.29
L -6	1.33	28.67	56.26	50	0.99	7.68
L -7	1.37	26.28	54.62	48	0.94	7.67
L -8	1.23	48.73	52.86	54	1.16	8.07
L -9	1.53	26.13	53.61	42	0.73	7.91
L -10	1.35	9.82	57.38	49	0.96	7.69
L -11	1.26	36.08	55.75	52	1.10	7.78
L -12	1.26	16.25	54.12	52	1.10	7.39
L -13	1.43	22.97	55.68	46	0.86	7.67
L -14	1.46	15.64	47.09	45	0.81	7.45
L -15	1.57	21.53	57.05	41	0.69	7.45
L -16	1.46	27.15	56.04	45	0.81	7.99
L -17	1.36	27.18	60.84	49	0.94	7.80
L -18	1.50	20.96	54.62	43	0.77	7.71
L -19	1.34	32.00	56.49	49	0.97	7.69
L -20	1.48	17.84	56.38	44	0.79	7.54
L -21	1.48	20.25	57.97	44	0.79	7.88
L -22	1.43	18.66	49.13	46	0.85	7.54
L -23	1.44	26.52	55.19	46	0.84	7.87
L -24	1.47	23.94	49.69	45	0.81	7.96
L -25	1.19	26.44	56.77	48	0.91	7.56
L -26	1.47	24.75	55.71	45	0.81	7.74
L -27	1.50	25.65	53.04	43	0.76	7.73
L -28	1.38	22.41	51.78	48	0.92	7.85
L -29	1.40	30.04	60.79	47	0.90	8.02
L -30	1.47	25.96	52.20	45	0.81	7.61

Moisture content of soil

Moisture content of the soils ranged from 9.82 to 48.73% with an average value of 25.04% (Table 62). The highest soil moisture content was noticed from L-8 at Nacholeupazila under Chapainawabganj district and the lowest soil moisture content was obtained from L-10 at Mandaupazila under Naogaon district. The amount of soil moisture ranged from 20.24 – 28.19% in most of the studied soils. From this test result, it is evident that the studied soil moisture condition is not favorable for plants and biota growth. Moisture content is very

much crucial for dissolving nutrients in the soil for availability of microbes and plants growth and development. It is determining factor of soil compaction, soil erosion and slope stability. The sources of moisture in soil are directly controlled by rate of precipitation and irrigation in agricultural field. So, harvesting of rain water, effective irrigation system and low water consumption crops should include in cropping system.

Soil porosity

Soil porosity values varied from 41% in L-15 and 54% in L-8 in among the different locations of studied areas (Table 62). The highest porosity value (54%) was found at Nachole in Chaipainawabganj district which was followed by L-11 and L-12 at Niamatpur and Mandaupazilas under Naogaondistrict. The porosity values ranged from 48 – 54%, 44 – 53%, 43 – 49%, 41 – 52% and 49 – 52% at Nachole, Gomastapur, Porsha, Niamatpur and Mandaupazilas, respectively. The average porosity value of Nachole, Gomastapur, Porsha, Niamatpur and Mandaupazilas were 51, 47.72, 45.25, 46.07 and 50.50%, respectively. Soil permeability is the ease with which air, water or plant roots penetrate or pass through soil. Soil with large pores that are connected are more permeable. Rainwater soaks in readily and moves down through the soil profile. Clayey soils can have greater total porosity that sand and still be less permeable than sand since the pores are small. Loose, porous soils have lower bulk densities and greater porosities than tightly packed soils. Porosity varies depending on particle size and aggregation. It is greater in clayey and organic soils than in sandy soils. A large number of small particles in a volume of soil produce a large number of soil pores. Compaction decreases porosity as bulk density increases. If compaction increases bulk density from 1.3 to 1.5 gcm^{-3}, porosity decreases from 50 percent to 43 percent.

Soil pH

Soil pH values varied from 7.29 in L-5 and 8.07 in L-8 in among the different locations of studied areas (Table 62). On average the highest pH values was found at Nachole in Chaipainawabganj district which was followed by L-29 at Niamatpurupazila under Chaipainawabganj district. The pH values ranged from 7.67 – 8.07, 7.45 – 7.85, 7.69 – 7.99, 7.29 – 8.02 and 7.39 – 7.69 at Nachole, Gomastapur, Porsha, Niamatpur and Mandaupazilas, respectively. The average pH value of Nachole, Gomastapur, Porsha, Niamatpur and Mandaupazilas were 7.88, 7.64, 7.82, 7.65 and 7.54, respectively. A pH value of 8.07 was observed in L-8 at Nacholeupazila under Chapainawabganj district and the lowest of 7.29 from L-4 at Gomastapurupazila under Chapainawabganj district. Most soils showed pH values of above 7.4 i.e. mildly alkaline in nature. Neutral and mildly alkalinity soil is classified ranged 6.6 – 7.3 and 7.4 – 8.4, respectively. In respect of our studied soils pH, neutral and mildly alkaline soils are covered 3 and 97% of the studied areas. In most cases, pH 6 – 7 is optimum for adequate availability of nutrient in soils. In case of pH results of the studied soil, liming is needed to correct the pH level for good crop production.

Carbon fractions in soil

A variable organic carbon content was measured at different locations (Figure 63). Organic carbon content of the studied locations ranged from 0.48 and 1.14%. The highest organic carbon (1.14%) was found in L-25 and the lowest from 0.48% in L-7 at Niamatpur under Chapainawabganj district. The inorganic carbon content ranged from 0.05 to 1.20% in L-10 and L-2 soil sample, respectively. The highest inorganic carbon content was obtained from Gomastapurupazila under Chapainawabganj district and the lowest inorganic carbon content was found at Mandaupazila under Naogaon district. The more or less similar trend of inorganic carbon content was found in L-2 and L-16 soil samples.

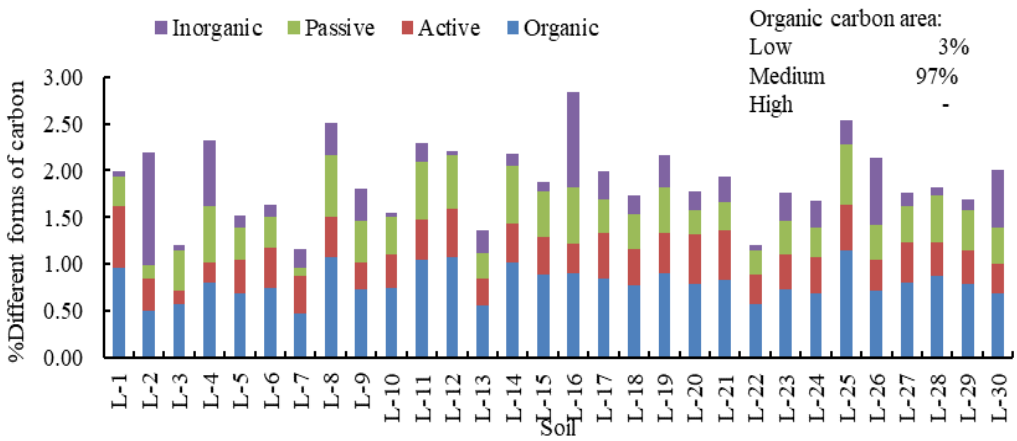


Figure 63. Different forms of soil carbon in drought prone areas of Bangladesh

Active carbon content ranged from 0.14 to 0.66% from L-3 and L-1 locations. The highest active carbon content was recorded from L-3 and the lowest active carbon content was obtained from L-1 location. In case of passive carbon, maximum carbon content (0.65%) was obtained from L-8 and L-26 locations. Minimum passive carbon content (0.15%) was observed in L-2 soil. L-2 soil contained the highest organic carbon content whereas the lowest passive carbon content was obtained from the same sample. The highest total carbon content (organic + inorganic carbon) content (1.93%) was recorded from L-16 location. Low, medium and high organic carbon status is mentioned <0.5, 0.5 – 7.5 and >7.5%, respectively. Low and medium organic carbon content covered 3 and 97% areas of the studied soils. Content of soil organic carbon is medium in our studied soils. So, organic carbon content is needed to improve of these areas by effective practices such as introduction of diverse with high biomass crops, cover crops, reduce tillage and rotational and prescribed grazing. Because optimum soil organic carbon reduces crusting and erosion of surface soil structure, increases water infiltration and decreases runoff , holds 10 to 1000 times more water and nutrients compared to mineral soils, increases the diversity and activity of beneficial soil microorganisms and water holding capacity in drought prone soils. Significant amount of inorganic carbon content was found in most of the studied soils and the pH of these soils is mildly alkaline in nature. This alkaline soil is contained significant amount of calcium and magnesium silicate rocks which can precipitate/react with atmospheric carbon dioxide to form calcium and magnesium carbonate known as inorganic carbon. As a result these soils also help to mitigate climate change through reducing atmospheric carbon dioxide by forming inorganic carbon.

Microbial biomass C in soil

It was observed that the amount of microbial biomass carbon content varied widely within different locations (Figure 64). The amount of microbial biomass carbon ranged from 35 kg C ha^{-1} in L-25 to 827 kg C ha^{-1} in L-3 locations.The highest microbial biomass carbon content was found in L-3 at Gomastapur underChapainawabganj district and the lowest amount of microbial biomass carbon was obtained from L-25 at Niamatpurupazila under Naogaon district. Most of the soils showed the amount of microbial biomass carbon from 304 kg C ha^{-1} to 453 kg C ha^{-1} in soils.

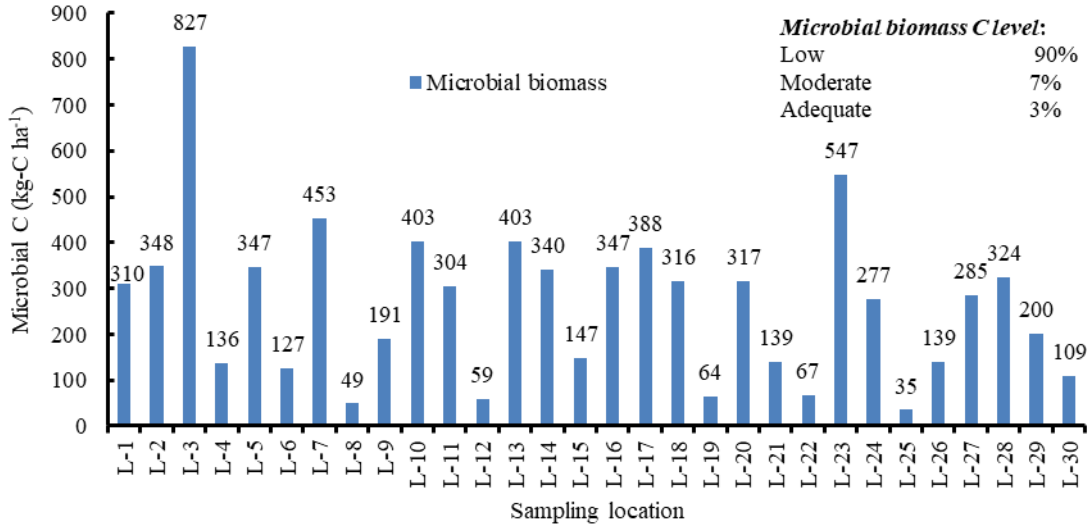


Figure 64. Microbial biomass C content in different drought prone areas of Bangladesh

According to microbial biomass carbon classification, low, moderate and adequate level of microbial biomass carbon is mentioned ≤215, 216 – 375 and >373 mg C kg^{-1} soil. In this regard, low, moderate and adequate amount of microbial biomass carbon samples are covered 90, 7 and 3%, respectively. Soil microbial biomass plays an important roles in nutrient cycling, plant-pathogen suppression, decomposition of residues, and degradation of pollutants, carbon sequestration in soil, forming the vital living components of soils and contributing to ecosystem sustainability due to their composition survival, massive efficient genetic pool, catabolic versatility and stress tolerance potential. In respect of organic carbon content results, diverse with high biomass crops, cover crops, reduce tillage and rotational and prescribed grazing should be practiced.

Nitrogen status in soil

It was observed that the amount of nitrogen content varied widely within different locations. The amount of nitrogen content ranged from 0.081 - 0.180% in different studied soils (Figure 4).

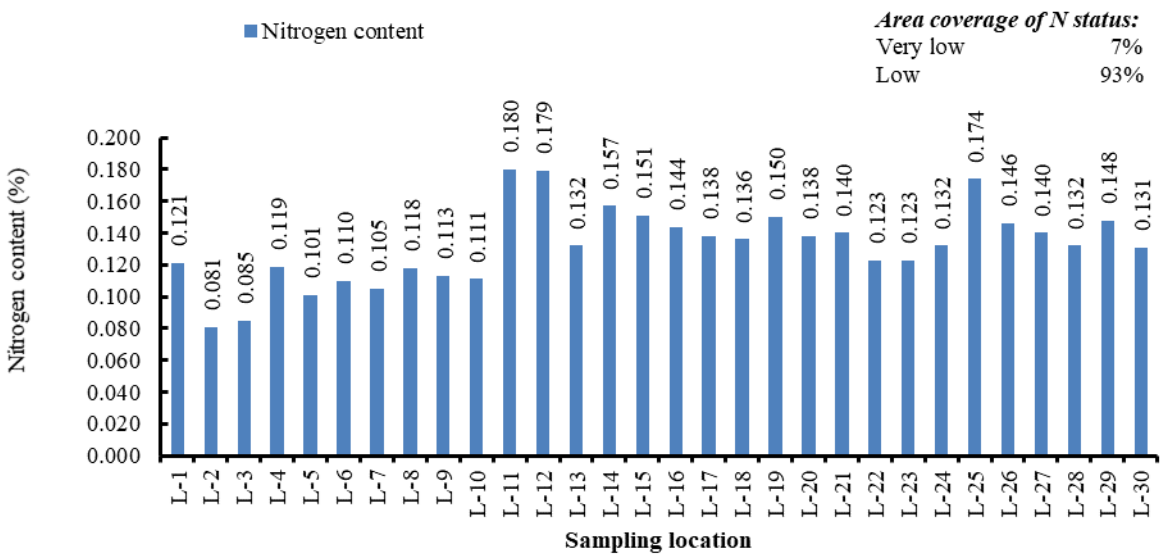


Figure 65. Nitrogen status at different locations of drought prone areas of Bangladesh

The highest nitrogen content was noticed from L-11 at Niamatpur under Chapainawabganj district and the lowest amount of nitrogen content was obtained from L-2 at Gomastapurupazila under Chapainawabganj district. Most soils showed the amount of nitrogen content from 0.101 – 0.180% in Niamatpurupazila under Naogaon district except L-2 and L-3 locations. According to nitrogen content classification, very low and low is mentioned ≤0.09 and 0.091 – 0.18%, respectively in soil. In this regard, 7% samples are very low and 93% samples are low in fertility status.

Available phosphorus in soil

Wide variation of available phosphorus was recorded from different soil samples (Figure 66). The amount of phosphorus content ranged from 27.60 – 146.70 ppm in different studied soils. The highest phosphorus content was found in L-2 at Gomastapur under Chapainawabganj district and the lowest amount of phosphorus content was obtained from L-21 at Porshaupazila under Naogaon district. Most soil showed the amount of phosphorus content from 40.20 – 59.10 ppm at different locations. According to phosphorus content classification, very low, low, medium, optimum, high and very high of available phosphorus is mentioned 0 – 7.5, 7.5 – 15, 15 – 22.5, 22.5 – 30, 30 – 37.5 and >37.5 ppm, respectively. In this regard, optimum, high and very high amount of available phosphorus covered 3, 10 and 87%, respectively.

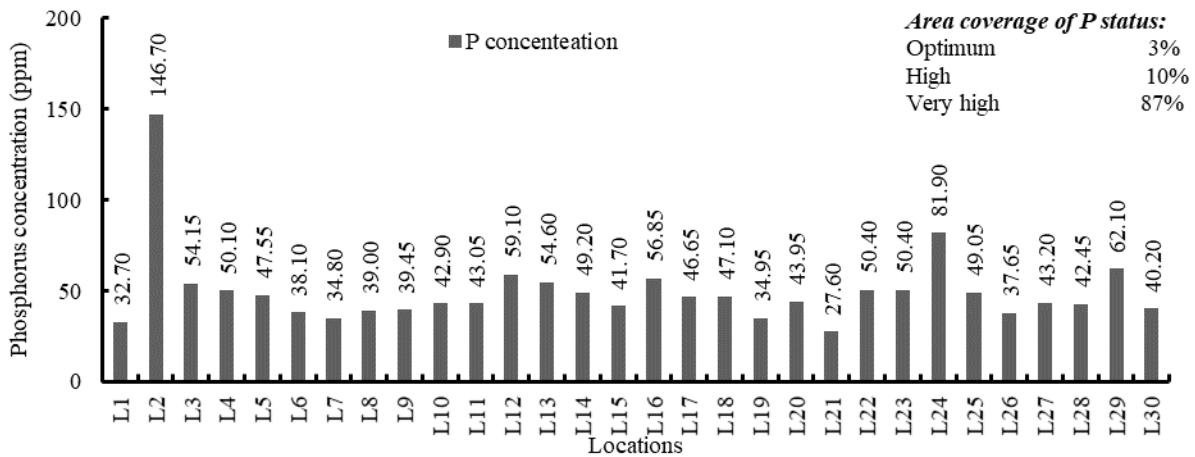


Figure 66. Phosphorus status at different locations of drought prone areas of Bangladesh

K content of soil samples of the studied areas ranged from 25.77 ppm in L-16 and 98.68 ppm in L-19(Figure 67). Maximum K content (98.68) was found in L-19 location and the minimum K content (25.77 ppm) was obtained from L-16 location. Fe content of soil samples of the studied areas ranged from 16.42 ppm– 54.94 ppm of which 100% samples is very high (Figure 68).According to Fe content classification, very low, low, medium, optimum, high and very high of available Fe is mentioned ≤3.0, 3.1 – 6.0, 6.1 – 9.0, 9.1 – 12.0, 12.1 – 15.0 and >15.0 ppm, respectively. Maximum Fe content was found in L-5 location and the minimum Fe content was obtained from L-13 location.

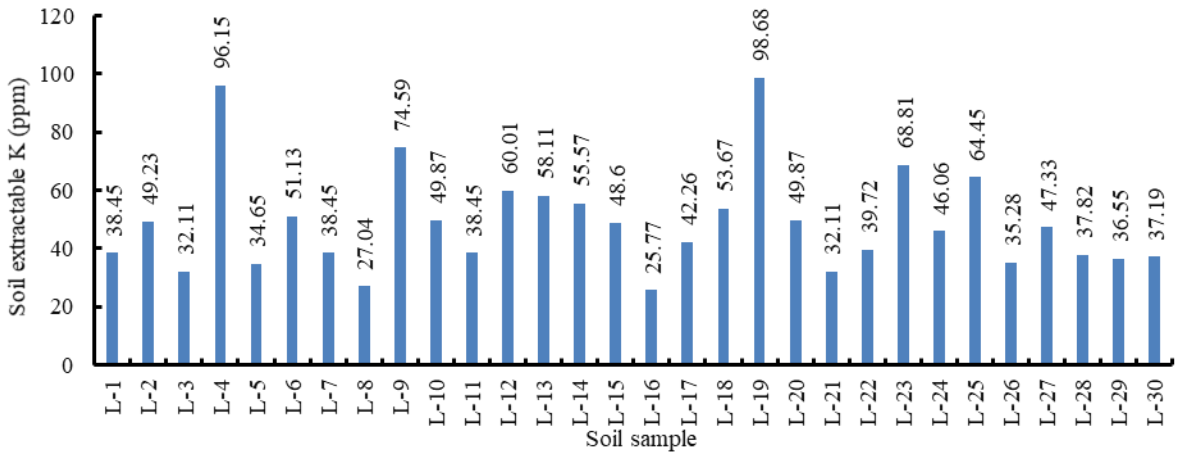


Figure 67. K status in different locations of drought prone areas of Bangladesh

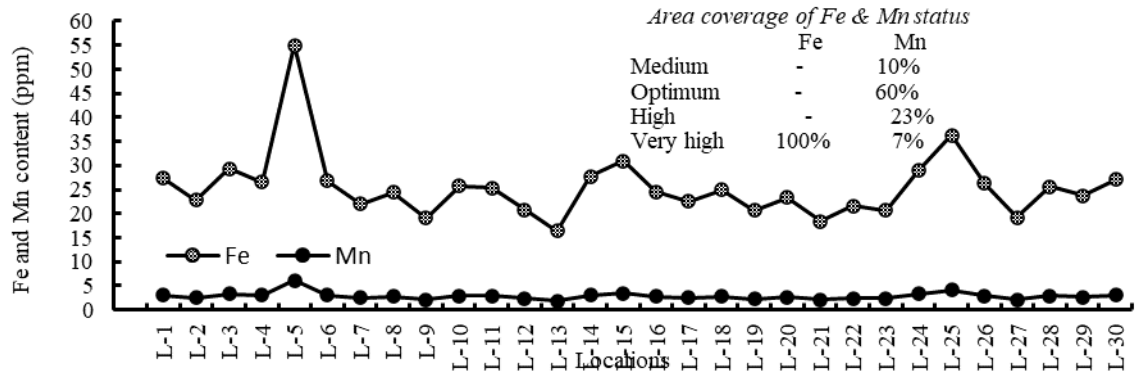


Figure 68. Fe and Cu status in different locations of drought prone areas of Bangladesh

Mn content of soil samples of the studied areas ranged from 1.85 ppm– 6.17 ppm of which 10% samples are medium, 60% samples are optimum, 23% samples are high, 7% samples are very high status (Figure 68). According to Mn content classification, very low, low, medium, optimum, high and very high of available Mn is mentioned ≤0.75, 0.756 – 1.5, 1.51 – 2.25, 2.256 – 3.0, 3.1 – 3.75 and >3.75 ppm, respectively. Maximum Mn content was recorded from L-5 location and the minimum Fe content was obtained from L-13 location. Cu content results ranged from 0.38 ppm – 1.24 ppm of which 13% samples are very medium, 57% samples are optimum and 23% samples are high status of the studied soils (Figure 8). According to Cu content classification, very low, low, medium, optimum, high and very high of available Cu is mentioned ≤0.15, 0.151 – 0.3, 0.31 – 0.45, 0.451 – 0.6, 0.61 – 0.75 and >0.75 ppm, respectively. Maximum Cu content was found in L-5 location and the minimum Cu content was recorded from L-13 location. Zn content of soil samples of the studied areas ranged from 0.28 ppm– 1.90 ppm of which 36% samples are very low, 40% samples are low, 10% samples are medium and 7% samples are optimum in fertility status (Figure 69). According to Zn content classification, very low, low, medium, optimum, high and very high of available Zn is mentioned ≤0.45, 0.451 – 0.9, 0.91 – 1.35, 1.351 – 1.8, 1.81 – 2.25 and >2.25 ppm, respectively. Maximum Zn content was found in L-12 location and the minimum Zn content was observed from L-2 location.

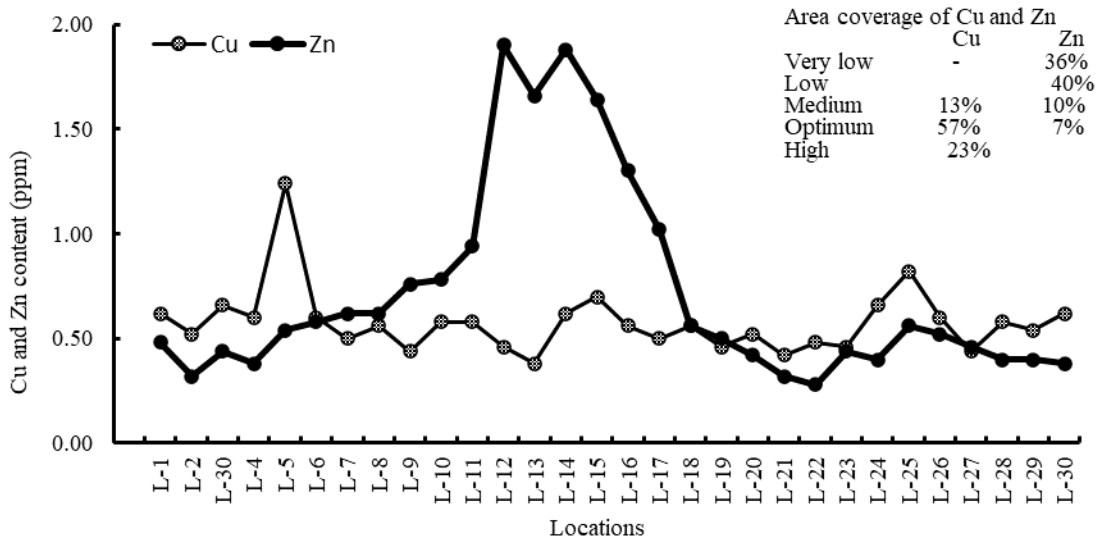


Figure 69. Cu and Zn status in different locations of drought prone areas of Bangladesh

Now-a-days, the farmers of the country are trying to increase the crop yield by applying more and more inorganic chemicals, mainly nitrogenous fertilizers. pesticides etc. For these reasons, reserve of nutrient depleted and available nutrient become unavailable and toxic to plants.

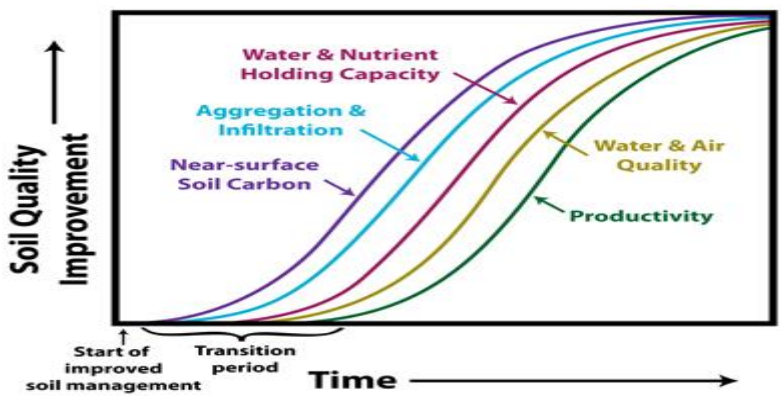


Figure 70. Effect of improved soil management practices on soil quality

Again excessive amount of applied fertilizers hinder the availability of other nutrients too. The farmers do not know the inherent nutrient status of soils and the use fertilizers blindly and uneconomically. On the other hand, soil physical parameters are important factor to select which crop is suitable for cultivation. In our tested soils are low organic carbon, microbial biomass carbon, low nutrient contents except phosphorus and potassium, high bulk density and sodium.These findings of this research are useful for solving the soil related problems and for consideration of land use and management in terms of nutrient and water management as well as crop selection for drought prone areas of north-western part of Bangladesh. Soil quality improvement (Figure 70) is possible if we consider all the studied information and follow the improve soil management practices like introduction of diverse with high biomass crops, organic fertilizers, cover crops, reduce tillage and rotational and cost effective irrigation system.

Collection and analysis of 30 soil samples from north-western part of drought prone areas of Bangladesh for the determination of bio-physico-chemical properties

Experiment 2:

Study on the mineralization rate of commonly used organic materials in Bangladesh under field capacity and CSW conditions

Results and Discussion

Carbon mineralization

Effect of water levels on carbon dioxide emission

Effect of water levels on the rate of carbon dioxide emission results is presented (Figure 71). Maximum carbon dioxide emission was found at 7 days of incubation for all moisture levels which was continuously in decreasing trend. After 7 days, the trend of carbon dioxide emission decreased with more or less regular fashion until 120 days. The highest rate of carbon dioxide emission was found in field capacity (73.57 mg d^{-1} kg^{-1} soil) at 7 days of incubation followed by (66.63-mg d^{-1} kg^{-1} soil) in continuous standing water condition. Soil water level such as field capacity condition hastened the emission of carbon dioxide during decomposition of organic amendments. Higher carbon dioxide emission was observed in field capacity condition than in continuous standing water condition. Carbon dioxide emission was sharply increased from 0 to 7 days after incubation.

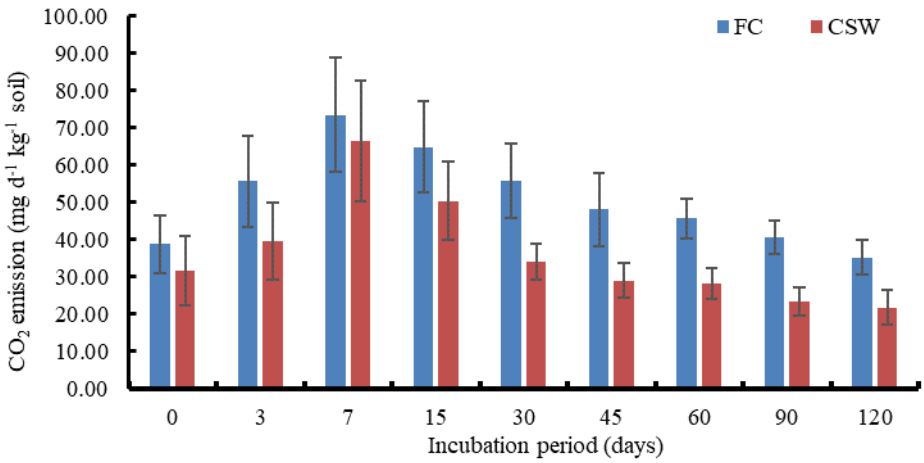


Figure 71. Effect of different soil moistures on the rate of carbon dioxide emission (FC: field capacity and CSW: continuous standing water)

Effect of organic amendments on carbon dioxide emission

Effect of organic amendments on carbon dioxide emission rate results is presented (Figure 72). Carbon dioxide emission results were significantly different at all the studied durations. The emitted CO_2 results varied among the treatments. Organic amendments with mixture of soil was significantly increased carbon dioxide emission over soil alone except 0, 3 and 7 days of incubation in biochar treated soil. Carbon dioxide was sharply increased from 0 -7 days of incubation in all the organic amendments treated soil and control. Organic fertilizer produced the highest carbon dioxide emission at 7 days of incubation which was continuously decreasing trend up to 120 days of incubation. The second highest carbon dioxide emission was recorded fromvermicompost treated soil. Carbon dioxide emission was increased from 0 to 7 days in vermicompost treated soil and then it decreased with the increase of time. Carbon dioxide emission was decreased with the increase of time in all the treatments except 0 to 3 days in biochar treated soil. The lowest carbon dioxide emission was found in 120 days after incubation for all the studied organic amendments including control.

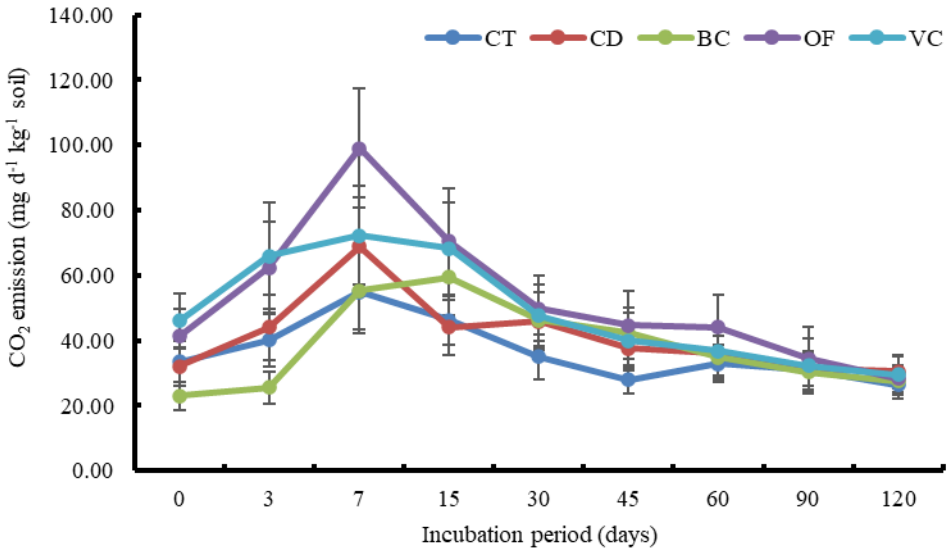


Figure 72. Effect of different organic amendments on the rate of carbon dioxide emission (CT: control, CD: cowdungbioslurry, BC: biochar, OF: organic fertilizer and VC: vermicompost)

Effect of interaction effect on carbon dioxide emission

Effect of water levels in combination with organic amendments on carbon dioxide results are presented (Figure 73). All the studied organic amendments, the cumulative carbon dioxide emission showed linear trend with significant variation during entire incubation period. In field capacity condition, maximum carbon dioxide emission was found (4707.60 mg) in vermicompost mixed soil. Control means only soil produced the minimum (3762.00 mg) carbon dioxide in 120 days after incubation. Field capacity with different organic amendments produced more carbon dioxide than continuous standing water with different organic amendments.

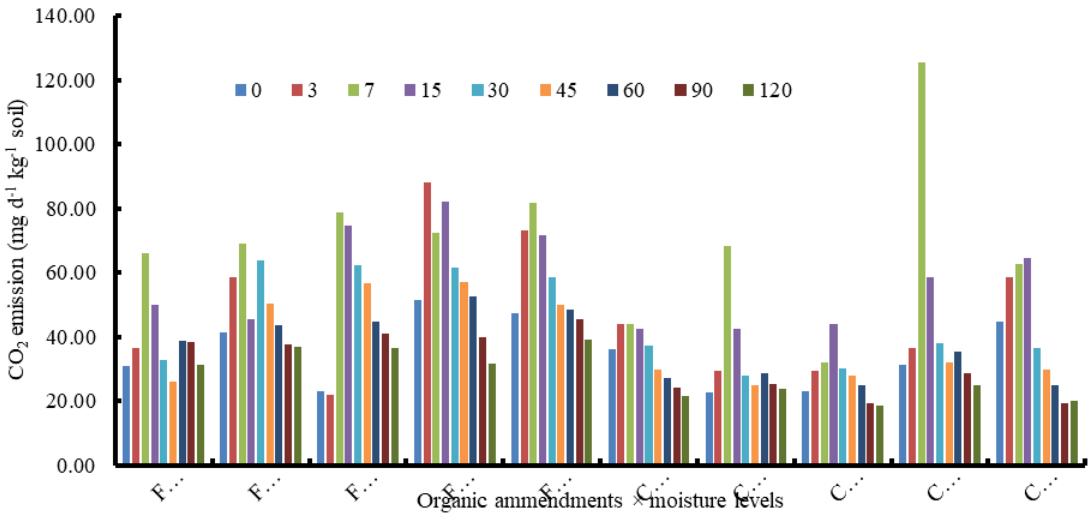


Figure 73. Interaction effect between moisture levels and organic amendments on the rate of carbon dioxide emission (FC: field capacity and CSW: continuous standing water, cont: control, CD: cowdungbioslurry, BC: biochar, OF: organic fertilizer and VC: vermicompost)

Similar trend was found in cumulative carbon dioxide emission from field capacity and continuous standing water conditions. Maximum cumulative carbon dioxide emission was observed 4224 and 2610.24 mg CO_2 d^{-1} kg^{-1} soil field capacity and continuous standing water

condition at 120 days after incubation (Figure 74). Cumulative carbon dioxide was increased with the increase of time. Continuous standing water with soil only produced more carbon dioxide over continuous water standing water with biochar and vermicompost treated soil. Interaction results revealed that mixing of organic amendments with soil and different levels of water significantly affected rates and cumulative carbon dioxide emission (Figure 64 & 67). Rate of CO_2 emission was increased from 0 to 7 days of incubation period except FC × OF, CSW × BC and CSW × VC treatments. At most cases, after 7 days the trend of CO_2 emission decreased with more or less regular fashion until 120 days of incubation. Field capacity with soil alone increased 12.54% carbon dioxide emission over continuous standing water with soil alone treatment. In field capacity, organic amendments produced varied from 25.56 to 53.30% carbon dioxide emission over control treatment. Maximum average carbon dioxide emission rate (59.69 mg d^{-1}) was obtained from organic fertilizer in combination with field capacity condition.

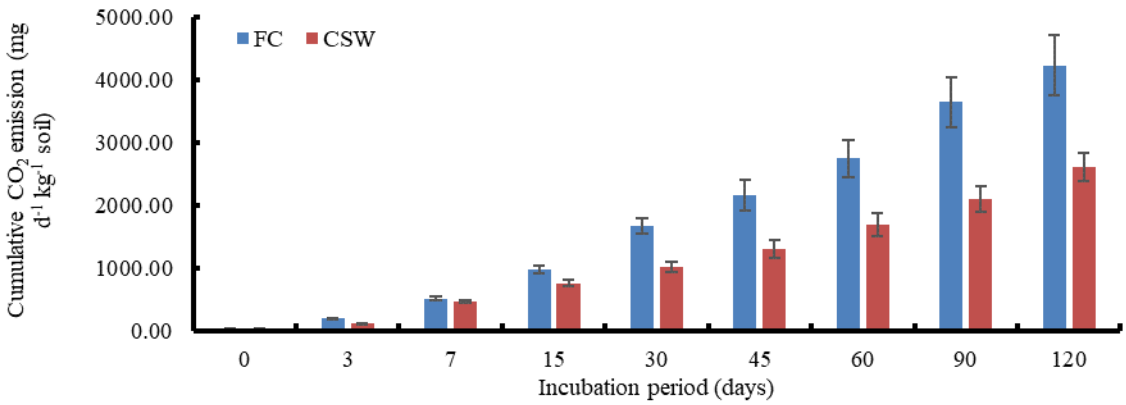


Figure 74. Effect of different soil moistures on cumulative carbon dioxide emission (FC: field capacity and CSW: continuous standing water)

Minimum average carbon dioxide emission (48.89 mg d^{-1}) in biochar treated soil (Figure 75). In respect of continuous standing water system, organic amendments reduced from 1.44 to 6.35 mg CO_2 d^{-1} from cowdung and biochar over control treatment. On the other hand, OF and VC increased 11.66 and 6.17 mg CO_2 d^{-1} over control treatment. FC × CD, FC × BC, FC × OF and FC × VC produced 27.57, 25.56, 53.30 and 48.38% more CO_2 than FC × control treatment (Figure 76).

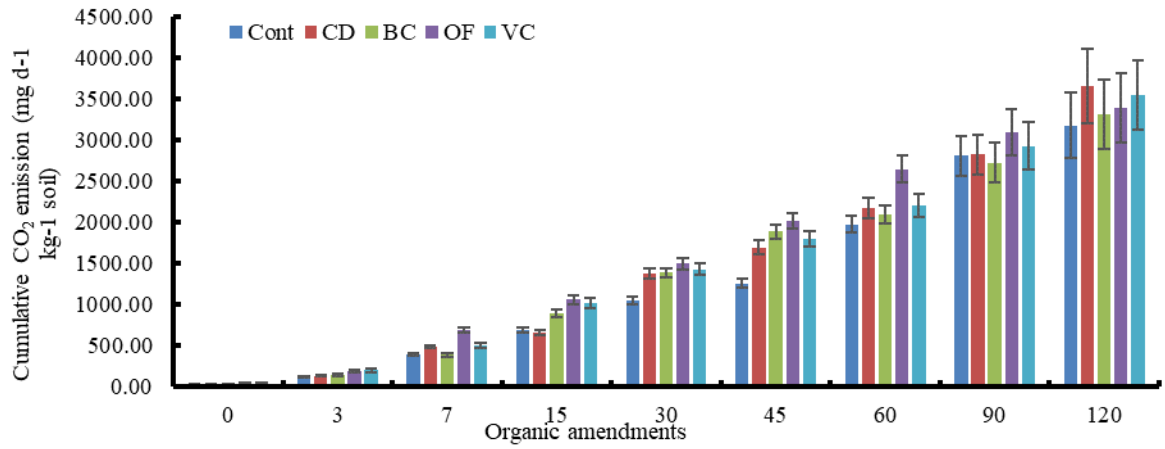


Figure 75. Effect of different organic amendments on cumulative carbon dioxide emission (cont: control, CD: cowdung, BC: biochar, OF: organic fertilizer and VC: vermicompost)

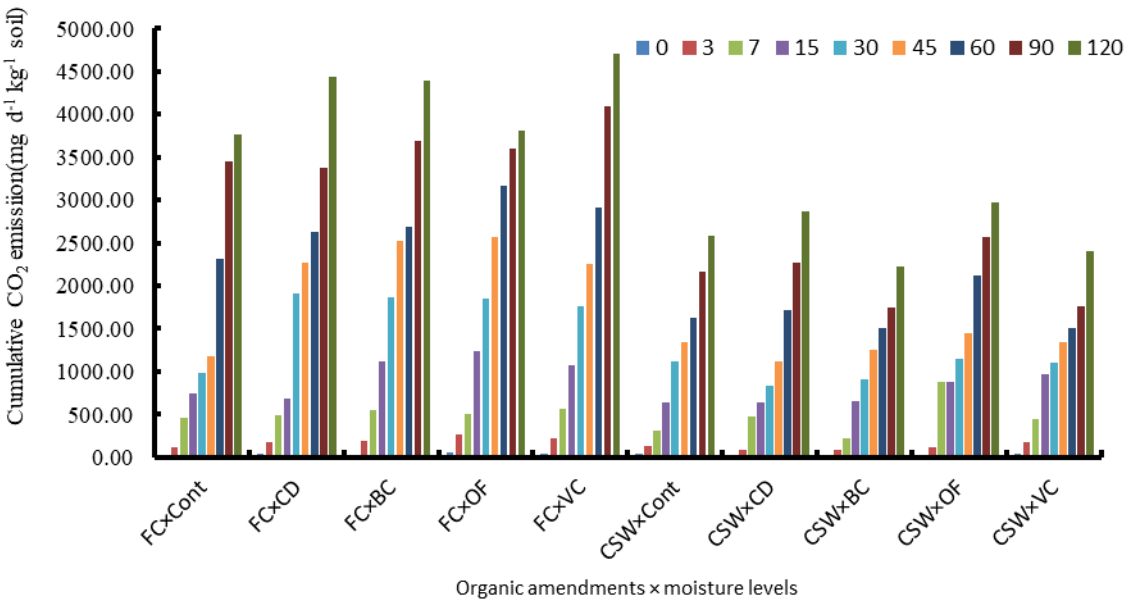


Figure 76. Interaction effect between moisture levels and organic amendments on cumulative carbon dioxide emission (FC: field capacity and CSW: continuous standing water, cont: control, CD: cowdung, BC: biochar, OF: organic fertilizer and VC: vermicompost)

Different factors such as water levels, organic sources and their interactions significantly affected organic carbon content in soil (Figure 77). In case of water levels, carbon content varied from 0.97 to 1.01%. Maximum carbon content was recorded from continuous standing water condition and the minimum carbon content was found in field capacity. On the other hand, carbon content varied from 0.81% in control treatment means only soil to 1.07% in vermicompost treated soil which followed by organic fertilizer (1.05%), biochar (1.06%) and cowdung (0.96%) treated soil. Cowdung produced the second lowest organic carbon content in soil. Maximum organic carbon was recorded from FC × VC treatment and the lowest organic carbon content (0.74%) was obtained from FC ×cont treatment.

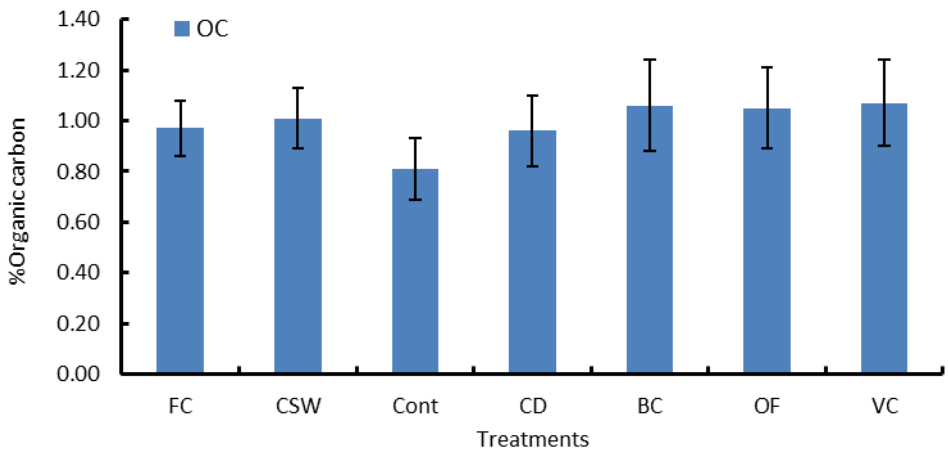


Figure 77. Effect of moisture levels and organic amendments on organic carbon content water levels (FC: field capacity, CSW:continuous standing water), organic amendments (CD:cowdung, BC:biochar, VC:vermicompost,OF:organic fertilizer)

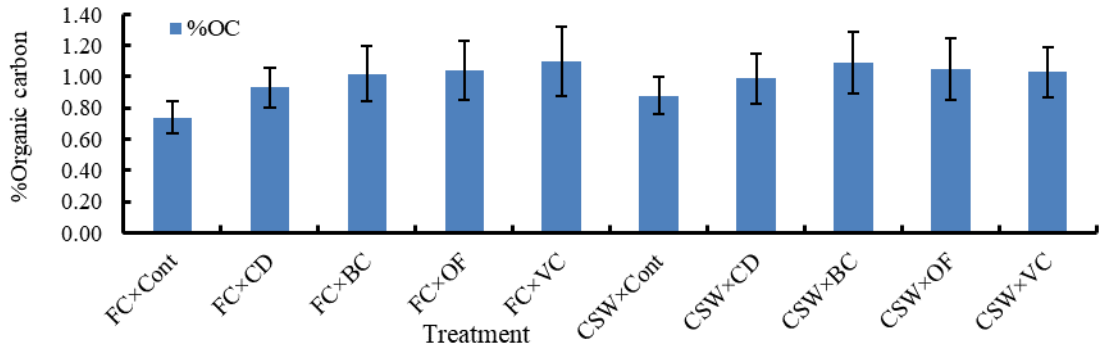


Figure 78. Interaction effect between moisture levels and organic amendments on organic carbon content (FC: field capacity and CSW: continuous standing water, cont: control, CD: cowdungbioslurry, BC: biochar, VC: vermicompost andOF: organic fertilizer)

In respect of interaction between moisture levels and organic amendments,organic carbon content varied from 0.74 to 1.10 (Figure 78).Maximum carbon content was found in FC × VC (1.10%) treated soil and the minimum organic carbon content (0.74%) was obtained from FC × control treated soil. CSW × BC showed the second highest organic carbon content in soil. On the other hand, CSW × Cont treatment produced the higher organic carbon content in soil over FC × Cont treated soil. Soil organic carbon concentration in different soil aggregate fractions are influenced by water levels and organic amendments.In case of soil aggregate stability, maximum amount of soil was found in 53µ size aggregate fraction whereas the second highest amount of soil was obtained from 250µ size aggregate fraction (Figure 79). Minimum soil amount was noticed from 2000µ size aggregate fraction.

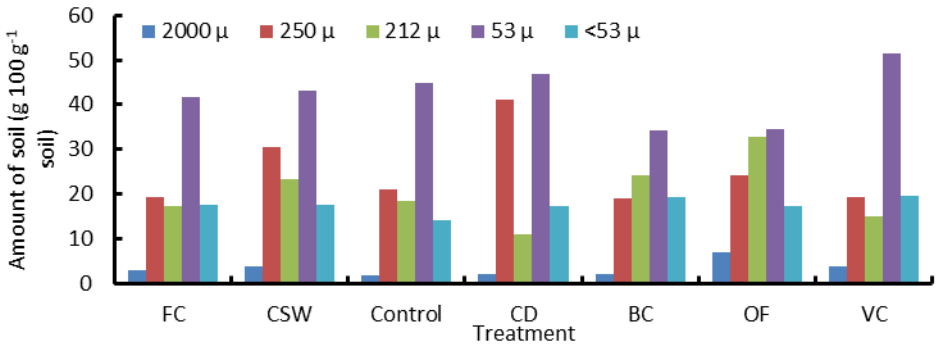


Figure 79. Effect of moisture levels and organic amendments on aggregate stability in different soil fractions

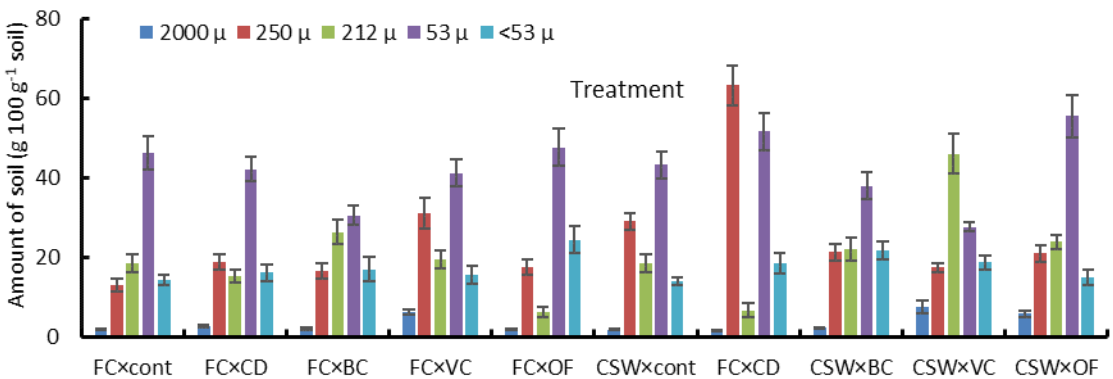


Figure 80. Effect of interaction between moisture levels and organic amendments on aggregate stability soil fractions

In respect aggregate stability, maximum amount of soil was found in 53µ size aggregate fraction except FC × CD and CSW × OF treatments. The lowest amount of soil was obtained from 2000 µ size aggregate fraction. The second highest soil amount was observed in FC × cont, FC × BC, CSW × BC, CSW × OF and CSW × VC treatments. On the other hand, the second highest amount of soil was found in FC × CD, FC × OF and CSW × cont treatments in 250µ soil aggregate fraction (Figure 80).

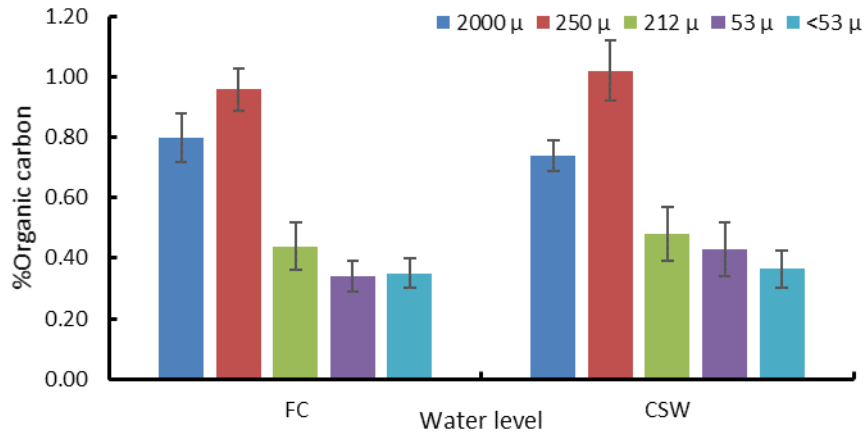


Figure 81. Effect of different moisture levels on organic carbon content in different soil aggregate fractions

The distribution of soil aggregate associated SOC in soil under different water levels and organic amendments at different durations of incubation study are presented (Figure 81-83).Higher soil organic carbon was found in 2000µ aggregate fraction under field capacity.

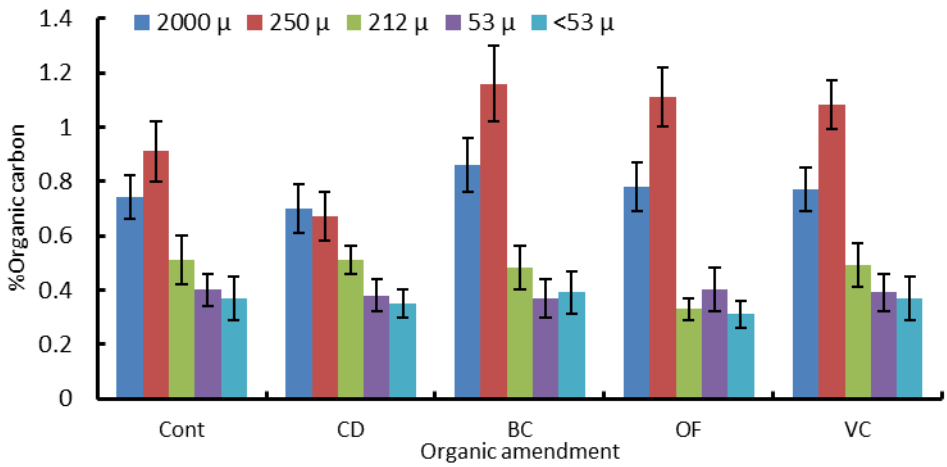


Figure 82. Effect of organic amendments on organic carbon content in different soil aggregate fractions

On the other hand, 250, 212, 53 and <53µ aggregate size fractions contained higher soil organic carbon in continuous standing water condition. Maximum soil organic carbon was present in 250 µ aggregate size fraction soil. In continuous standing water condition, soil organic carbon was decreased with the decrease of soil aggregate size except 2000µ aggregate size soil fraction. On the other hand, soil organic carbon content was reduced with the reducing trend of soil aggregate size fractions except 2000 and 53µ aggregate size of soil under field capacity.

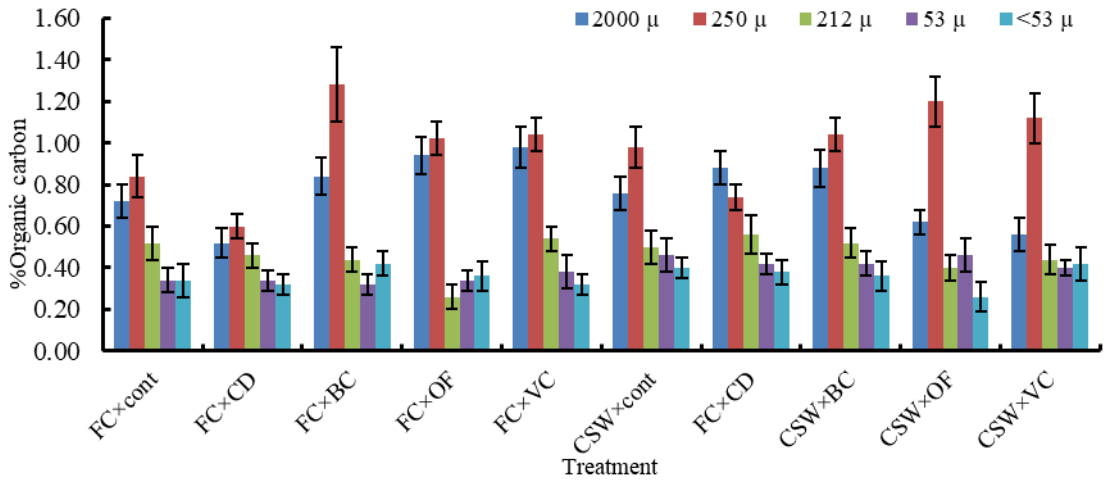


Figure 83. Interaction effect between moisture levels and organic amendments on organic carbon contentin different soil aggregate fractions (FC: field capacity and CSW: continuous standing water, cont: control, CD: cowdungbioslurry, BC: biochar, VC: vermicompost and OF: organic fertilizer)

Irrespective of soil aggregate size fractions, on average 4.84% soil organic carbon content was found in continuous standing water condition over field capacity. The highest soil organic carbon content was found in BC treated soil in 2000µ aggregate soil fraction which was followed by OF and VC treated soils. On the other hand, the lowest soil organic carbon content was obtained from CD treated soil for the same soil aggregate fraction. In respect of interaction effect between water levels and organic amendments, soil organic carbon was decreased with the decreasing soil aggregate fractions except CD and BC treated soil.

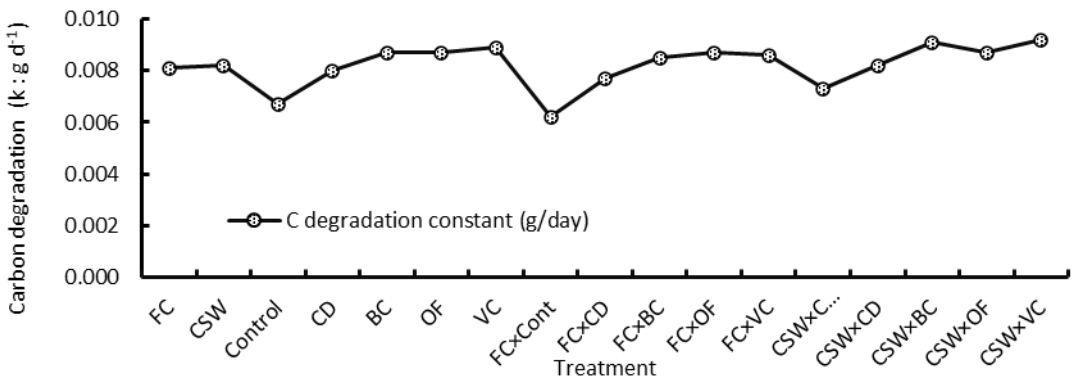


Figure 84. Effect of organic amendments and moisture levels on C degradation rate constant: water levels (FC: field capacity, CSW: continuous standing water), organic amendments (CD: cowdung, BC: biochar, OF: organic fertilizer, VC: vermicompost and cont: control)

Different factors such as water levels, organic sources and their interaction significantly affected C degradation rate constant (k). In case of water levels, the carbon degradation rate constant varied from 0.0081 to 0.0082 g C d^{-1} (Figure 23). Maximum k value was observed in continuous standing water condition and the minimum k value was found in field capacity. On the other hand, C degradation rate constant varied from 0.0067 in control treatment means only soil treatment to 0.0092 g C d^{-1} in vermicompost treated soil. Biochar and organic fertilizer produced the same C degradation rate constant (0.0087 g C d^{-1}). Cowdung produced the second lowest C degradation rate constant (0.0089 g C d^{-1}). The higher k value indicates the slower is the degradation of vermi-compost and continuous standing water systems. Based on this information, it may be concluded that organic amendments helped to

preserve organic carbon in soil. On the other hand, low organic carbon or without treated organic amendments cann't sustain, preserve or improve organic carbon in soil for enhancing C degradation in soil. In conclusion, organic amendments inhibit the degradation of soil carbon to enrich carbon content in soil and as well as to improve soil physical, chemical and biological conditions. Interaction effect between water levels and organic amendments on the degradation rate constant (k) value is presented (Figure 68). Control × field capacity produced the lowest k value (0.0062) and the second lowest k value was found in CSW × control treatment. Maximum k value was observed in CSW × VC and CSW × BC treatments. Vermicompost with field capacity and continuous standing water produced 0.0086 and 0.0092 g C d^{-1}, respectively. Researchers reported that different organic materials can produce different C degradation rate constant in soil. These different k values depend on the nature and types of organic residues and environmental condition such as moisture levels of soil. Different organic amendments with different water levels showed different decomposition rate constant due to some reasons. Firstly, decomposition rate depends on C:N ratio of the tested materials. A high C:N ratio containing organic residue slows the rate of residue breakdown because lignin content was higher than other easily decomposable compounds. The rate of decomposition of organic materials composition is in the following order sugars, starches and protein>hemicellulose>cellulose>fats, waxes>lignin. On the other hand, it is especially important where the C:N ratio of organic material is high and thus decomposition is slowed by a lack of nitrogen. This delay may help to reduce nutrient loss and better synchronize nutrient availability and crop demand. Secondly, good aeration is an important factor for the proper activity of microorganisms involved in the decomposition of organic matter. Under anaerobic conditions fungi and actinimycetes are almost suppressed and only a few bacteria take part in anaerobic decomposition. The rate of decomposition is markedly related in anaerobic condition. Some researchers claimed that aerobic condition 65% of the total organic matter decomposes during six months, while under anaerobic condition only 47% organic matter can be decomposed during the same period. Thirdly, decomposition constant depends on the content of labile and non-labile C. Based on these discussion, organic residues along with continuous standing water condition improved soil organic carbon and reduced environmental pollution.

Mineral nitrogen mineralization

Effect of water levels on NH_4^+-N mineralization

The amount of KCl extractable NH_4^+-N varied markedly depending on soil moisture with different periods of incubation (Figure 85). At the onset of the incubation, NH_4^+-N content increased sharply and within 0-7 days it reached the maximum both in field capacity and continuous standing water conditions. Afterwards the trend was decreasing and the remarkable decrease was observed up to 60 days. Further, from 60 days to 120 days, NH_4^+-N slightly increased in FC and CSW conditions. Both field capacity and continuous standing water condition slightly increased from 60 to 120 days. Amount of NH_4^+-N in initial stage (0 day) was 126.17 ppm both in field capacity and continuous standing water condition. The maximum amount of NH_4^+-N were found 210.60 and 193.62 ppm at 7 days of incubation both FC and CSW condition. Continuous standing water produced higher amount of NH_4^+-N over FC treated soil at all the studied durations of incubation study. CSW condition produced 31% more NH_4^+-N over field capacity in treated soil.

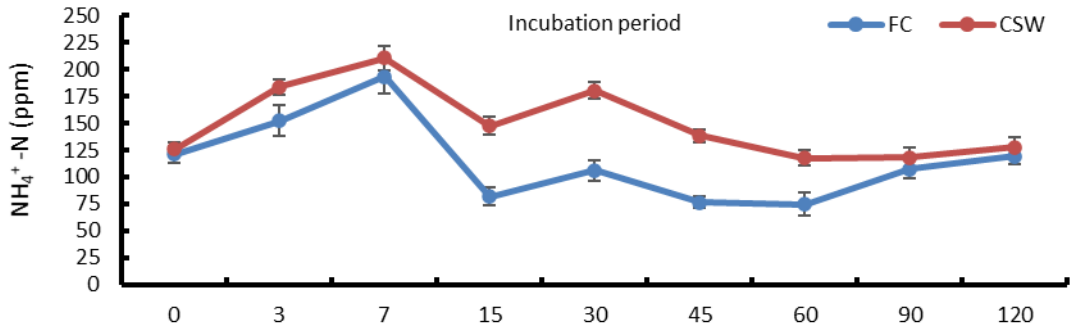


Figure 85. Effect of different water levels on NH_4^+- N content in soil at different durations (FC: field capacity and CSW: continuous standing water)

Effect of organic amendments on NH_4^+-N mineralization

Effect of different organic amendments on NH_4^+-N results are shown (Figure 86). Results of the tested soils amended with CD, BC and VC followed almost similar trend of ammonification except organic fertilizer treated soil. Irrespective of the organic amendments treatments, there was an initial faster rate of ammonification and reached the maximum in day 7 except vermicompost treated soil which required 3 days. Among the organic amendments, biochar treated soil produced the lowest amount of NH_4^+-N in soil at all the studied periods except 45 and 90 days of incubation. Maximum NH_4^+-N was produced in organic fertilizer treated soil in all the studied durations. The highest amount of NH_4^+-N (311.52) was found in 7 days of incubation. Cowdung and biochar reduced the production of NH_4^+-N (0.96 and 7.30%) over control treatment means soil alone. On the other hand, OF and VC increased the production of NH_4^+-N (64 and 9%) over control treatment. At 0 day of incubation, organic fertilizer produced 153% moreNH_4^+-N over biochar treated soil. The second highest amount of NH_4^+-N was found in control treatment from 7 to 60 days except 0, 3, 45, 90 and 120 days of incubation.

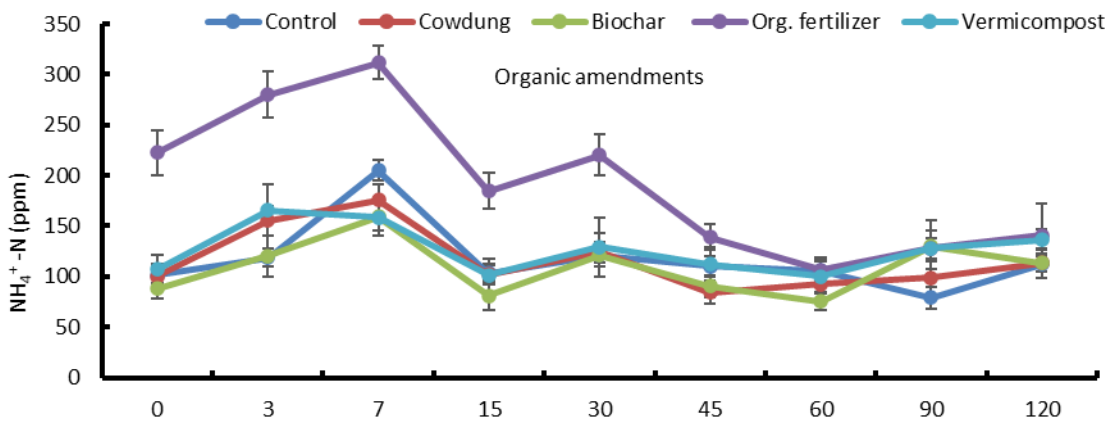


Figure 86. Effect of different organic amendments on NH_4^+- N content in soil at different durations

At day 7, ammonification rate of control treated soil was higher than all the organic amendments except organic fertilizer amended soil whereas, at day 3, ammonification rate of vermicompost treated soil was higher than all the treatments except organic fertilizer amended soil. Only soil and organic amendments treated soil produced significant amount of NH_4^+-N during entire period of incubation study. Because total nitrogen content in soil was

high. Different organic amendment treated soils produced different amount of NH_4^+-N in soil due to the different types of organic amendments and different enriched nitrogen content in amendments. In this case, the maximum ammonification was completed within 7 days and then there was a gradual decrease of ammonification up to 120 days of incubation. Thus for immediate and higher N requirements of crops, readily organic amendments like organic fertilizer and vermicompost may serve better but for relatively slow and steady release of NH_4^+-N, cowdung and biochar could be best alternative.

Effect of interaction on NH_4^+-N mineralization

Interaction effect of moisture levels and organic amendments on NH_4^+-N results are shown (Figure 87).NH_4^+-N content increased sharply and it reached the maximum from 0 to 7 days after incubation. Afterwards the trend was inconsistently decreasing and increasing up to 120 days of incubation study. At the onset of the incubation study, 0 and 120 days produced 123.70 and 123.38 ppm NH_4^+-N. Maximum NH_4^+-N was found in continuous standing water with OF treated soil at 7 days of incubation. Maximum average NH_4^+-N (238.35 ppm) was obtained from continuous standing water × organic fertilizer treated soils and minimum average NH_4^+-N was found in field capacity × control treated soil. The amount of NH_4^+-N in different interactions between moisture levels and organic amendments ranged from 99.88 in field capacity × control to 238.35 ppm in continuous standing water × organic fertilizer treated soil. Field capacity × biochar produced 5.72% higher NH_4^+-N over field capacity × control treated soil.

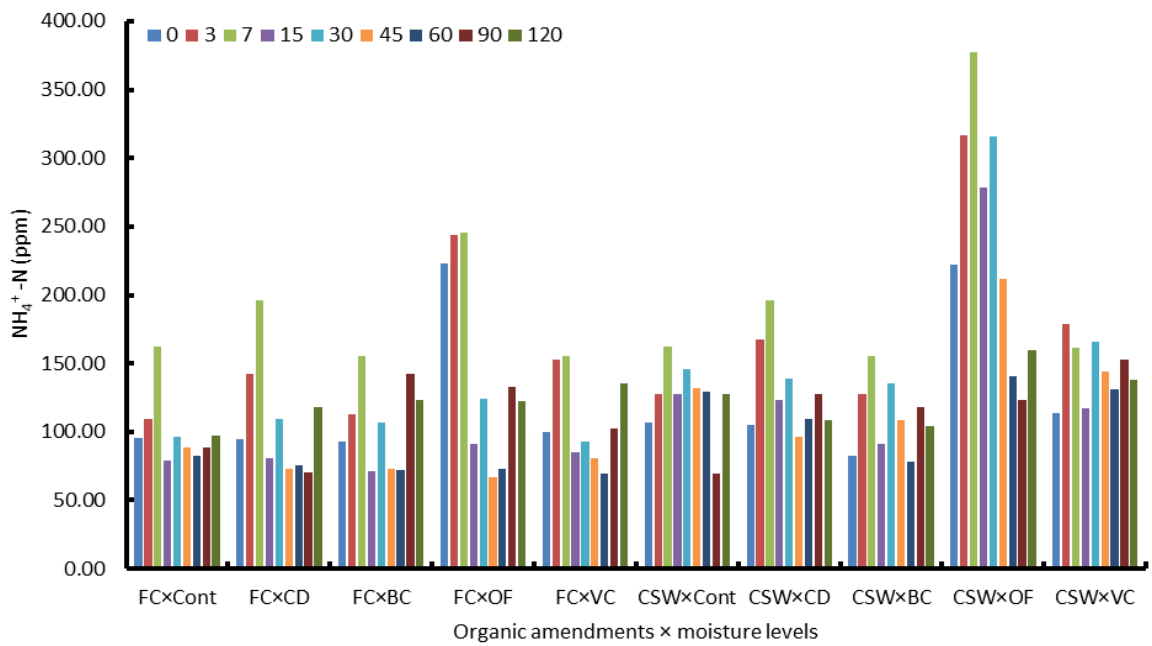


Figure 87. Interaction effect between moisture levels and organic amendments on NH_4^+- N content in soil at different durations (FC: field capacity and CSW: continuous standing water, cont: control, CD: cowdungbioslurry, BC: biochar, OF: organic fertilizer and VC: vermicompost)

On the other hand, continuous standing water × organic fertilizer contributed 138.63% more NH_4^+-N than field capacity × control treated soil. The lowest NH_4^+-N (105.59 and 104.06 ppm) in field capacity × biochar and continuous standing water × biochar treatments. On the other hand, maximum NH_4^+-N was produced (147.02 and 238.35 ppm) in field capacity × organic fertilizer and continuous standing water, respectively. But in case of water levels, vermicompost produced the medium level of NH_4^+-N (108.30 and 144.82 ppm) in field capacity × vermicompost and continuous standing water × vermicompost, respectively. Only soil produced 99.88 and 125.36 ppm NH_4^+-N in field capacity and continuous standing water

condition, respectively. Field capacity increased 26% more ammonification process over continuous standing water condition. The utilization ways of NH_4^+-N in soil are oxidation to NO_3^--N, volatilization as NH_3, immobilization and fixation in soil clays. Higher rate of ammonification for an extended period in this experiment may be due to lack of facility of leaching loss in incubation condition which is one of the main reasons of rapid disappearance of N in field condition.

Effect of water levels on nitrification

The trend of nitrification due to water levels as a function of incubation time has been illustrated (Figure 88). NO_3^--N content was decreased in all treatment compared to NH_4^+-N content in soil. This period can be considered lag period of nitrogen transformation in soil. NO_3^--N content results were significantly different at all the studied durations. Field capacity and continuous standing water sharply increased NO_3^--N from 0 to 7 days after incubation. After seven days, the trend of NO_3^--N content was inconsistently increased and decreased until 120 days. Maximum NO_3^--N content. After 7 days of incubation, NO_3^--N content was found 134.16 ppm in field capacity at 7 days of incubation whereas field capacity produced the highest NO_3^--N content at 30 days of incubation.

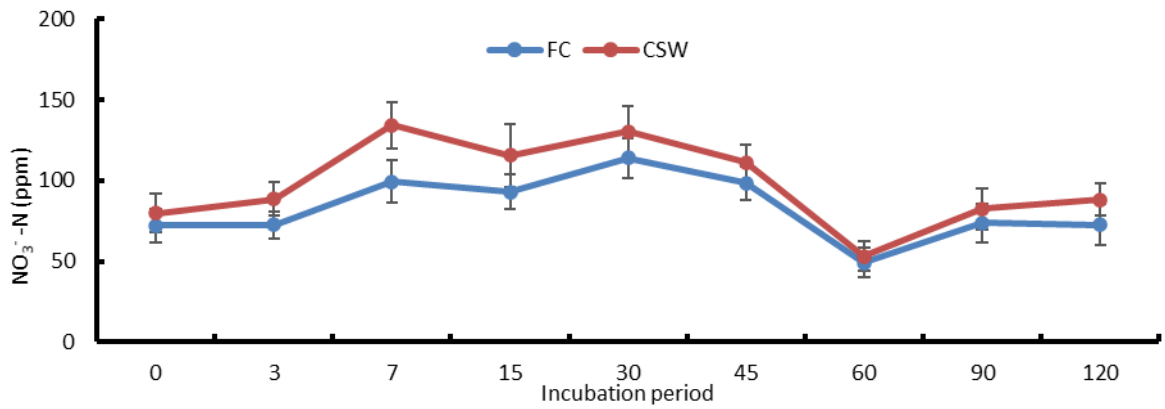


Figure 88. Effect of different water levels on NO_3^- -N content in soil at different durations (FC: field capacity and CSW: continuous standing water)

On the other hand, minimum NO_3^--N content was obtained (53.19 and 49.08 ppm) from continuous standing water and field capacity at 60 days after incubation. After 7 days of incubation. NO_3^--N content was decreased in both field capacity and continuous standing water treated soil and thereafter it increased at 30 days of incubation. After 30 days of incubation, NO_3^--N content decreased with more or less irregular fashion until 120 days. Field capacity hastened 19% more nitrification process than continuous standing water condition.

Effect of organic amendments on nitrification

At 0 day means after six hours, cowdung produced the highestNO_3^--N content and followed by control, vermicompost and organic fertilizer treated soil (Figure 89). The lowest NO_3^--N content was found in biochar treated soil. Cowdung and control treatments decreased NO_3^--N from 0 to 3 days of incubation. Maximum NO_3^--N content (168.31 ppm) increased in organic fertilizer treated soil at 7 days after incubation, minimum NO_3^--N was produced from all the organic amendments at 60 days of incubation. Control treatment produced the lowest average NO_3^--N content (88.95 ppm) and the highest average NO_3^--N content (102.37 ppm) produced in organic fertilizer treated soil. Cowdung, biochar, organic fertilizer and vermicompost produced 6.81, 3.70, 23.42 and 11.61% more NO_3^--N than control treatment.

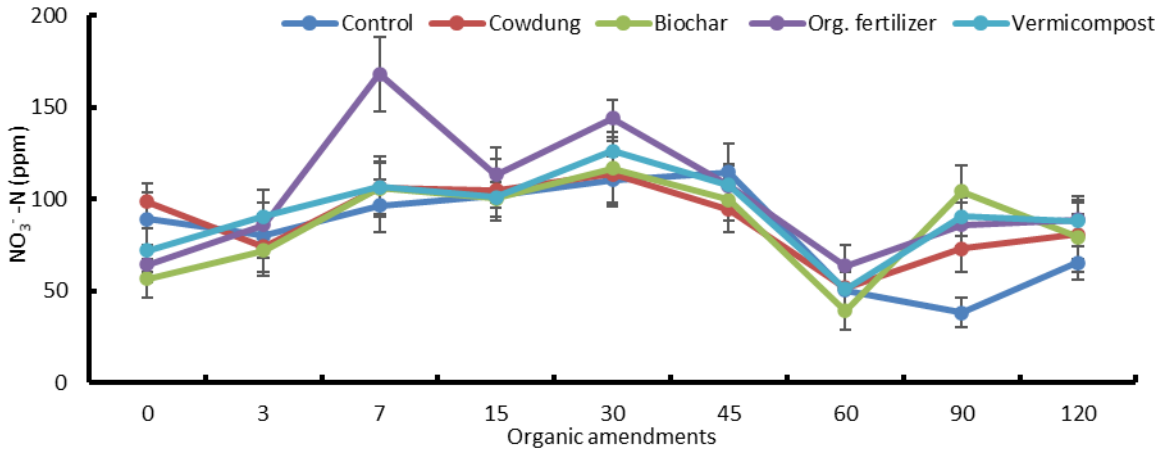


Figure 89. Effect of different organic amendments on NO_3^- -N content in soil at different durations

Organic fertilizer produced 23.42% higher NO_3^--N content over control treatment. The second highest NO_3^--N content was found in vermicompost treated soil. Among the organic amendments, biochar produced the lowest NO_3^--N content in soil. Control treatment produced the lowest NO_3^--N content at 7, 15, 30, 90 and 120 days of incubation except 0, 3, 45 and 60 days after incubation. On the other hand, organic fertilizer produced the highest NO_3^--N content at 7, 15, 30, 60 and 120 days except 0, 3, 45 and 90 days of incubation. Among the studied period biochar produced the lowest NO_3^--N at 0, 3, 15 and 60 days of incubation.

Effect of interaction effect on nitrification

The highest NO_3^--N content (245.26 ppm) was produced in continuous standing water × organic fertilizer at 7 days of incubation and the lowest NO_3^--N content (30.29 ppm) was recorded from continuous standing water × control treatment (Figure 29). At 30 days of incubation, all the interaction treatments produced the highest average NO_3^--N (122.22 ppm) content and the lowest average NO_3^--N content (51.13 ppm) at 60 days of incubation.

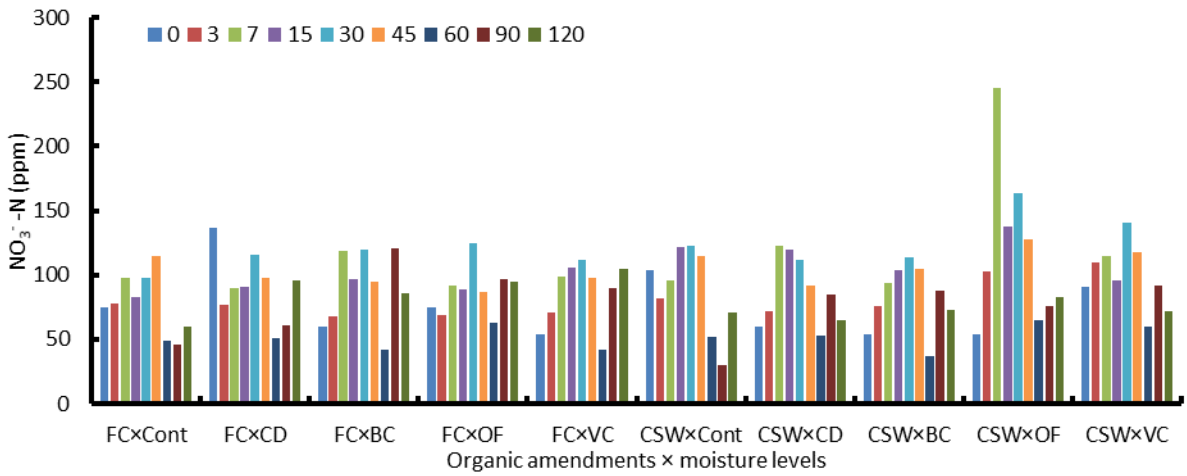


Figure 90. Interaction effect between moisture levels and organic amendments on NO_3^- -N content in soil at different durations (FC: field capacity and CSW: continuous standing water, cont: control, CD: cowdungbioslurry, BC: biochar, OF: organic fertilizer and VC: vermicompost)

CSW ×OF produced 39.27 ppm NO_3^--N over FC ×control treatment. NO_3^--N content results varied from 77.74 to 117.01 ppm in different interaction treatments. In respect of percent NO_3^--N production, results varied from 5.99 to 50.52% in different interaction treatments. CSW × OF produced 50.52% more NO_3^--N content over FC × control treatment. On the other hand, CSW × biochar produced 5.99% more NO_3- -N content over FC × control treatment.

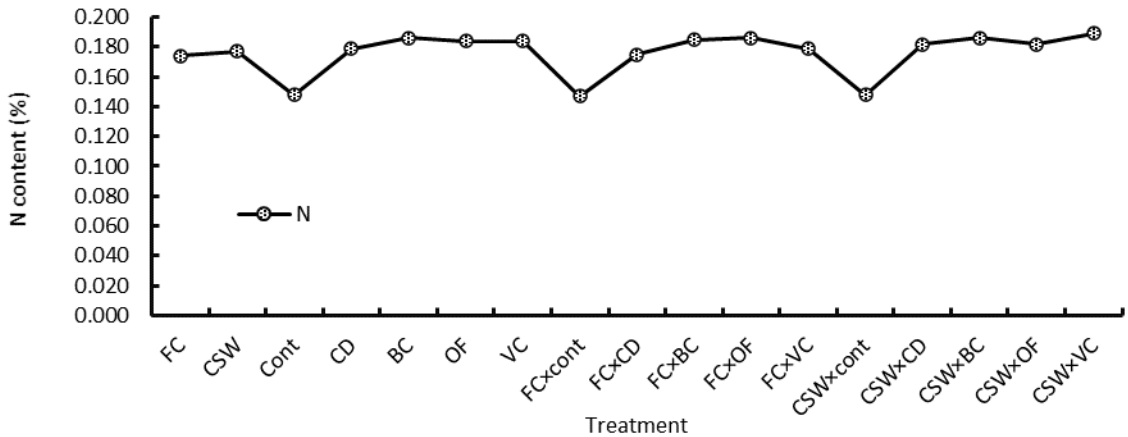


Figure 91. Effect of water levels, organic amendments and their interactions on total N content in soil

Nitrogen content in soil was significantly affected by different water levels, organic amendments and their interaction (Figure 91). Nitrogen content was increased with increasing soil moisture content. The higher nitrogen content (0.18%) was recorded from continuous standing water condition and the lower nitrogen content (0.17%) was obtained from field capacity of soil. In case of organic amendments, the highest nitrogen content (0.18%) was observed from VC and the lowest nitrogen content (0.15%) was recorded from control treatment. In respect of interaction effect, maximum nitrogen content (0.19%) was noticed from CSW ×VC and the minimum nitrogen cont (0.15%) was obtained from FC ×cont and CSW ×cont treatments.

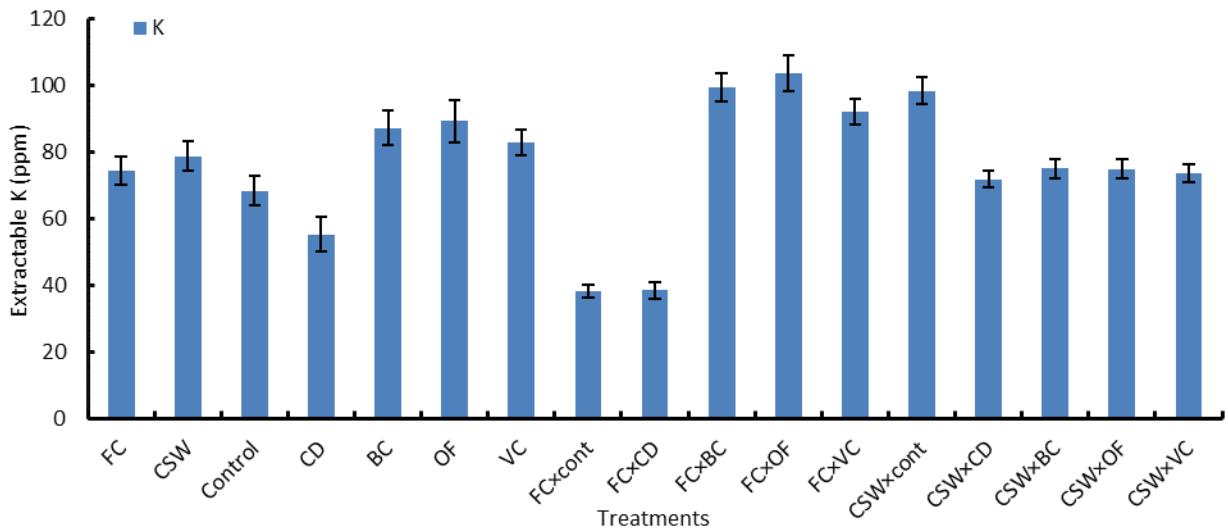


Figure 92. Effect of water levels, organic amendments and their interactions on extractable K content in soil

Potassium content in soil was significantly affected by different water levels, organic amendments and their interaction (Figure 92). Potassium content was increased with increasing soil moisture content. The higher potassium content (78.77 ppm) was recorded from continuous standing water condition and the lower potassium content (74.41ppm) was obtained from field capacity of soil. In case of organic amendments, the highest potassium content (89.28%) was observed from OF and the lowest potassium content (55.18 ppm) was recorded from CD treatment. In respect of interaction effect, maximum potassium content (103.70 ppm) was noticed from FC × OF and the minimum potassium content (38.25 ppm) was obtained from FC ×cont treatment. Field capacity produced the maximum extractable Fe, Cu and Mn contents (92.90, 1.02 and 8.45 ppm) over continuous standing water condition, respectively (Table 6). On the other hand, the higher Zn availability (1.68 ppm) was found in continuous standing water condition. Among the organic amendments, biochar produced the highest Fe, Cu, Mn and Zn (93.20, 1.03, 8.47 and 1.76 ppm) in soil. The lowest Fe, Cu, Mn and Zn were observed 87.62, 0.97, 7.96 and 1.04 ppm in vermicompost, cowdund and vermicompost, vermicompost and control treatment, respectively.

Table 63. Effect of water levels, organic amendments and their interaction on Fe, Cu, Mn and Zn content in soil

Treatment	Fe	Cu	Mn	Zn	Na	Ca
	----------ppm----------					me/100g soil
Water level (WL)						
FC	92.90±6.70	1.02±0.14	8.45±0.47	1.12±0.12	43.55±3.55	6.42±0.42
CSW	87.63±7.61	0.96±0.12	7.96±0.28	1.68±0.34	45.57±3.57	7.40±0.50
Organic amendment (OA)						
Control	92.74±7.29	1.02±0.12	8.42±1.00	1.04±0.10	30.45±3.45	6.43±0.43
CD	88.36±5.88	0.97±0.11	8.03±0.80	1.24±0.16	34.49±3.49	7.09±0.59
BC	93.20±5.94	1.03±0.13	8.47±0.63	1.76±0.36	51.62±3.62	7.31±0.82
OF	89.41±7.18	0.98±0.10	8.13±1.00	1.34±0.20	61.70±3.70	6.87±0.67
VC	87.62±7.36	0.97±0.10	7.96±0.98	1.61±0.32	44.56±3.65	6.87±0.67
WL×OA						
FC ×cont	95.72±6.52	1.06±0.14	8.69±0.80	1.00±0.98	30.45±3.25	5.98±0.98
FC ×CD	97.74±7.50	1.08±0.15	8.89±0.99	1.02±1.02	27.43±3.43	5.98±0.98
FC ×BC	101.90±5.66	1.12±0.20	9.27±1.02	1.20±0.18	66.74±3.74	6.87±0.87
FC ×VC	84.86±8.62	0.94±0.11	7.71±0.89	1.22±0.20	59.68±3.68	5.98±0.98
FC ×OF	84.30±9.06	0.92±0.10	7.67±0.80	1.14±0.14	33.47±3.47	7.31±0.41
CSW ×cont	89.76±9.24	0.98±0.12	8.15±0.95	1.04±0.10	30.45±3.45	6.87±0.87
CSW ×CD	78.98±8.74	0.86±0.08	7.17±0.82	1.24±0.16	41.54±3.54	8.20±0.99
CSW ×BC	84.50±5.77	0.94±0.10	7.67±0.79	1.76±0.36	36.50±3.50	7.75±0.75
CSW ×VC	90.38±8.18	1.00±0.12	8.21±0.81	1.61±0.32	63.71±3.71	7.75±0.75
CSW ×OF	94.52±8.29	1.04±0.14	8.59±0.99	1.34±0.21	55.65±3.65	6.42±0.42

Minimum Fe, Cu, Mn content was found in vermicompost treated soil. Continuous standing water produced the maximum extractable Caand Na contents (7.40 me/100 g soil and 45.57 ppm ppm) over field capacity, respectively. Among the organic amendments, biocharproduced the highest Ca and Na (7.31 me/100 g soil and 51.62 ppm) in soil. The lowest Ca and Na were observed 6.43 me/100 g soil and 30.45ppm in control treatment, respectively.CSW × CD and produced the highest Ca content (8.20 me/100 g soil) and the minimum Ca content (5.98 me/100 g soil ppm) was obtained from FC × cont, FC × CD and FC × VC treatments. On the other hand, FC × BC produced the highest Na content (66.74 ppm) and the minimum Na content (27.43 ppm) was obtained from FC × CD treatment.

Mineralization study of different organic amendments at Soil Science Laboratory, Bangladesh Institute of Nuclear Agriculture (BINA), Mymensingh

Experiment 3:
Improvement of soil health in unfavorable eco-systems with organic amendments for sustainable crop production

Results and Discussion

Experiment 3(1) Significant variation was observed on the plant height of rice when the field was incorporated with different treatments (Table 64). The tallest plant (82.93 cm) was

observed from recommended dose of chemical fertilizer in combination with 2.0 t/ha biochar application and the smallest (82.20 cm) was noticed from control treatment. Biochar might have increased the soil moisture content, soil porosity and other plant enhancing characters and for that reason increased plant height.

Table 64. Effect of chemical and it's combination with organic fertilizers on yield and yield attributing characters of Boro rice 2018

Treatment	Plant height (cm)	Panicle length (cm)	Effective tiller (no.)	Non-effective tiller (no.)	Root weight (gm)	1000 seed weight (g)	Grain weight (t/ha)	Straw weight (t/ha)
T_0	82.20	19.80c	7.46b	3.62c	65.25	21.83	2.50c	3.40d
T_1	83.33	22.87a	10.87a	4.46a	72.93	22.67	3.84ab	4.50a
T_2	82.93	22.92a	11.20a	3.93b	72.48	22.13	3.98ab	4.52a
T_3	83.20	22.60ab	10.95a	4.03b	86.52	22.07	3.90a	4.32b
T_4	82.46	21.47b	10.30a	4.10b	69.70	22.57	3.12bc	4.12c
T_5	83.40	22.27ab	10.60a	3.67c	80.32	21.70	3.59b	4.22bc
Sig. Level	NS	*	*	*	NS	NS	*	*
CV(%)	3.45	2.96	7.60	3.16	14.85	2.47	15.34	2.07

Table 65. Effect of chemical and it's combination with organic fertilizers on yield and yield attributing characters of rice in Aman 2019

Treatment	Plant height (cm)	Panicle length (cm)	Root weight (gm)	Total tiller (no.)	Non-effective tiller (no.)	Filled grain(no)	Unfilled grain(no)	1000 seed weight (g)	Grain weight (t/ha)	Straw weight (t/ha)
T_0	96.80c	20.60b	2.69	10.93	0.80	97.13	8.27	21.40	5.92	6.70
T_1	101.13ab	21.27ab	2.76	12.53	1.00	115.53	15.00	21.27	6.00	7.41
T_2	100.67ab	21.47ab	2.86	13.00	0.93	123.20	10.60	21.00	6.26	7.34
T_3	103.13a	21.67ab	2.56	11.87	0.80	127.53	10.87	14.80	6.05	7.12
T_4	98.20bc	21.33ab	2.10	12.07	0.87	104.53	11.27	21.13	6.03	6.84
T_5	99.60bc	22.20a	2.42	12.73	0.78	118.93	10.27	21.47	6.53	7.56
Sig. Level	*	NS	NS	NS	NS	NS	NS	NS	NS	NS
CV(%)	1.82	3.71	18.79	11.10	35.68	25.77	34.22	8.11	12.04	11.18

Recommended dose of chemical fertilizer with 2.0 t/ha biochar also produced the highest panicle length and effective tiller per hill of rice. The significant result was found in non-effective tiller hill^{-1} of rice by the different treatments (Table 64). Recommended dose of chemical fertilizer produced the highest non-effective tiller per hill of rice. The highest root weight (86.52 g) was obtained from recommended dose of chemical fertilizer with 3.0 t/ha poultry manure treated plot. T_1 treatment produced the maximum 1000 seed weight of rice. The highest grain and straw yield (3.98 and 4.52 t/ha) was observed from recommended dose of chemical fertilizer in combination with 2.0 t/ha biochar treatment, respectively. Yield and yield attributing character results significantly did not perform except plant height in different treatments (Table 65). Maximum panicle length (22.20 cm), total tiller (12.73) and thousand seed weight (21.47 g) were observed in recommended fertilizer using IPNS + 3.0 t ha^{-1} organic fertilizer treated plot. On the other hand, the lowest non-effective tiller per plant was obtained from the same treatment.

Table 66. Effect of chemical and it's combination with organic fertilizers on yield and yield attributing characters of mustard in Aman 2020

Treatment	Plant height (cm)	Panicle length (cm)	Total tiller (no.)	Non-effective tiller (no.)	Grain (no)	1000 seed weight (g)	Grain weight (t/ha)	Straw weight (t/ha)
T_0	74.93b	12.13b	33.93c	6.67b	20.93	3.34	0.75b	1.12
T_1	95.67a	13.00ab	46.53abc	7.93a	25.40	3.06	1.52a	2.07
T_2	97.13a	13.10ab	42.40abc	8.10a	23.53	2.94	1.55a	2.31

T_3	96.53a	14.07a	54.13a	7.85a	24.13	3.30	1.77a	2.97
T_4	96.40a	14.00a	47.67ab	7.13ab	24.67	3.27	1.77a	2.79
T_5	94.27a	13.60ab	40.00bc	7.93a	24.07	3.40	1.67a	2.75
Sig. Level	**	*	*	**	NS	NS	**	NS
CV(%)		7.25	8.43	17.29	10.80	12.02	17.29	10.80

Maximum root weight (2.86 g) per plant was found in recommended fertilizer using IPNS + 3.0 t ha^{-1} poultry manure. As a result, highest grain and straw yields were found in recommended fertilizer using + 3.0 t ha^{-1} organic fertilizer. The second highest grain and straw yields were found in recommended fertilizer using IPNS + 3.0 t ha^{-1} poultry manure. Effects of chemical fertilizer and IPNS based (chemical and organic amendments) fertilizer treatments on yield and yield components results are presented (Table 66). In Rabi season, maximum seed and straw yields of mustard were observed in recommended fertilizer + 3.0 t ha^{-1} poultry manure due to higher panicle length, total tiller per plant and thousand seed weight. All the treatments produced significant yield and yield attributes except control treatment. Maximum organic carbon was found in 0-15cm soil depth.

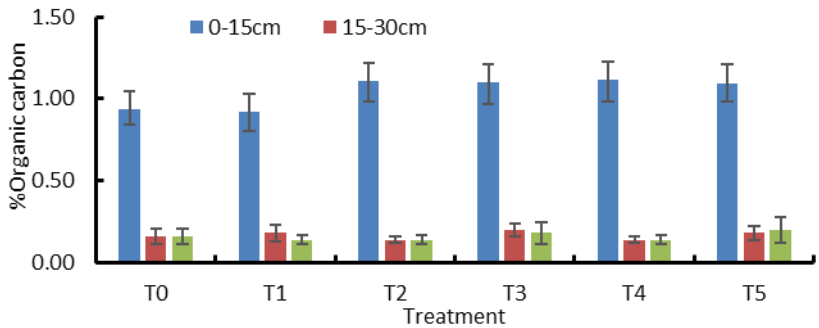


Figure 93. Effect of chemical fertilizers and organic fertilizers on organic carbon at different depths of soil

Organic carbon decreased with th increase of soil depth. At 0-15cm soil depth, the highest organic carbon (1.12%) was found in T_4 treatment which was followed by T_2, T_3 and T_5 treatments (Figure 32). At 15-30 and 30-45cm soil depths, organic carbon content was followed more or less similar trend in different treatments. Effect of different treatments results on total nitrogen content is presented (Figure 33). T_4 produced the highest total nitrogen content in soil which followed by T_3 and T_5 treatments. Maximum total nitrogen content (0.55%) in T_4 treatments and the minimum total nitrogen content was obtained from control treatment at 0-15cm soil depth. The second highest total nitrogen content (0.50%) was observed in T_3 at 0-15cm soil depth.

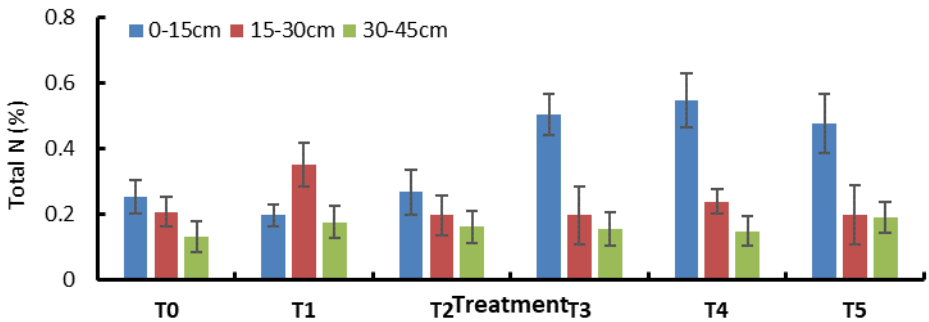


Figure 94. Effect of chemical fertilizers and in combination with organic fertilizers on total nitrogen at different depths of soil

Total nitrogen content was decreased with the increase of soil depth. At 15-30cm soil depth, the highest total nitrogen content was found in T_5 treatment.

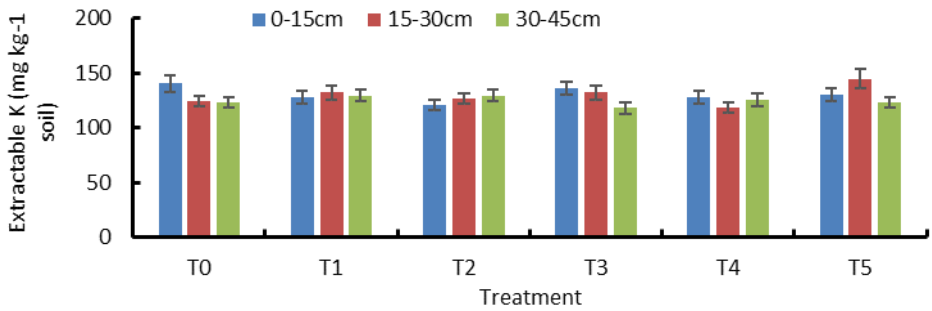


Figure 95. Effect of chemical and organic fertilizers on K content in soil

Maximum K content (144.83 ppm) was observed from T_5 treatment at 15-30 cm soil depth and the minimum K content (117.84 ppm) was recorded from T_3 treatment at 30-45 cm soil depth (Figure 34). K content was decreased with increasing soil depth. Extractable Fe and Mn content of soil were affected by different treatments (Figure 35). At 0-15 cm soil depth, the highest Fe content (86.04 ppm) was recorded from T_0 treatment while the lowest Fe content (38.00 ppm) was noticed from T_1 treatment. At 15-30 and 30-45cm soil depth, the highest Fe content (34.76 and 31.26 ppm) was obtained from T_1 treatment. Fe content decreased with increasing soil depth. The lowest Fe content was observed in 30-45 cm soil depth.

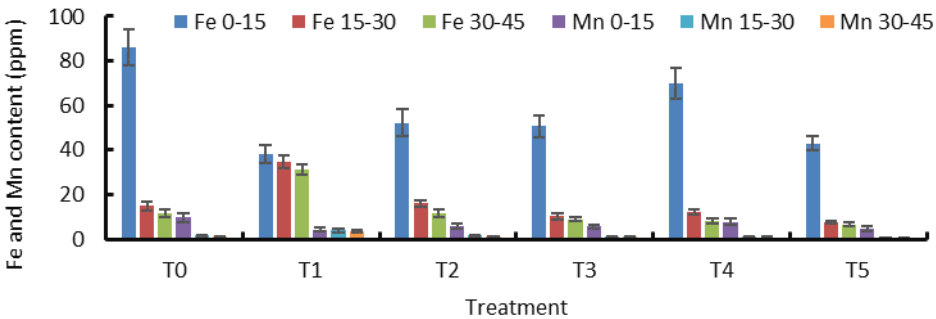


Figure 96. Effect of chemical fertilizers and in combination with organic fertilizers on Fe and Mn content at different depths of soil

On the other hand, maximum Mn content (9.67 ppm) was observed from T_0 treatment and the minimum Mn content (5.89 ppm) was recorded from T_2 treatment. Mn content was decreased with increasing soil depth.

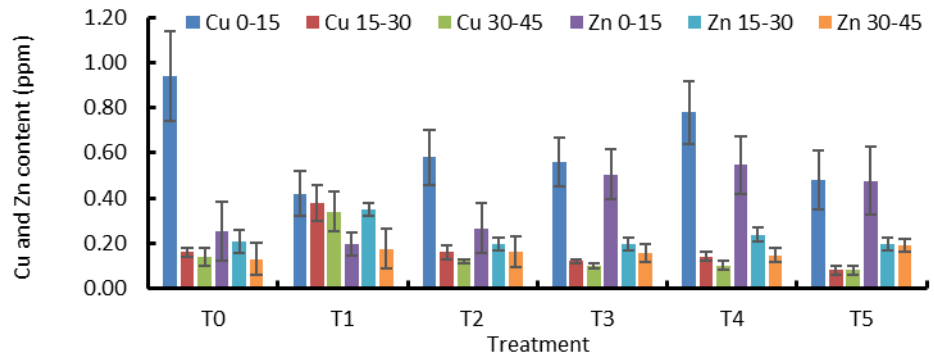


Figure 97. Effect of chemical fertilizers and in combination with organic fertilizers on Cu and Zn content at different depths of soil

Extractable Cu and Zn content of soil were affected by different treatments (Figure 36). At 0-15 cm soil depth, the highest Cu content (0.94 ppm) was recorded from T_0 treatment while the lowest Cu content (0.42 ppm) was noticed from T_1 treatment. At 15-30 and 30-45cm soil depth, the highest Cu content (0.38 and 0.34 ppm) was obtained from T_1 treatment. Cu content decreased with increasing soil depth. The lowest Cu content was observed in 30-45 cm soil depth. In case of Zn, the highest Zn content (0.55 ppm ppm) was recorded from T_4 treatment while the lowest Zn content (0.20 ppm) was noticed from T_4 and T_2 treatments, respectively. At 15-30 and 30-45cm soil depth, the highest Zn content (0.35 and 0.20 ppm) was obtained from $T_1$and T_5treatments, respectively. Zn content decreased with increasing soil depth. The lowest Zn content was observed in 30-45 cm soil depth.

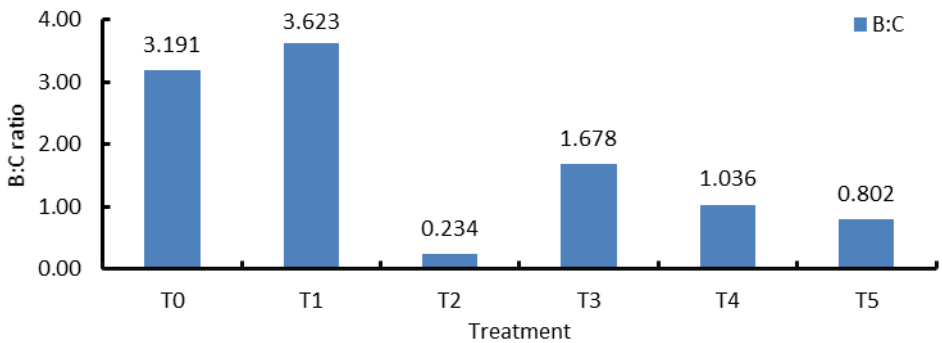


Figure 98. Effect of different treatments on benefit–cost ration of boro-T. aman-rabi cropping pattern

Effect of diffrenet treatments on benefit-cost ratio (B:C) results are presented (Figure 98). B:C results ranged from 0.234 to 3.623. Maximum B:C ration was recorded from recommended dose of chemical fertilizers and the lowest B:C ration was noticed from recommeded dose of cemical fertilizers along with biochar treatment. Recommended dose of chemical fertilizer is profitable practice for boro-T. aman-rabi cropping pattern but in terms of IPNS in combination with biochar, PM, VC and OF would be the sustainable practice for improving soil quality and increasing crop production.

Field experiment view, crop establishment and soil collection at Nacholeupazilla of Chapainawabganj district

Experiment 3(2)

Results and Discussion

Recommended dose of chemical fertilizers alone and in combination with 3.0 tha^{-1} treatments showed significant variation on yield and yield attributing characters of rice (Table 67). Maximum yield attributing characters such as plant height, panicle length, effective tiller, non-effective tiller, root weight, 1000 seed weight were found in recommended doses of chemical fertilizers in combination with 3.0 t/ha treatment.

Table 67. Effect of chemical and poultry manure on yield and yield attributing characters of Boro rice 2018

Treatment	Plant height (cm)	Panicle length (cm)	Effective tiller (no.)	Non-effective tiller (no.)	Root weight (gm)	1000 seed weight (g)	Grain weight (t/ha)	Straw weight (t/ha)
T_1	86.58b	21.17	14.30	2.90	74.67	22.47	4.17	4.50
T_2	91.00a	21.77	14.74	2.91	75.46	22.56	4.76	5.20
Sig. Level	*	NS	NS	NS	NS	NS	NS	NS
CV(%)	0.63	1.36	14.87	10.65	6.92	1.66	11.08	6.63

Table 68. Effect of chemical and poultry manure on yield and yield attributing characters of Aman rice 2019

Treatment	Plant height (cm)	Panicle length (cm)	Total tiller (no.)	Non-effective tiller (no.)	Root weight (gm)	Filled grain (no)	Unfilled grain (no)	1000 seed weight (g)	Grain weight (t/ha)	Straw weight (t/ha)
T_1	85.13	22.93	11.03	1.00	6.55	156.37	24.43	21.00	6.54	6.94
T_2	84.43	23.33	10.70	1.00	6.61	152.83	20.13	21.40	6.42	6.98
Sig. Level	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
CV(%)	1.49	2.05	7.30	23.66	12.16	9.48	33.94	2.60	12.16	7.21

Table 69. Effect of chemical and poultry manure on yield and yield attributing characters of mustard 2020

Treatment	Plant height (cm)	Root weight (gm)	Total tiller (no.)	Pod length (cm)	Seed per pod (no)	1000 seed weight (g)	Grain weight (t/ha)	Straw weight (t/ha)
T_1	97.73	11.87	56.60	7.67	28.40	2.63	0.97	4.67
T_2	93.80	14.20	57.53	8.00	25.00	2.81	0.61	3.08
Sig. Level	NS	NS	NS	NS	NS	NS	NS	NS
CV(%)	1.55	7.70	25.95	4.54	5.05	13.35	14.62	12.09

Table 70. Effect of chemical and poultry manure on yield and yield attributing characters of lentil 2020

Treatment	Plant height (cm)	Root weight (gm)	Total tiller (no.)	100 seed weight (g)	Seed yield (t/ha)	Hay yield (t/ha)
T_1	31.20a	5.40	77.40	1.77	2.59	2.52
T_2	28.20b	4.40	70.70	1.29	2.51	2.14
Sig. Level	*	NS	NS	NS	NS	NS
CV(%)	1.43	14.42	16.24	16.18	1.61	6.53

Table 71. Effect of chemical and poultry manure on yield and yield attributing characters of wheat 2020

Treatment	Plant height (cm)	Root weight (gm)	Total tiller (no.)	Spike length (cm)	100 seed weight (g)	Grain weight (t/ha)	Straw weight (t/ha)
T_1	91.60	7.80	5.47	9.16	4.72	3.83	7.24
T_2	88.87	8.00	6.80	9.27	5.28	3.89	6.36
Sig. Level	NS	NS	NS	NS	NS	NS	NS
CV(%)	3.44	12.53	17.91	3.52	17.49	17.83	15.52

The highest grain and straw yield were obtained from recommended doses of chemical fertilizers with 3.0 t ha^{-1} poultry manure treatment. Effect of chemical fertilizer alone and combined use of chemical and organic amendments on yield and yield attributes results are presented (Table 68). IPNS based treatment (chemical + poultry manure) treated plot produced the higher grain and straw yield of rice. Yield and yield attributes results were not statistically significant. In lentil and mustard experiments, maximum seed and hay yield were observed in recommended fertilizer using IPNS + 3.0 t ha^{-1} poultry manure (Table 70). On the other hand, chemical fertilizer produced the higher grain and straw yield of wheat over recommended fertilizer using IPNS + 3.0 t ha^{-1} poultry manure (Table 71).

Field experiment view with different crops at rabi crop season

BAU Component

Activity 1: Initial charaterisation of soils at acid soil and charland soil sites, Site characteristics

The study focused on acid soils in Madhupur, Tangail (24º59.82′ N, 90º03.99′ E) and charland soils in Islampur, Jamalpur (25º80.73′ N, 89º81.90′ E) in two farmers' fields with major cropping patterns in both sites. The climate in the region is subtropical monsoon, with an average annual temperature of 26º C, an average annual rainfall of 1800 mm, and an average relative humidity of 85 % (Local weather station). The general soil type of acid soil in Madhupur, Tangail with a deep red to brown terrace soils (Aquic Ustochrepts in the US Soil Taxonomy) (FAO and UNDP, 1988) is located in Agro-ecological zone 28 (AEZ-28; Madhupur Tract), while Charland soil in Islampur, Jamalpur with a Non-Calcareous Dark Grey Floodplain Soils (Aeric Haplaquept in the US Soil Taxonomy) (FAO and UNDP, 1988) is located in Agro-ecological zone 9 (AEZ-9; Old Brahmaputra Floodplain). The soil texture of Madhupur site was clay loam with a pH of 5.5, making it strongly acidic, whereas the texture of Islampur site was sandy loam with a pH of 6.6, making it near about neutral in nature. The initial physicochemical properties of soil in Madhupur and Islampur sites were presented in Table 72, Table 73 and Table 74. All nutrient elements in soil decreased with soil depth. When compared between the two sites, all nutrients except the exchangeable K were higher in acidic soil site than in char land site (Table 72). Bulk density of the soils at char land site was higher than the acidic soil site because of the higher sand content in the soil (Table 73). Total Zn and Fe contents were higher in acidic soil site than the char land site. By contrast, Ca and Mg contents were higher in char land site than the acidic soil site (Table 74). The B content ranged from 0.38 ppm to 0.68 ppm in acidic soil site while it ranged from 0.09 ppm to 0.42 ppm in char land site. Interestingly, soil aggregate mean weight diameter was higher in acidic soil site with silty clay loam than in char land site with sandy loam texture (Fig. 99). Likewise, soil aggregate dry mass for macro aggregates were higher in acidic soil site than in char land site (Fig. 100).

Table 72. Initial physico-chemical properties of soils at Madhupur and Islampur sites

Site/Depth (cm)	SOC (%)	TN (%)	Available P (ppm)	Exc. K (meq. $100g^{-1}$)	Available S (ppm)
Acid soil					
0-15	0.99±0.06	0.09±0.00	17.63±0.37	0.12±0.03	14.95±0.02
16-30	0.48±0.13	0.03±0.01	16.23±0.65	0.11±0.02	13.06±0.02
31-45	0.37±0.03	0.02±0.00	15.84±0.37	0.10±0.01	11.16±0.02
Charland					
0-15	0.53±0.01	0.05±0.01	12.37±0.37	0.12±0.04	10.53±0.02
16-30	0.39±0.04	0.03±0.01	11.14±0.57	0.09±0.02	8.26±0.02
31-45	0.21±0.04	0.02±0.01	7.86±0.11	0.08±0.01	7.25±0.02

Table 73. Initial physico-chemical properties of soil at Madhupur and Islampur site

Site/Depth (cm)	pH	Moisture (%)	CEC (meq. /100 g)	Bulk density(g cm^{-3})
Acid soil				
0-15	5.5	21.69	17.71	1.15
16-30	5.6	28.10	16.96	
31-45	6.1	32.13	13.27	
Charland				
0-15	6.6	17.28	10.31	1.32
16-30	6.6	22.74	10.39	
31-45	6.9	28.61	10.84	

Table 74. Initial macro and micro nutrient contents of soils at Madhupur and Islampur sites

Site/Depth (cm)	Zn (ppm)	Fe (II) (ppm)	Ca^{2+}(meq./100 g)	Mg^{2+}(meq./100 g)	B (ppm)
Acid soil					
0-15	4.49	99.26	2.71	0.88	0.66
16-30	2.04	44.98	2.51	0.90	0.68
31-45	0.54	7.81	2.77	1.23	0.38
Charland					
0-15	0.32	10.08	4.10	1.77	0.42
16-30	0.25	8.79	3.56	1.16	0.39
31-45	0.25	3.05	2.68	1.05	0.09

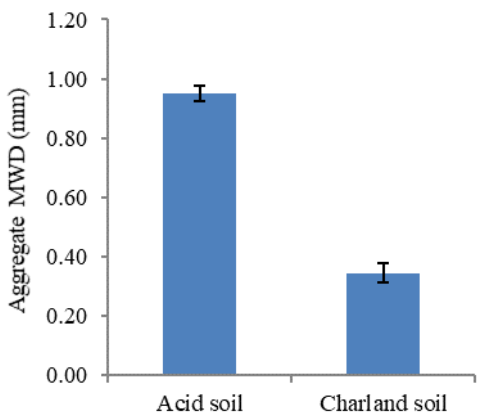


Figure 99. Soil aggregates mean weight diameter at acid and charland soil sites as measured prior to experimentation

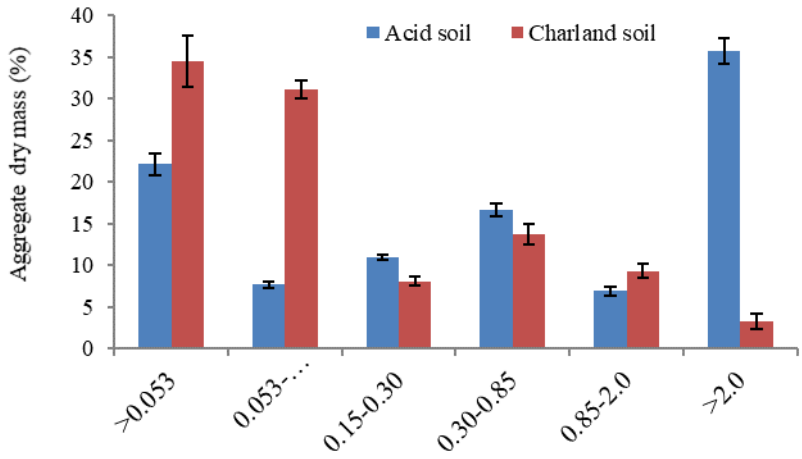


Figure 100. Soil aggregate size distribution (% dry mass) at acid and charland soil sites as measured prior to experimentation

Statement of soil related problems of the study sites

Problems of acid soils

- Initial characterization of acid soils showed that these soils have low pH, low organic matter, deficiency of macronutrients, soil erosion due tow infiltration rates and low cropping intensity.
- Present land Use: Boro - T. Aman
- Proposed Cropping Pattern: Mustard - Boro - T. Aman

Problems of charland soils

- Initial characterization of charland showed that these soils are low in organic matter content, less cropping intensity, higher leaching loss, flood affected; higher soil erosion and lower cropping intensity.
- Present land use: Maize – Jute
- Proposed cropping pattern: Maize - Jute - T. Aman

Activity 2: Production of biochar using different available sources and their characterization

Biochar plant

- A biochar plant was established at BAU equipped with necessary facilities, especially a thermostat to maintain the targeted temperature (Fig. 101);
- Poultry manure biochar, rice husk biochar and rice straw biochar were prepared successfully and characterized accordingly for their physical and chemical properties (Fig. 102). Biochars can be easily prepared in Bangladesh and can be made available for agricultural use.

Figure 101. Biochar plant at BAU

Figure 102. Biochar produced in the BAU biochar plant and used in the current experiment

Particle size distribution of poultry manure and rice husk biochar

After preparation, poultry manure and rice husk biochars were mixed well and homogenized. Majority of the biochars were found larger than 0.30 mm where the highest biochar size group was between 0.85 and 2.0 mm (Table 75 and Table 76). The lowest amount of biochars was below 0.053 mm. However, aging of biochar or peroxide treatment of biochar can make biochars particles much smaller and stable.

Chemical properties of biochars produced at BAU Farm

Organic carbon content of biochars ranged from 17.5% in rice husk biochar to 30.8% in poultry manure biochar (Table 6). Likewise, in other organic amendments, organic carbon (OC) ranged from 7.27 to 8.56% which were much less than the OC in the either biochar. The pH was higher in poultry manure and poultry manure biochar than all other treatments suggesting that both poultry manure and poultry manure biochar have greater liming impact that raises soil pH. Similarly cation exchange capacity (CES), available P and S and exchangeable K were higher in both biochars than in other treatments where the CEC was also different between the former two being higher in poultry manure biochar than in rice husk biochar (Table 77).

Table 75. Particle size distribution of poultry manure biochar

Particle size class (mm)	Particle size distribution (g)	Particle size distribution (%)
< 0.053	7.26	3.67
0.053-0.15	11.42	5.67
0.15-0.30	14.03	7.00
0.30-0.85	53.32	26.67
0.85-2.00	80.99	40.33
> 2.00	32.27	16.00

Table 76. Particle Size Distribution of Rice Husk Biochar

Particle size class (mm)	Size distribution (g)	Particle Size distribution (%)
< 0.053	2.00±0.4	1.0±.25
0.053-0.15	6.84±0.8	3.0±1.3
0.15-0.30	13.88±1.2	7.0±1.5
0.30-0.85	64.17±2.3	32±1.7
0.85-2.00	85.55±3.2	43±2.4
> 2.00	27.08±3.4	14±1.6

Table 77. Physico-chemical properties of biochars along with other organic amendments used for crop production

Biochar	OC (%)*	TN (%)*	pH	CEC* meq.100g^{-1}	Available P (ppm)	Exc. K meq.100g^{-1}	Available S (ppm)
RHB*	17.5±0.31	1.81±0.05	7.5	19.54	1149	15.99	415
PMB*	30.8±0.20	3.08±0.13	8.5	35.68	1437	22.61	2094

*OC stands for organic carbon, TN for total nitrogen and CEC for cation exchange capacity, RHB for rice husk biochar and PMB for poultry manure biochar

Activity 3: Comparative performance of organic materials and dolomite for correction of soil acidity- crop performance and soil health evaluation

Madhupur soil

Agronomic performance

Different treatments significantly influenced mustard yield in both 2019 and 2020 ($p<0.001$, Table 78). In 2019, mustard yield in different treatments ranged from 0.6 to 1.3 t ha^{-1} exhibiting the highest yield in PMB and RD and the lowest yield in control. The increase in yield over control varied from 66.7 to 116.7%. The highest increase was observed in PMB and RD, and the lowest increase in PM and Dolomite + RD. In 2020, mustard yield in different treatments ranged from 0.7 to 1.6 t ha^{-1}exhibiting the highest yield in Dolomite + RD which was similar to RD and the lowest yield in control. The increase in yield over control varied from 85.7 to 128.67%. The highest increase was observed in Dolomite + RD, and the lowest increase in PMB and RHB.

Likewise, yield of boro rice was also significantly influenced by different treatments in both 2019 and 2020 ($p<0.001$, Table 8). In 2019, boro rice yield in different treatments ranged from 4.0 to 6.7 t ha^{-1} exhibiting the highest yield in RHB which was identical to PMB, PM, and RD and the lowest yield in control. The increase in yield over control varied from 47.5 to 67.5%. The highest increase was observed in RHB, and the lowest increase in Dolomite + RD. In 2020, boro rice yield in different treatments ranged from 3.5 to 7.1 t ha^{-1}exhibiting the highest yield in PMB which was similar to all the treatments except RHB and control, and

the lowest yield in control. The increase in yield over control varied from 80.0 to 102.9%. The highest increase was observed in PMB, and the lowest increase in RHB.

Similarly, yield of T. Aman rice was also significantly influenced by different treatments in both 2019 and 2020 ($p<0.001$, Table 78). In 2019, T. Aman rice yield in different treatments ranged from 3.6 to 6.0 t ha^{-1}exhibiting the highest yield in Dolomite + RD which was identical to PMB, RHB, and RD and the lowest yield in control. The increase in yield over control varied from 50.0 to 66.7%. The highest increase was observed in Dolomite + RD, and the lowest increase in PM. In 2020, T. Aman rice yield in different treatments ranged from 3.5 to 5.6 t ha^{-1}exhibiting the highest yield in RHB which was similar to all the treatments except control, and the lowest yield in control. The increase in yield over control varied from 42.9 to 60.0%. The highest increase was observed in RHB, and the lowest increase in RD.

Different treatments significantly increased total system productivity of the Mustard–Boro–T. Aman rice cropping pattern compared to the control both in 2019 and 2020 ($p<0.001$, Table 78). In 2019, the increase in system productivity in different treatments over control ranged from 55.4 to 69.6%, exhibiting the highest value in PMB and the lowest in Dolomite + RD. In 2020, the increase over control varied from 74.7 to 82.8%. The highest increase was observed in Dolomite + RD and the lowest in RHB.

Figure 103. Land preparation and treatment application in the field at Madhupur

Table 78. Effect of different treatments on yield and system productivity of Mustard–Boro–T. Aman cropping pattern

Treatments	2019				2020			
	Mustard yield (t ha^{-1})	Boro yield (t ha^{-1})	T. Aman yield (t ha^{-1})	System productivity (t ha^{-1})	Mustard yield (t ha^{-1})	Boro yield (t ha^{-1})	T. Aman yield (t ha^{-1})	System productivity (t ha^{-1})
Control	0.6±0.2d	4.0±0.1c	3.6±0.1c	9.2±0.2d	0.7±0.1d	3.5±0.1c	3.5±0.2b	8.7±0.2b
PM	1.0±0.1c	6.5±0.1a	5.4±0.1b	14.4±0.3bc	1.4±0.2bc	6.6±0.3ab	5.2±0.4a	15.3±0.8a
RHB	1.1±0.1b	6.7±0.1a	5.5±0.1ab	15.0±0.1abc	1.3±0.3c	6.3±0.05b	5.6±0.2a	15.2±0.3a
PMB	1.3±0.1a	6.6±0.04a	5.7±0.1ab	15.6±0.1a	1.3±0.3c	7.1±0.03a	5.5±0.06a	15.8±0.1a
Dolomite + RD	1.0±0.1c	5.9±0.09b	6.0±0.1a	14.3±0.1c	1.6±0.6a	6.5±0.1ab	5.4±0.2a	15.9±0.4a
RD	1.3±0.1a	6.2±0.1ab	5.6±0.1ab	15.1±0.2ab	1.5±0.1ab	6.6±0.1ab	5.0±0.1a	15.5±0.1a
Level of sig.	***	***	***	***	***	***	***	***

PM = Poultry manure, RHB = Rice husk biochar, PMB = Poultry manure biochar, RD = Recommended dose of fertilizer

Figure 104. Mustard grown in acid soil at Madhupur site in an annual mustard–Boro–T. Aman rice pattern

Figure 105. T. Aman rice grown in field at Madhupur site in an annual mustard–Boro–T. Aman rice pattern

Treatment effects on nitrogen uptake and use efficiency of rice

Similarly, different IPNS treatments significantly influenced N uptake by boro rice in both 2019 and 2020, and NUE in 2019 (Table 79). In 2019, the increase in N uptake over control ranged from 65.7 to 74.7%, exhibits the highest value in RHB and the lowest value in RD (Table 79). The increase in N uptake over control ranged from 76.4 to 96.2% in 2020. The highest increase was observed in PMB and the lowest increase was observed in RHB (Table 79). The highest NUE was noted in PMB in both 2019 and 2020, whereas the lowest NUE was noted in Dolomite + RD and RHB, in 2019 and 2020 (Table 79).

Table 79. Effects of organic amendments on nitrogen uptake and NUE at Madhupur site; mean ± SE (n=4)

Treatment	N uptake (kg N ha^{-1})				NUE (%)			
	Aman 2019	Aman 2020	Boro 2019	Boro 2020	Aman 2019	Aman 2020	Boro 2019	Boro 2020
Control	54.1±3.5c	53.4±3.9b	57.4±2.9b	52.6±2.5c				
PM	83.7±0.6ab	82.3±4.4a	97.7±3.2a	93.4±1.5b	32.8±0.8a	32.1±4.9ab	33.6±2.7	34.0±1.25b
RHB	78.5±2.08b	83.7±4.7a	100.3±3.9a	92.8±1.1b	27.1±2.3b	33.6±5.3b	35.7±3.3	33.5±0.92b
PMB	88.4±1.04a	88.6±2.3a	102.4±0.3a	103.2±1.0a	38.1±1.2a	39.0±2.6a	37.5±0.3	42.2±0.9a
Dolomite + RD	82.2±1.5ab	83.6±3.02a	95.1±2.1a	95.2±2.1ab	31.2±1.7b	33.5±3.4ab	31.4±1.8	35.5±1.8b
RD	82.2±0.5ab	82.3±1.8a	96.8±1.07a	94.3±1.3b	31.2±0.6b	32.0±2.0ab	32.8±0.9	34.8±1.1b
Level of sig.	***	***	***	***	**	*	ns	**

PM = Poultry manure, RHB = Rice husk biochar, PMB = Poultry manure biochar, RD = Recommended dose of fertilizer;

Averaged values within a column, succeeded by different small letters (a, b, c) differ significantly, ns indicates non-significant, * indicates significant at 5% level of significance, ** indicates significant at 1% level of significance, *** indicates significant at 0.1% level of significance.

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Treatment effect on carbon pools, lability indices, stock and microbial biomass

Effects of different treatments on MBC and MBN

At Madhupur site, MBC was significantly influenced by different treatments ($p<0.05$, Fig. 106). PMB had the highest MBC which was statistically similar to RHB and PM whereas the lowest value was observed in control which was statistically identical to all the treatments except PMB (ca. 275.0, 233.3, 225.0, 212.5, 200.0 and 183.3 mg kg soil^{-1} in PMB, PM, RHB, Dolomite + RD, RD and control, respectively) (Fig. 106). MBC increased about 9.1 to 50.0% in different treatments over control exhibiting the highest value in PMB and the lowest in RD. In contrast, the effect of incorporation of different treatments to the soil on MBN was not statistically significant.

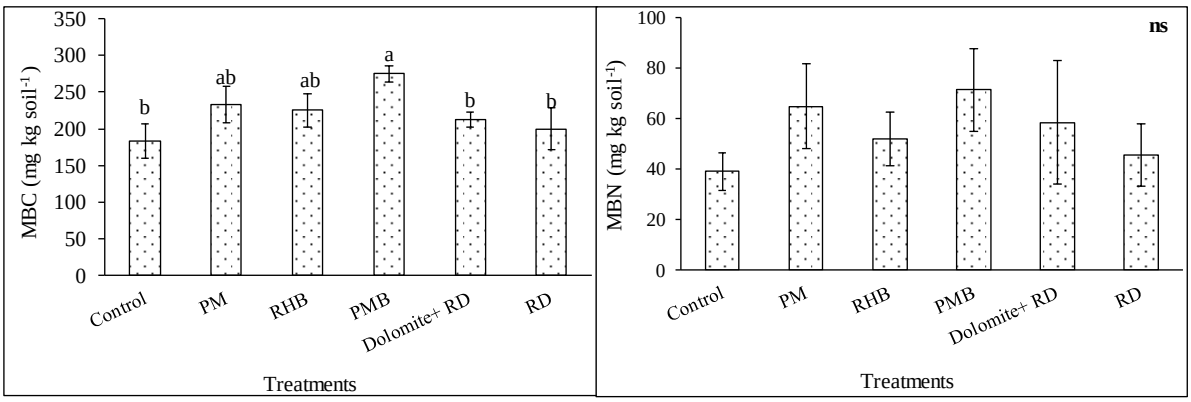


Figure 106. Effects of different treatments on MBC and MBN at Madhupur site (PM = Poultry manure, RHB = Rice husk biochar, PMB = Poultry manure biochar, RD = Recommended dose of fertilizer)

Effects of organic amendments on basal respiration

Different treatments significantly influenced BR at Madhupur site ($p<0.05$) (Fig. 107). The highest BR was observed in PMB which was statistically similar to all the treatments except control whereas the lowest value was observed in control which was statistically identical to all the treatments except PMB. The mean BR was 154.17, 135.42, 72.92, 54.17, 41.67 and 29.17 mg CO_2-C h^{-1} kg soil^{-1}, in PMB, Dolomite + RD, RHB, RD, PM and control, respectively (Fig. 107). The increase in BR due to incorporation of different treatments varied from 43 to 429% exhibiting the highest value in PMB and the lowest in PM.

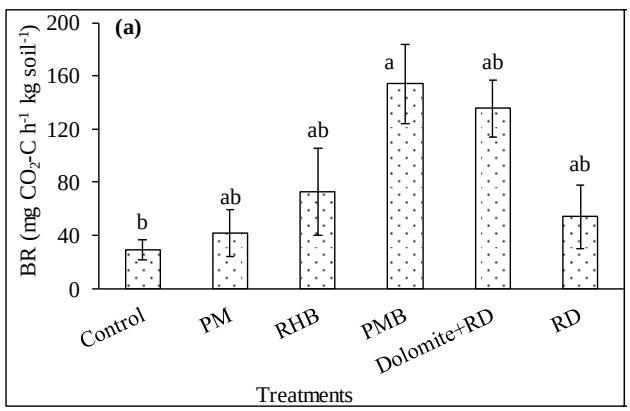


Figure 107. Effects of different treatments on basal respiration at Madhupur site

Effects of different treatments on organic carbon pools

At Madhupur site, application of biochar (PMB and RHB), organic amendment (PM) and inorganic fertilizer (Dolomite + RD and RD) had significant impact on SOC and POC in soil ($p<0.05$, Table 80). The SOC value ranged from 9.3 to 11.5 g kg soil^{-1} in different treatments. The highest SOC content in soil was determined in Dolomite + RD which were statistically similar to PMB, RHB and RD whereas the lowest value was observed in control being identical to all the treatments except dolomite. The increase in SOC content in soil over control ranged from 1.1 to 23.6% exhibiting the highest increase in Dolomite + RD and the lowest in PM. Similarly, the POC value ranged from 799.4 to 2207.9 mg kg soil^{-1} in different treatments. The highest POC content in soil was observed in PMB which was statistically similar to all the treatments except control whereas the lowest value was observed in control being identical to all the treatments except PMB and RD. The increase in POC content in soil over control ranged from 88.0 to 176.2% exhibiting the highest increase in PMB and the lowest in PM. In contrast, the effects of application of biochar (PMB and RHB), organic amendment (PM) and inorganic fertilizer (Dolomite + RD and RD) on POXC and soil bulk density were not significant (Table 80).

Table 80. Effects of different treatments on SOC, POC, POXC and bulk density at Madhupur and Islampur sites at a depth of 0-15 cm

Treatment	SOC (g kg soil^{-1})	POC (mg kg soil^{-1})	POXC (mg kg soil^{-1})	Bulk density (g cm^{-3})
Control	9.28 b	799.40 b	111.62	1.26
PM	9.38 b	1502.80 ab	143.67	1.16
RHB	9.73 ab	1804.50 ab	120.62	1.22
PMB	10.77 ab	2207.90 a	167.42	1.21
Dolomite + RD	11.47 a	1574.90 ab	177.88	1.23
RD	10.48 ab	2061.70 a	165.38	1.24
SE	0.88	475.55	38.60	0.05
CV (%)	12.22	40.55	36.94	5.59
Level of sig.	*	*	ns	ns

OC= Soil organic carbon, POC= Particulate organic carbon, POXC= permanganate oxidizable carbon, PM= Poultry manure, RHB= Rice husk biochar, PMB= Poultry manure biochar, RD= Recommended dose of fertilizer, SE= Standard error of means, CV%= Co-efficient of variation, Figures in a column having different letter are statistically different at 5% level of significance.

Effects of different organic and inorganic treatments on soil carbon lability and management indices

At Madhupur site, CL_I and CMI of AC were not significantly influenced by different treatments (Table 81). In contrast, CL_I and CMI of MBC significantly differed due to application of different treatments ($p<0.05$, Table 81). CL_I of MBC ranged from 1.0 to 1.5 in different treatments. The highest value was observed in PMB which was statistically similar to all the treatments except control whereas the lowest value was observed in control being identical to all the treatments except PMB. Likewise, the highest value of CMI (1.8) was observed in PMB which was identical to PM (1.6) and RHB (1.5) whereas the lowest value was noted in control (1.1) being identical to RD (1.3), Dolomite + RD (1.4) and RHB (1.5).

Table 81. Effects of different treatments on carbon lability and management indices of active and microbial biomass at Madhupur and Islampur sites at a depth of 0-15 cm

Madhupur site				
Treatment	AC		MBC	
	CL_I	CMI	CL_IMBC	CMI
Control	1.05	1.09	1.02 b	1.06 c
PM	1.40	1.54	1.48 ab	1.55 ab
RHB	1.03	1.14	1.41 ab	1.47 abc
PMB	1.41	1.67	1.53 a	1.83 a
Dolomite + RD	1.39	1.92	1.09 ab	1.40 bc
RD	1.31	1.52	1.16 ab	1.31 bc
SE	0.31	0.46	0.22	0.20
CV (%)	34.54	44.09	24.79	19.60
Level of significance	ns	ns	*	*

AC= Active carbon, MBC= Microbial biomass carbon, CL_I= Carbon lability index, CMI= Carbon management index, PM= Poultry manure, RHB= Rice husk biochar, PMB= Poultry manure biochar, RD= Recommended dose of fertilizer, SE= Standard error of means, CV%= Co-efficient of variation, Figures in a column having different letter are statistically different at 5% level of significance.

Effects of different treatments on soil carbon stocks

At Madhupur site, TOC stock was significantly influenced by different treatments ($p<0.05$, Table 82). TOC stock in soils treated with different treatments ranged from 17.4 to 21.1 Mg ha^{-1}. The highest TOC stock was observed in Dolomite + RD which was statistically similar to PMB and RHB whereas the lowest value was observed in PM being identical to all the treatments except Dolomite + RD. TOC stock decreased by about 6.6% in PM compared to the control whereas the highest increase (20.9%) in TOC stock was observed in Dolomite + RD (Table 82). Likewise, POC stock was also significantly influenced by different treatments ($p<0.05$, Table 82). POC stock in soils treated with different treatments ranged from 1.5 to 3.9 Mg ha^{-1}. PMB had the highest POC stocks which were identical to all the treatments except control and control exhibited the lowest POC stock being identical to all the treatments except PMB. Increase in POC stock in different treatments over control ranged from 74 to 162% exhibiting the highest value in PMB and the lowest in PM. In contrast, the impact of different treatments on POXC stock was non-significant. On the other hand, different treatments significantly influenced MBC stock ($p<0.05$, Table 82). The highest MBC stock was observed in PMB which was statistically similar to PM, RHB and Dolomite + RD whereas the lowest value was observed in control being identical to all the treatments except PMB. The increase in MBC stock in different treatments over control ranged from 23.3 to 66.7%. The highest increase was noted in PMB whereas the lowest in RD.

Table 82. Effects of different treatments on total organic carbon, particulate organic matter, particulate organic carbon, permanganate oxidizable carbon, microbial biomass carbon stocks at Madhupur and Islampur sites at a depth of 0-15 cm

Madhupur site				
Treatment	**Stock**$_{TOC}$ (Mg ha^{-1})	**Stock**$_{POC}$ (Mg ha^{-1})	**Stock**$_{POXc}$ (Mg ha^{-1})	**Stock**$_{MBC}$ (Mg ha^{-1})
Control	17.44 b	1.50 b	0.21	0.30 b
PM	16.28 b	2.61 ab	0.26	0.41 ab
RHB	17.82 ab	3.30 ab	0.22	0.41 ab
PMB	19.43 ab	3.93 a	0.30	0.50 a
Dolomite + RD	21.09 a	2.98 ab	0.33	0.39 ab
RD	19.49 ab	3.76 a	0.31	0.37 b
SE	1.62	0.85	0.07	0.05
CV (%)	12.32	40.05	37.48	18.72
Level of significance	*	*	ns	*

TOC = Total organic carbon, POC = Particulate organic carbon, POXC = Permanganate oxidizable carbon, MBC = Microbial biomass carbon, PM = Poultry manure, RHB = Rice husk biochar, PMB = Poultry manure biochar, RD = Recommended dose of fertilizer, SE = Standard error of means, CV% = Co-efficient of variation, LS = Level of significance, ns = non-significant. Figures in a column having different letter are statistically different at 5% level of significance.

Effects of different treatments on microbial population

At Madhupur site, soil bacterial population was significantly influenced by different treatments ($p<0.05$, Table 83). Bacterial population in soil ranged from 3.75×10^6 to 3.07×10^9 CFU g soil^{-1}. The highest bacterial population was observed in soil treated with Dolomite + RD which was statistically similar to RHB and PMB and the lowest one in control being identical to all the treatments except Dolomite + RD. Likewise, soil fungal population was also significantly enhanced due to addition of different treatments ($p<0.05$, Table 13). The highest fungal population (3.54×10^5 CFU g soil^{-1}) was observed in RHB and the lowest number was observed in control (2.68×10^3 CFU g soil^{-1}) being statistically similar to all the treatments except RHB. In contrast, PSB population was not significantly influenced due to addition of different treatments. In contrast, different treatments significantly influenced B:F ratio in soil. The B:F ratio was observed in PMB which was identical to Dolomite + RD and the lowest B:F ratio was observed in control which was statistically similar to PM, RHB and RD (Table 83).

Table 83. Effects of different treatments on microbial population at Madhupur and Islampur sites at a depth of 0-15 cm

Treatments	Bacteria (CFU g soil^{-1})	Fungi (CFU g soil^{-1})	PSB (CFU g soil^{-1})	B:F ratio
Control	3.75×10^6 b	2.68×10^3 b	3.71×10^5	1.63×10^3 b
PM	2.57×10^7 b	5.73×10^3 b	2.58×10^5	4.56×10^3 b
RHB	2.44×10^9 ab	3.54×10^5 a	2.76×10^5	1.52×10^4 b
PMB	1.77×10^9 ab	4.17×10^4 b	4.61×10^5	6.35×10^5 a
Dolomite + RD	3.07×10^9 a	4.63×10^3 b	4.65×10^4	6.23×10^5 a
RD	3.05×10^7 b	4.06×10^3 b	9.93×10^4	7.76×10^3 b
SE	1.24×10^9	1.41×10^5	2.20×10^5	2.20×10^5
CV (%)	142.95	291.09	123.29	144.88
Level of significance	*	*	ns	*

PSB= Phosphate solubilizing bacteria, B:F ratio =ratio of bacteria and fungi population, PM = Poultry manure, RHB = Rice husk biochar, PMB= Poultry manure biochar, RD = recommended dose of fertilizers, SE = Standard error of means, CV% = Coefficient of variation, LS = Level of significance, ns = non-significant. Figures in a column having different letter are statistically different at 5% level of significance.

Effect of organic amendments on soil aggregate size distribution

The proportion of soil material in aggregate size classes of <0.053 were higher in control which was statistically similar to RD whereas the lowest value was observed in PMB which was identical to all the treatments except control. The aggregate size classes of 0.053-0.15, 0.15-0.30, 0.30-0.85, and 0.85-2 mm were statistically similar in all the treatments. Aggregate size class >2.0 mm increased due to the application of treatments compared to the control exhibiting the highest value in PMB, although it was similar to other treatments except control (Fig. 108).

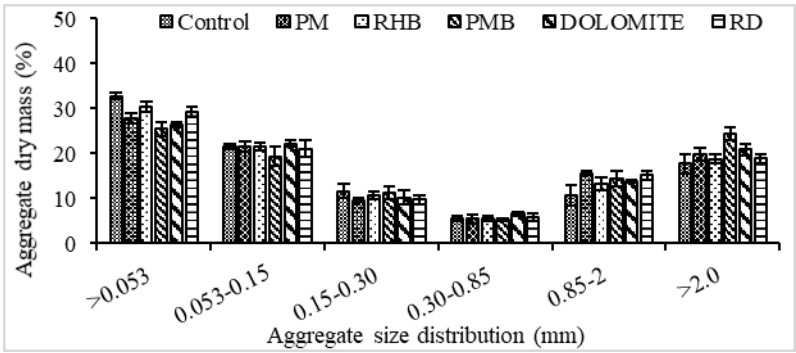


Figure 108. Distribution of aggregate size fractions (bars=average and line=SEM, n=10) of the 0-15 cm layer of field under different treatments

The proportion of micro aggregates (<0.30 mm) were greater in all the treatments than macro aggregates (>0.30) (Table 84). The highest micro aggregate proportion (%) was observed in control which was statistically similar to RD whereas treatments except control were similar. In contrast, macro aggregate increased in all the treatments compared to the control. MWD, GMD, and SI increased due to the application of different treatments compared to the control treatment. All the treatments except control were similar to each other (Table 84).

Table 84. Effects of organic amendments on soil aggregate properties (Madhupur Soil); mean ± SE (n=4)

Treatment	MaAS (%)	MiAS (%)	SI (ratio)	MWD (mm)	GMD (mm)
Control	33.97±1.50b	66.03±1.50a	0.52±0.03b	0.60±0.03b	0.22±0.01b
PM	40.92±0.76a	59.08±0.76b	0.69±0.02ab	0.71±0.02ab	0.27±0.01ab
RHB	40.94±0.75a	59.06±0.75b	0.69±0.02ab	0.72±0.01ab	0.28±0.01ab
PMB	44.00±2.21a	56.00±2.21b	0.79±0.07a	0.78±0.04a	0.32±0.03a
Dolomite + RD	41.19±1.70a	58.81±1.70b	0.70±0.05ab	0.71±0.03ab	0.28±0.01ab
RD	39.89±0.47ab	60.11±0.47ab	0.66±0.01ab	0.69±0.01ab	0.26±0.00ab
Level of significance	**	**	*	**	**

PM = Poultry manure, RHB = Rice husk biochar, PMB = Poultry manure biochar, RD = Recommended dose of fertilizer; Averaged values within a column, succeeded by different small letters (a, b, c, d) differ significantly, * indicates significant at 5% level of significance, ** indicates significant at 1% level of significance

Effect of different treatments on soil physicochemical properties

Different treatments had a significant influence on soil TN ($p<0.001$, Table 85). All the treatments except RHB significantly increased TN content in the soil compared to the control. The highest TN increase over control was observed in PMB (33.3%), whereas the least increase was observed in RD (11.1%; Table 85). Soil available P was higher in the poultry manure biochar treated plots than all other treatments in the top soil layer (0-15 cm) where it was similar to each other in all other treatments. Available S and exchangeable K were equal in all the treatments in all soil depths.

Soil pH was also significantly influenced by different treatments ($p<0.001$, Table 16). Soil pH ranged from 5.22 to 5.72 in different treatments. The highest soil pH was observed in PMB, which was identical to PM, whereas the lowest value was observed in Dolomite + RD and RD. Soil pH decreased by 3.3 and 3.5% in RD and Dolomite + RD, respectively, compared to the control, whereas soil pH increased by 2.4, 3.0, and 5.7%, respectively, in RHB, PM, and PMB, respectively. In contrast, different treatments had no significant effect on soil BD, except in rice husk and poultry manure biochars in top soil depth (0-15 cm) only, suggesting that biochar can reduce soil bulk density in both sandy soils (Table 86). Soil moisture content at field capacity was similar in all treatments at top soil layer but differed significantly in the subsoil layer (15-30 cm), while it was similar in the deeper soil layer. Bicarbonate content in soils was increased in both biochars over the control and other treatments in 0-15 and 15-30 cm soil layers but in the deeper soil layer it was alike in all treatments (Table 16). Total Fe, Mn and Zn was similar in all treatments in all depths except the total Fe which was significantly higher in poultry manure and in both biochars than other treatments in the top soil layer, where the former three were similar to each other (Table 87).

Table 85. Physicochemical properties of soils amended with different organic sources for two consecutive years under mustard – Boro – T. Aman pattern; mean±SE (n=4)

MD	TN (%)			Available P (µg/g)-Bray			Exchangeable K (meq/100 g)			Available S (µg/g)		
Treatment	Depth (cm)			Depth (cm)			Depth (cm)			Depth (cm)		
	0-15	16-30	31-45	0-15	16-30	31-45	0-15	16-30	31-45	0-15	16-30	31-45
Control	0.10 ab	0.03 a	0.03 a	2.21 b	0.97 a	4.42 a	0.11 a	0.12 a	0.18 a	3.63 b	8.18 b	6.48 a
PM	0.09 ab	0.04 a	0.04 a	2.69 b	1.95 a	1.50 a	0.13 a	0.10 a	0.18 a	6.88ab	8.64 ab	10.12a
RHB	0.09 b	0.03 a	0.03 a	1.95 b	0.69 a	5.74 a	0.11 a	0.08 a	0.16 a	5.88ab	11.94ab	6.82 a
PMB	0.11 ab	0.04 a	0.04 a	5.07 a	2.07 a	3.17 a	0.15 a	0.12 a	0.22 a	8.25ab	13.18 a	9.55 a
Dolomite + RD	0.10 ab	0.04 a	0.04 a	2.84 b	1.40 a	1.01 a	0.13 a	0.14 a	0.19 a	10.38 a	12.39ab	9.21 a
RD	0.11 a	0.03 a	0.03 a	2.42 b	1.73 a	1.25 a	0.13 a	0.14 a	0.16 a	6.75ab	12.84ab	8.75 a
SE	0.01	0.01	0.01	0.79	1.11	2.93	0.02	0.03	0.05	2.21	2.29	1.87
LSD	0.02	0.01	0.01	1.68	2.37	6.25	0.05	0.07	0.10	4.71	4.88	3.98
CV (%)	13.70	23.94	23.94	38.84	106.97	145.63	24.24	42.43	36.12	44.92	28.90	31.13
LS	ns	ns	ns	*	ns	ns	ns	ns	ns	ns	ns	ns

PM = Poultry manure, RHB = Rice husk biochar, PMB = Poultry manure biochar, RD = Recommended dose of fertilizer; Averaged values within a column, succeeded by different small letters (a, b, c) differ significantly between different treatments at $p < 0.05$ significance level. * Significant at the 0.05 probability level. ** Significant at the 0.01 probability level. *** Significant at the 0.001 probability level. ns= non-significant

Table 86. Physicochemical properties of soils amended with different organic sources for two consecutive years under mustard – Boro – T. Aman pattern; mean±SE (n=4)

MD	Bulk density (g/cm^{-3})			Field capacity moisture (%)			pH (H_2O)			HCO_3^- (mg/kg)		
Treatment	Depth (cm)			Depth (cm)			Depth (cm)			Depth (cm)		
	0-15	16-30	31-45	0-15	16-30	31-45	0-15	16-30	31-45	0-15	16-30	31-45
Control	1.26a	1.84	1.58	40.22 a	29.01a	16.82a	5.49ab	6.39ab	6.07 a	45.75 b	45.75 b	40.75 a
PM	1.21a	1.88	1.62	43.00 a	24.87ab	16.78a	5.50ab	6.54ab	6.22 a	45.75 b	45.75 b	38.13 a
RHB	1.15a	1.82	1.58	44.51 a	28.96 a	15.56a	5.47 b	6.27 b	6.18 a	53.38 a	68.63 a	38.13 a
PMB	1.16b	1.71	1.74	41.71 a	23.22 b	19.33a	5.70 a	6.71 a	6.34 a	58.13 c	65.75 a	40.75 a
Dolomite +RD	1.23a	1.71	1.79	43.14 a	23.52 b	21.02a	5.15 c	6.56ab	6.38 a	53.38 a	45.75 b	40.75 a
RD	1.24a	1.87	1.63	39.12 a	23.45 b	16.57a	5.18 c	6.37ab	6.48 a	30.50 d	38.13 c	43.38 a
SE	0.05	0.10	0.11	2.39	2.12	3.31	0.10	0.21	0.24	13.01	14.38	11.76
LSD	0.10	0.21	0.23	5.09	4.52	7.06	0.21	0.44	0.51	7.73	7.3	25.06
CV (%)	5.59	7.55	9.05	7.86	11.76	26.48	2.63	4.49	5.34	41.36	42.11	37.38
LS	*	ns	ns	ns	*	ns	**	ns	*	ns	ns	ns

PM = Poultry manure, RHB = Rice husk biochar, PMB = Poultry manure biochar, RD = Recommended dose of fertilizer; Averaged values within a column, succeeded by different small letters (a, b, c) differ significantly between different treatments at $p < 0.05$ significance level. * Significant at the 0.05 probability level. ** Significant at the 0.01 probability level. *** Significant at the 0.001 probability level. ns= non-significant

Table 87. Effect of organic amendments on trace element contents in soi

MD	Available Fe (ppm)			Available Mn (ppm)			Available Zn (ppm)		
Treatment	Depth (cm)			Depth (cm)			Depth (cm)		
	0-15	16-30	31-45	0-15	16-30	31-45	0-15	16-30	31-45
Control	226.86b	37.32a	30.83a	31.59a	10.48a	11.33a	5.05a	0.95 a	1.01 a
PM	248.66a	55.88a	31.68a	34.86a	11.07a	8.56 a	5.41a	1.18 a	0.88 a
RHB	237.48ab	36.20a	30.60a	32.77a	9.30 a	7.48 a	6.06a	0.75 a	0.78 a
PMB	250.47 a	46.45a	25.47a	30.12 b	18.29a	10.12a	5.72 a	1.02 a	0.72 a
Dolomite +RD	283.96 a	46.34a	27.06a	35.00a	11.77a	4.71 a	6.55a	0.79 a	0.80 a
RD	188.64 c	58.15a	32.94a	34.82a	13.53a	7.22 a	5.97a	1.39 a	0.94 a
SE	38.98	23.09	5.82	5.45	4.78	4.49	0.80	0.39	0.16
LSD	21.08	49.20	12.40	11.63	10.19	9.56	1.70	0.84	0.34
CV (%)	27.31	69.87	27.64	25.84	54.52	77.01	22.70	54.76	26.39
LS	***	ns	ns	**	ns	ns	***	ns	ns

PM = Poultry manure, RHB = Rice husk biochar, PMB = Poultry manure biochar, RD = Recommended dose of fertilizer;

Activity 4: Improvement of soil health in Char land with organic amendments for sustainable intensification and better crop production

Islampur soil

Agronomic performance

Different treatments significantly influenced maize yield in both 2019 and 2020 ($p<0.001$, Table 88). In 2019, maize yield in different treatments ranged from 4.6 to 8.7 t ha^{-1} exhibiting the highest yield in PM which was similar to all the treatments except VC and control, and the lowest yield in control. The increase in yield over control varied from 60.9 to 89.1%. The highest increase was observed in PM, and the lowest increase in VC. In 2020, maize yield in different treatments ranged from 3.3 to 7.6 t ha^{-1}exhibiting the highest yield in PMB and the lowest yield in control. The increase in yield over control varied from 106.1 to 130.3%. The highest increase was observed in PMB, and the lowest increase in VC.

Likewise, yield of jute was also significantly influenced by different treatments in both 2019 and 2020 ($p<0.001$, Table 18). In 2019, jute yield in different treatments ranged from 2.5 to 3.7 t ha^{-1}exhibiting the highest yield in VC which was identical to all the treatments except control, and the lowest yield in control. The increase in yield over control varied from 24.0 to 48.0%. The highest increase was observed in VC, and the lowest increase in RD. In 2020, jute yield in different treatments ranged from 1.2 to 2.6 t ha^{-1}exhibiting the highest yield in PMB which was similar to PM, and the lowest yield in control. The increase in yield over control varied from 33.3 to 116.7%. The highest increase was observed in PMB, and the lowest increase in OF and RD

Similarly, yield of T. Aman rice was also significantly influenced by different treatments in both 2019 and 2020 ($p<0.001$, Table 18). In 2019, T. Aman rice yield in different treatments ranged from 3.7 to 5.4 t ha^{-1} exhibiting the highest yield in OF which was identical to PMB and RD and the lowest yield in control. The increase in yield over control varied from 24.3 to 45.9%. The highest increase was observed in OF and PMB, and the lowest increase in PM. In 2020, T. Aman rice yield in different treatments ranged from 1.8 to 4.3 t ha^{-1}exhibiting the highest yield in OF which was similar to RD, and the lowest yield in control. The increase in yield over control varied from 77.8 to 138.9%. The highest increase was observed in OF, and the lowest increase in VC.

Different IPNS treatments significantly increased total system productivity of the Maize-Jute-T. Aman rice cropping pattern compared to the control both in 2019 and 2020 ($p<0.001$, Table 88). In 2019, the increase in system productivity in different treatments over control ranged from 43.3 to 51.1%, exhibiting the highest value in PMB and the lowest in RD (Table 18). In 2020, the increase over control varied from 74.4 to 115.4%. The highest increase was observed in PMB and the lowest in VC.

Table 88. Effect of different treatments on yield and system productivity of Maize-Jute-T. Aman cropping pattern

Treatments	2019				2020			
	Maize yield (t ha^{-1})	Jute yield (t ha^{-1})	T. Aman yield (t ha^{-1})	System productivity (t ha^{-1})	Maize yield (t ha^{-1})	Jute yield (t ha^{-1})	T. Aman yield (t ha^{-1})	System productivity (t ha^{-1})
Control	4.6±0.3c	2.5±0.1b	3.7±0.1d	14.1±0.3b	3.3±0.0d	1.2±0.2c	1.8±0.1d	7.8±0.4d
PM	8.7±0.2a	3.3±0.1ab	4.6±0.1c	20.5±0.3a	7.1±0.0bc	2.3±0.2ab	3.4±0.1c	15.4±0.6ab
PMB	7.9±0.1ab	3.6±0.2a	5.4±0.2ab	21.3±0.4a	7.6±0.2a	2.6±0.2a	3.5±0.1bc	16.8±0.4a
OF	8.0±0.2ab	3.4±0.2ab	5.4±0.1a	21.1±0.5a	7.0±0.07bc	1.6±0.1bc	4.3±0.0a	14.6±0.2bc
VC	7.4±0.1b	3.7±0.3a	4.8±0.1bc	20.5±0.7a	6.8±0.0c	1.7±0.1bc	3.2±0.1c	13.6±0.1c
RD	8.1±0.1ab	3.1±0.1ab	5.2±0.1ab	20.2±0.4a	7.2±0.1b	1.6±0.1bc	3.9±0.1ab	14.3±0.2bc
Level of sig.	***	*	***	***	***	***	***	***

PM = Poultry manure, PMB = Poultry manure biochar, OF = Organic fertilizer (compost), VC = Vermicompost, RD = Recommended dose of fertilizer;

Figure 109. Field site visit during maize growing stage and meeting with farmers at Islampur Charland

Treatment effect on nitrogen uptake and use efficiency of rice and maize

Different organic amendments, including the inorganic ones, significantly increased total system productivity of the Maize – Jute –T. Aman rice cropping pattern compared to the control both in 2019 and 2020 ($p<0.001$, Table 89). In 2019, the increase in system productivity in different treatments over control ranged from 43.3 to 51.1%, exhibiting the highest value in PMB and the lowest in RD (Table 89). In 2020, the increase over control varied from 74.4 to 115.4%. The highest increase was observed in PMB and the lowest in VC. Likewise, N uptake and NUE by T. Aman rice were also significantly influenced by different IPNS treatments in both 2019 and 2020 (Table 19). In 2019, the increase in N uptake over control from 35.5 to 47.2% exhibits the highest value in OF and the lowest value in PM (Table 89). The increase in N uptake over control ranged from 87.1 to 109.3% in 2020. The highest increase was observed in OF and the lowest increase was observed in PM (Table 89). The highest NUE was noted in PMB and the lowest NUE was noted in PM in both 2019 and 2020, respectively (Table 89).

Similarly, different IPNS treatments significantly influenced N uptake and NUE by maize in both 2019 and 2020 (Table 19). In 2019, the increase in N uptake over control ranged from 71.5 to 79.2%, which exhibits the highest value in OF and the lowest value in VC (Table 19). The increase in N uptake over control ranged from 94.5 to 105.7% in 2020. The highest increase was observed in OF and the lowest increase was observed in PM (Table 19). The highest NUE was noted in OF in both 2019 and 2020, whereas the lowest NUE was noted in VC and PM, in both 2019 and 2020 (Table 89).

Table 89. Effects of organic amendments on N uptake and NUE at Islampur site; mean± SE (n=4)

Treatment	N uptake (kg ha^{-1})				NUE (%)			
	Aman 2019	Aman 2020	Maize 2019	Maize 2020	Aman 2019	Aman 2020	Maize 2019	Maize 2020
Control	67.1±3.7c	31.1±0.8d	97.8±3.7b	72.1±1.2c				
PM	90.9±0.9b	58.2±0.8c	169.5±1.5a	140.2±0.5b	26.4±1.0c	30.1±1.0c	32.6±0.7b	31.0±0.2c
PMB	95.4±0.5ab	60.2±0.4bc	170.0±0.4a	144.0±1.3b	31.5±0.6b	32.3±0.5bc	32.8±0.2ab	32.7±0.6b
OF	98.8±0.6a	65.1±0.2a	175.3±0.6a	148.3±0.2a	35.3±0.7a	37.7±0.3a	35.3±0.3a	34.6±0.1a
VC	96.2±0.3ab	59.8±0.6bc	167.7±1.3a	143.7±0.2b	32.4±0.4b	31.9±0.8bc	31.8±0.6b	32.6±0.1b
RD	96.0±0.3ab	61.8±0.7b	170.2±1.1a	144.3±0.6ab	32.2±0.4b	34.1±0.8b	32.9±0.5ab	32.8±0.3b
Level of sig.	***	***	***	***	***	***	**	***

PM = Poultry manure, PMB = Poultry manure biochar, OF = Organic fertilizer (compost), VC = Vermicompost, RD = Recommended dose of fertilizer;

Averaged values within a column, succeeded by different small letters (a, b, c) differ significantly, ** indicates significant at 1% level of significance, *** indicates significant at 1% level of significance.

Treatment effect on carbon pools, lability indices, stock and microbial biomass

Likewise, at Islampur site, different treatments significantly influenced MBC and MBN ($p<0.05$, Fig. 110). MBC in different treatments ranged from 141.7 to 200.0 mg kg soil^{-1} showing the highest value in OF (200.0 mg kg soil^{-1}) which was statistically similar to PMB (183.3 mg kg soil^{-1}) and the lowest in control (141.7 mg kg soil^{-1}) being identical to VC (162.5 mg kg soil^{-1}) and RD (154.2 mg kg soil^{-1}). MBC content in soil increased about 8.8 to 41.2% over control due to addition of different treatments showing the highest value in OF and the lowest in RD. Similarly, MBN in different treatments ranged from 32.4 to 90.8 µg g soil^{-1} exhibiting the highest value in OF (90.8 mg kg soil^{-1}) which was statistically similar to PMB (64.9 mg kg soil^{-1}) and the lowest in control (32.4 mg kg soil^{-1}) which was identical to all the treatments except OF (Fig. 110). MBC content in soil increased about 20 to 180% over control due to addition of different treatments showing the highest value in OF and the lowest in RD.

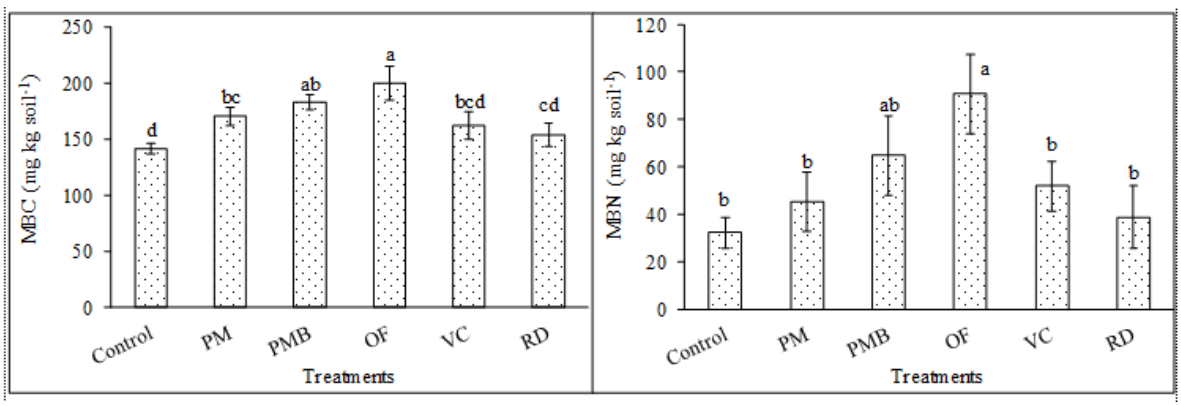


Figure 110. Effects of different treatments on MBC and MBN at Islampur soil (PM = Poultry manure, PMB = Poultry manure biochar, OF = Organic fertilizer (compost), VC = Vermicompost, RD = Recommended dose of fertilizer**)**

Effects of organic amendments on basal respiration

Different treatments significantly influenced BR at Islampur site ($p<0.05$) (Fig. 13). BR ranged from 39.58 to 114.58 mg CO_2-C h^{-1} kg soil^{-1}. The highest mean BR was observed in PMB which was statistical similar to OF and the lowest value was observed in control which was statistically similar to VC, RD and PM (Fig. 111). BR increased from 16 to 189% in different treatments over control. The highest increase was noticed in PMB and the lowest one in PM (Fig. 111).

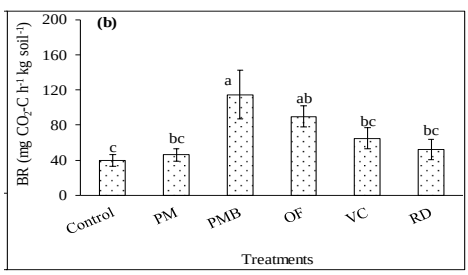


Figure 111. Effects of different treatments on basal respiration at Islampur site (PM = Poultry manure, PMB = Poultry manure biochar, OF = Organic fertilizer (compost), VC = Vermicompost, RD = Recommended dose of fertilizer)

Effects of different treatments on organic carbon pools

At Islampur site, biochar (PMB and RHB), organic amendment (PM) and inorganic fertilizer (Dolomite + RD and RD) significantly influenced SOC ($p<0.05$) and POC ($p<0.01$) content in soil (Table 90). The SOC content in soil varied from 4.9 to 6.8 g kg soil^{-1} in different treatments. The highest SOC content was determined in PMB which was statistically similar to all the treatments except RD whereas the lowest value was observed in RD being identical to all the treatments except PMB. SOC content in soil decreased over control by about 0.9 and 11.8% when treated with PM and RD, respectively, whereas SOC content increased by 4.6, 9.1 and 20.9% in OF, VC and PMB treated soil, respectively. Likewise, the POC content in soil varied from 642.8 to 1915.5 mg kg soil^{-1} in different treatments. The highest POC content in soil was observed in PMB which was statistically similar to OF whereas the lowest value was observed in control being identical to all the treatments except PMB and OF. The increase in POC content in soil over control ranged from 6.0 to 198.0% exhibiting the highest increase in PMB and the lowest in RD. In contrast, application of biochar (PMB and RHB), organic amendment (PM) and inorganic fertilizer (Dolomite + RD and RD) did not affect POXC content and soil bulk density (Table 90).

Table 90. Effects of different treatments on SOC, POC, POXC and bulk density at Madhupur and Islampur sites at a depth of 0-15cm

Treatment	SOC (g kg soil^{-1})	POC (mg kg soil^{-1})	POXC (mg kg soil^{-1})	Bulk density (g cm^{-3})
Control	5.60 ab	642.80 c	285.93	1.33
PM	5.55 ab	1233.00 bc	287.88	1.32
PMB	6.77 a	1915.50 a	283.99	1.32
OF	5.86 ab	1597.30 ab	270.38	1.29
VC	6.11 ab	1179.50 bc	282.05	1.32
RD	4.94 b	681.40 c	270.38	1.35
SE	0.62	318.62	19.34	0.05
CV (%)	14.99	37.29	9.77	4.96
Level of sig.	*	**	ns	ns

SOC = Soil organic carbon, POC = Particulate organic carbon, POXC = permanganate oxidizable carbon, PM = Poultry manure, PMB = Poultry manure biochar, OF = Organic fertilizer (compost), VC = Vermicompost, RD = Recommended dose of fertilizer, SE = Standard error of means, CV% = Co-efficient of variation, figures in a column having different letter are statistically different at 5% level of significance.

Effects of different treatments on soil carbon lability and management indices

At Islampur site, CL_I and CMI of AC were not significantly influenced by different treatments (Table 91). Similarly, CL_I of MBC was not affected by different treatments (Table 91). In contrast, CMI of MBC was significantly influenced by different treatments ($p<0.05$, Table 91). CMI of MBC ranged from 0.9 to 1.3 in different treatments exhibiting the highest value in OF which was statistically similar to PMB whereas the lowest value was observed in RD being identical to VC, control and PM, respectively.

Table 91. Effects of different treatments on carbon lability and management indices of active and microbial biomass at Madhupur and Islampur sites at a depth of 0-15 cm

Treatment	AC		MBC	
	CL_I	CMI	CL_IMBC	CMI
Control	1.02	1.02	0.97	0.97 bc
PM	1.04	1.01	1.17	1.05 bc
PMB	0.81	0.97	0.97	1.16 ab
OF	0.93	0.96	1.22	1.27 a
VC	0.85	0.97	0.85	0.98 bc
RD	1.05	0.94	1.02	0.90 c
SE	0.15	0.08	0.23	0.10
CV (%)	22.94	11.52	31.98	13.00
Level of sig.	ns	ns	ns	*

AC = Active carbon, MBC = Microbial biomass carbon, CL_I = Carbon lability index, CMI = Carbon management index, PM = Poultry manure, PMB = Poultry manure biochar, OF = Organic fertilizer (compost), VC = Vermicompost, RD = Recommended dose of fertilizer, SE = Standard error of means, CV% = Co-efficient of variation, figures in a column having different letter are statistically different at 5% level of significance

Effects of different treatments on soil carbon stocks

At Islampur site, different treatments significantly influenced TOC stock in soil ($p<0.05$, Table 92). TOC stock in soils treated with different treatments ranged from 10.0 to 13.4 Mg ha^{-1}. The highest TOC stock was observed in PMB which was statistically similar to all the treatments except RD whereas the lowest value was observed in RD being identical to all the treatments except PMB (Table 92). TOC stock in soil decreased by about 2.2 and 10.0% in PM and RD, respectively, compared to the control whereas OF, VC and PMB increased TOC stock over the control by 1.4, 8.9 and 20.3%, respectively. In contrast, POC and POXC stock were not influenced by different treatments (Table 92). Unlike different treatments significantly influenced MBC stock ($p<0.05$, Table 92). The highest MBC stock was observed in OF which was statistically similar to PM and PMB whereas the lowest value was observed in RD being identical to control, PM and VC. MBC stock decreased by about 6.5% in RD compared to control whereas MBC stock increased by about 3.2, 9.7, 16.1 and 25.8% in VC, PM, PMB and OF, respectively over the control (Table 92).

Table 92. Effects of different treatments on total organic carbon, particulate organic matter, particulate organic carbon, permanganate oxidizable carbon, microbial biomass carbon stocks at Madhupur and Islampur sites at a depth of 0-15 cm

Treatment	**Stock** $_{TOC}$ (Mg ha^{-1})	**Stock** $_{POC}$ (Mg ha^{-1})	**Stock** $_{POXc}$ (Mg ha^{-1})	**Stock** $_{MBC}$ (Mg ha^{-1})
Control	11.16 ab	9.43	0.57	0.31 bc
PM	10.92 ab	9.34	0.57	0.34 abc
PMB	13.42 a	10.29	0.56	0.36 ab
OF	11.32 ab	9.33	0.53	0.39 a
VC	12.15 ab	8.94	0.56	0.32 bc
RD	10.04 b	8.68	0.55	0.29 c
SE	1.28	1.15	0.04	0.03
CV (%)	15.71	17.36	9.06	12.38
Level of sig.	*	ns	ns	*

TOC = Total organic carbon, POC = Particulate organic carbon, POXC = Permanganate oxidizable carbon, MBC = Microbial biomass carbon, PM = Poultry manure, PMB = Poultry manure biochar, OF = Organic fertilizer (compost), VC = Vermicompost, RD = Recommended dose of fertilizer, SE = Standard error of means, CV% = Co-efficient of variation, LS = Level of significance, ns = non-significant. Figures in a column having different letter are statistically different at 5% level of significance.

Effects of different treatments on microbial population

At Islampur site, different treatments significantly influenced soil bacterial population ($p<0.05$, Table 93). Bacterial population in soil ranged from 1.13×10^7 to 2.96×10^7 CFU g soil^{-1}. The greater number of bacteria was recorded in soils treated with OF which was statistically identical to all the treatments except PM whereas the lowest number was observed in PM which was identical to VC and RD. Similarly, fungal population in soil was also significantly influenced by different treatments ($p<0.05$, Table 23). Fungal population in soil ranged from 4.18×10^3 to 1.28×10^4 CFU g soil^{-1}. The highest fungal population was observed in soil treated with VC which was statistically similar to OF and the lowest one in RD being identical to all the treatments except control and VC. In contrast, PSB population was not significantly influenced by the treatments. However, B:F ratio in soil was statistically significant due to incorporation of the treatments ($p<0.05$, Table 23). The highest B:F ratio (7.75×10^3) was observed in PMB which was statistically similar to RD (5.76×10^3) and OF (4.30×10^3) whereas the lowest ratio was observed in VC (2.07×10^3) being identical to PM (2.24×10^3), control (3.04×10^3) and RD (5.76×10^3).

Table 93. Effects of different treatments on microbial population at Madhupur and Islampur sites at a depth of 0-15 cm

Treatment	Bacteria (CFU g soil^{-1})	Fungi (CFU g soil^{-1})	PSB (CFU g soil^{-1})	B:F ratio
Control	2.95×10^7 a	1.00×10^4 ab	2.90×10^5	3.04×10^3 ab
PM	1.13×10^7 b	5.90×10^3bc	1.87×10^5	2.24×10^3 b
PMB	2.39×10^7 ab	5.25×10^3bc	2.07×10^5	7.75×10^3 a
OF	2.96×10^7 a	7.65×10^3abc	3.26×10^5	4.30×10^3 ab
VC	2.28×10^7 ab	1.28×10^4 a	3.28×10^5	2.07×10^3 b
RD	1.69×10^7 ab	4.18×10^3 c	2.50×10^5	5.76×10^3 ab
SE	6.44×10^6	2.43×10^3	8.46×10^4	2.35×10^3
CV (%)	40.78	45.13	45.19	79.13
Level of sig.	*	*	ns	*

PSB = Phosphate solubilizing bacteria, B:Fratio = ratio of bacteria and fungi population, PM = Poultry manure, PMB = Poultry manure biochar, OF = Organic fertilizer (compost), VC = Vermicompost, RD = Recommended dose of fertilizer, SE = Standard error of means, CV% = Coefficient of variation, LS = Level of significance, ns = non-significant. Figures in a column having different letter are statistically different at 5% level of significance.

Effect of organic amendments on soil aggregate size distribution

The proportion of soil material in aggregate size classes of <0.053 were higher in control which was statistically similar to RD, PM, and VC, whereas the lowest value was observed in PMB which was identical to OF and VC. The aggregate size classes of 0.053-0.15, 0.15-0.30, and 0.30-0.85 mm were statistically similar in all the treatments (Fig. 14). Aggregate size class 0.85-2.0 mm increased in PMB which was similar to OF compared to the control (Fig. 112). Aggregate size class >2.0 mm increased in PMB which was identical to PM compared to the control (Fig. 112).

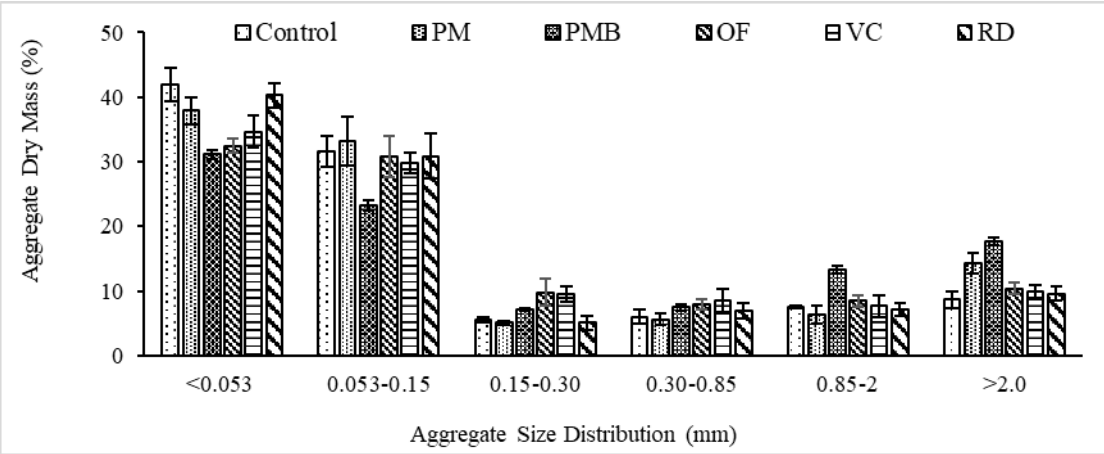


Figure 112. Distribution of aggregate size fractions (bars=average and line=SEM, n=10) of the 0-15 cm layer of field under six treatments (Control, Poultry Manure, Poultry Manure Biochar, Organic Fertilizer, Vermicompost, Recommended Dose)

The proportion of micro aggregates (<0.30 mm) were greater in all the treatments than macro aggregates (>0.30) (Table 24). The highest micro aggregate proportion (%) was observed in RD which was statistically similar to all the treatments except PMB. In contrast, macro aggregate increased in PMB compared to the control, other treatments were statistically similar. MWD, GMD, and SI increased by 32, 11, and 19% in PMB compared to the control treatment. All the treatments except PMB were similar to control in all these cases (Table 24).

Table 94. Effects of organic amendments on soil aggregate properties; mean±SE (n=4)

Treatment	MaAS (%)	MiAS (%)	SI (ratio)	MWD(mm)	GMD (mm)
Control	25.24±2.88b	74.76±2.88a	0.34±0.05b	0.46±0.05b	0.16±0.01b
PM	26.36±2.05b	76.14±1.97a	0.35±0.03b	0.48±0.04b	0.16±0.01b
PMB	30.83±2.26a	69.17±2.26b	0.45±0.05a	0.51±0.04a	0.19±0.02a
OF	25.86±1.68b	74.14±1.68a	0.35±0.03b	0.45±0.03b	0.17±0.01b
VC	26.02±3.26b	73.98±3.26a	0.36±0.06b	0.43±0.04b	0.17±0.02b
RD	23.76±1.45b	76.24±1.45a	0.31±0.02b	0.40±0.02b	0.15±0.01b
Level of sig.	***	***	***	***	***

PM = Poultry manure, PMB = Poultry manure biochar, OF = Organic fertilizer (compost), VC = Vermicompost, RD = Recommended dose of fertilizer; Averaged values within a column, succeeded by different small letters (a, b, c, d) differ significantly between different treatments at $p < 0.05$ significance level. * Significant at the 0.05 probability level. ** Significant at the 0.01 probability level. *** Significant at the 0.001 probability level.

Effect of organic amendments on soil physicochemical properties

Organic amendment based IPNS approaches had no significant effects on soil TN and pH after the completion of the experiment ($p>0.05$, Table 97). In contrast, different treatments in this study had a significant influence on soil BD ($p<0.05$, Table 96). Soil BD ranged from 1.26 to 1.33 g cc^{-1} exhibiting the highest value in control and RD, which were identical to other treatments except PMB, and the lowest value was observed in PMB, which was identical to PM and OF, respectively. Bulk density decreased by about 0.8, 2.3, 3.0, and 5.3% in VC, PM, OF, and PMB, respectively, compared to control. For the trace elements, Fe was similar in all treatments while Mn and Zn were higher in poultry manure, poultry manure biochar and vermicompost in the top soil layer (Table 98).

Table 95. Effects of organic amendments on physico-chemical properties; mean±SE (n=4)

Treatment	Bulk density (g/cc)			Field capacity moisture (%)			pH (H_2O)			HCO_3^- (mg/kg)		
	Depth (cm)			Depth (cm)			Depth (cm)			Depth (cm)		
	(0-15)	(16-30)	(31-45)	(0-15)	(16-30)	(31-45)	(0-15)	(16-30)	(31-45)	(0-15)	(16-30)	(31-45)
Control	1.35 a	1.35 a	1.41 a	33.23 a	28.24a	25.77ab	6.47 a	6.83 a	7.09a	53.38 ab	114.37 ab	137.25 a
PM	1.32 a	1.31 a	1.37 a	33.56 a	24.39a	30.78 a	6.53 a	6.84 a	7.20a	61.00 ab	99.13 ab	137.25 a
PMB	1.32 a	1.33 a	1.33 a	33.75 a	25.34a	32.15 a	6.55 a	7.06 a	7.27a	61.00 ab	114.37 ab	129.63 a
OF	1.29 a	1.34 a	1.32 a	33.52 a	23.20a	22.21 b	6.59 a	6.98 a	7.18 a	68.63 a	91.50 b	99.13 a
VC	1.32 a	1.38 a	1.40 a	34.71 a	26.07a	26.28ab	6.43 a	6.90 a	7.06 a	38.13 b	122.00 a	114.37 a
RD	1.33 a	1.33 a	1.39 a	33.67 a	25.02a	27.06ab	6.43 a	6.93 a	7.10 a	61.00 ab	91.50 b	129.63 a
SE	0.05	3.86	0.05	2.03	3.86	3.65	0.14	0.19	0.13	12.19	10.84	21.92
LSD	0.10	8.22	0.11	4.33	8.22	7.78	0.30	0.41	0.29	25.98	23.11	46.73
CV (%)	4.96	21.50	5.51	8.52	21.50	18.87	3.07	3.95	2.67	30.14	14.54	24.89
LS	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	*	ns

PM = Poultry manure, PMB = Poultry manure biochar, OF = Organic fertilizer (compost), VC = Vermicompost, RD = Recommended dose of fertilizer

Averaged values within a column, succeeded by different small letters (a, b, c, d) differ significantly, * indicates significant at 5% level of significance, ns indicates non-significant

Table 96. Physicochemical properties of soils amended with different organic sources for two consecutive years under mustard – Boro – T. Aman pattern; mean±SE (n=4)

Treatment	TN (%)			Available P(µg/g)-Bray			Exchangeable K (meq/100 g)			Available S(µg/g)		
	Depth (cm)			Depth (cm)			Depth (cm)			Depth (cm)		
	0-15	16-30	31-45	0-15	16-30	31-45	0-15	16-30	31-45	0-15	16-30	31-45
Control	0.07 a	0.05 a	0.04 a	2.46 c	5.70 b	6.69 bc	0.15 b	0.15 ab	0.11 bc	8.25 b	6.93 a	6.92 a
PM	0.07 a	0.06 a	0.04 a	5.19 b	11.33 a	7.07 bc	0.17ab	0.16 a	0.15 ab	12.38ab	8.85 a	7.02 a
PMB	0.07 a	0.05 ab	0.04 a	7.23 a	8.36 ab	5.43 c	0.20 a	0.14 ab	0.13 bc	13.25ab	8.56 a	6.25 a
OF	0.08 a	0.04 b	0.02 b	5.32ab	8.83 ab	9.67 a	0.15 b	0.13 b	0.11 bc	8.38 b	7.50 a	8.27 a
VC	0.06 a	0.05 ab	0.04 a	3.58 bc	10.58ab	5.99 bc	0.16 b	0.14 ab	0.10 c	9.88 ab	8.37 a	3.56 b
RD	0.07 a	0.06 a	0.04 a	3.42 bc	10.57ab	7.45 b	0.18ab	0.15 ab	0.17 a	14.25 a	7.41 a	8.17 a
SE	0.01	0.01	0.005	0.93	2.43	0.92	0.02	0.01	0.02	2.68	2.43	1.04
LSD	0.02	0.01	0.01	1.98	5.18	1.96	0.04	0.03	0.03	5.71	5.18	2.22
CV (%)	21.64	19.65	18.97	28.96	37.27	18.40	14.06	12.68	17.21	34.23	43.31	21.95
LS	ns	ns	*	**	ns	**	ns	ns	**	ns	ns	*

PM = Poultry manure, PMB = Poultry manure biochar, OF = Organic fertilizer (compost), VC = Vermicompost, RD = Recommended dose of fertilizer

Table 97. Effect of organic amendments on trace element contents in soil

Treatment	Available Fe (ppm)			Available Mn (ppm)			Available Zn (ppm)		
	Depth (cm)			Depth (cm)			Depth (cm)		
	0-15	16-30	31-45	0-15	16-30	31-45	0-15	16-30	31-45
Control	92.34 a	44.82ab	25.33b	12.40ab	9.25 a	5.93bc	0.44 b	0.44 ab	0.34 a
PM	78.31 a	50.80 a	34.64a	11.39ab	11.25a	7.09ab	0.95 a	0.76 a	0.45 a
PMB	94.35 a	31.88ab	27.44b	10.46 b	7.83 a	5.93bc	0.97 a	0.36 b	0.32 a
OF	80.76 a	25.92 b	21.34b	11.10 b	7.64 a	4.58 d	0.78ab	0.32 b	0.35 a
VC	87.78 a	29.36ab	21.60b	11.53ab	7.44 a	4.92cd	0.72ab	0.42 b	0.37 a
RD	121.07a	41.59ab	33.90a	20.06 a	9.47 a	8.05 a	0.57 b	0.44 ab	0.40 a
SE	20.98	10.83	2.98	4.12	2.17	0.55	0.16	0.15	0.09
LSD	44.72	23.08	6.35	8.79	4.63	1.18	0.34	0.32	0.19
CV (%)	32.10	40.95	15.39	45.47	34.85	12.90	30.47	46.94	34.30
LS	ns	*	**	*	ns	***	*	*	ns

PM = Poultry manure, PMB = Poultry manure biochar, OF = Organic fertilizer (compost), VC = Vermicompost, RD = Recommended dose of fertilizer

Discussion on management impacts on crop yields, and soil health in both acidic and char land sites

Treatments effects on soil physico-chemical properties

IPNS treatments in the present study significantly influenced soil physicochemical properties of the acidic and char land soils. All the treatments, particularly biochar and compost significantly increased water-soluble macroaggregate (WSA) groups in soils, stability index, MWD and GMD (Table 3 and 6) observed in previous studies (Burrell et al., 2016; Hartley et al., 2016; Blanco-Canqui, 2017). According to Ibrahim et al. (2021), biochar and compost substantially enhanced aggregate stability and water-soluble macroaggregate (>0.25 mm) in loamy sand soil. Mi et al. (2018) found that NPK and organic matter (straw residue or cattle manure) significantly increased the water-soluble aggregate >0.25 mm, MWD, and GMD, while reducing the proportion of 0.25 mm aggregates, at two field experiment sites in Jinhua, Zhejiang province, and Jintan, Jiangsu province. According to Annabi et al. (2007), adding organic matter to loam soils affects aggregate stability, and they ascribe this to increased microbial activity, which improves aggregate stability. In research conducted by Šimanský et al. (2016), using N fertilizer in combination with biochar increased the macroaggregates. The values of water-soluble WSA in the size fractions 3–2 mm (75%) and 5–3 mm (149%) were more significant in the B20N80 treatment (20 t biochar ha^{-1} + 80 kg N ha^{-1}), whereas the size fraction of 0.5–0.25 mm (27%) was lower than in B20N0 (20 t biochar ha^{-1} + no nitrogen). Similar results were also observed by Ma et al. (2015), who reported that both the NPK fertilizer + maize straw and NPK + biochar treatment significantly enhanced the relative proportion of macroaggregates (>2 mm) and the mean weight diameter while decreasing the relative ratio of microaggregates (<0.25 mm). Organic matter is essential for repositioning soil particles so that aggregates can form (Das et al., 2014). Organic material incorporation to soil considerably increases soil organic matter content while also releasing organic acids, polysaccharides, and other by products that bind free primary particles into macroaggregates, resulting in an higher (>2 mm) in macroaggregate size (Wang et al., 2015). Another assumption is that organic manures function as a stimulant for microbes (Six et al., 2004), encouraging microbial development and increasing the density and efficacy of mycorrhizal hyphae, which enhances aggregate stability (Mikha and Rice, 2004; Helgason et al., 2010; Zhang et al., 2014). Adding nitrogen to the soil can speed up the biochar mineralization process, resulting in increased aggregation (Bronic and Lal, 2005; Šimanský et al., 2016). However, Xin et al. (2016) reported that integrated application of half organic compost and half mineral fertilizer did not result in greater proportions of the >0.25 mm aggregate than after using NPK for 23 years. Biochar made from a mixture of wood and straw, on the other

hand, did not influence aggregate stability (Annabi et al., 2007). Furthermore, due to differences in parameters such as the quality, amount, and timing of organic matter addition, the research does not clearly show a link between aggregate stability and rates of organic input (Abiven et al., 2009).

Addition of organic and inorganic fertilizers significantly increased soil TN in acidic soil (Table 74), which aligns with Islam et al. (2021a, b, c; Van Chuong, 2019). Previous research has shown that the C:N ratio of the manure is essential for mineralization and the build-up of SOC and TN, and that a low C:N ratio boosts up the mineralization process, resulting in increased soil TN (Tong et al., 2009; Khalil et al., 2005). However, the effect of IPNS on soil TN in charland soil was non-significant (Table 77). Our results suggest that IPNS is more efficient in acidic soil than charland soil in terms of increase in soil TN.

Our results demonstrated that IPNS treatments significantly increased soil pH compared to the control, although sole application of chemical fertilizer decreased soil pH, supported by previous studies (Dong et al., 2012; Kai et al., 2020; Mi et al., 2018). Lin et al. (2019) observed that organic fertilizer and chemical fertilizer significantly increased tea orchard soil pH and microbial population. This is attributed to the increased soil organic matter content, encouraged soil maturation, improved soil structure, and raised the soil base saturation percentage by the organic manure, which can help to reduce soil acidity (Zhang et al., 2009; Li et al., 2010). On the other hand, chemical fertilizer undergoes rapid hydrolysis and subsequent nitrification, resulting in the release of protons and a decrease in soil pH.

The results revealed that IPNS treatments had no significant effect on soil bulk density in acidic soil although IPNS treatments significantly decreased soil bulk density in charland soil. Many studies have shown that including organic material reduces soil bulk density (Oladele et al., 2019, Ramos, 2017, Yazdanpanah et al., 2016). The reason for the decreased soil bulk density is the addition of organic materials, which increases soil organic matter content, resulting in soils that are more friable, porous, and chemically active, reducing soil bulk density (Athira et al., 2019). However, in acidic soil, the effect was not observed may be due to the clay type soil texture.

Treatments effects on crop yield, nitrogen uptake and nitrogen use efficiency

Chemical fertilizers are widely used in present agricultural farming system, which has a detrimental impact on soil health, the environment, and crop yield. Nitrogen is the most important yet limiting nutrient among chemical fertilizers worldwide due to very low NUE due to gaseous losses such as denitrification, volatilization, and leaching from agricultural cropping systems (Uddin et al., 2021). Our results showed that combined application of organic manure, inorganic fertilizer and dololime significantly increased total crop yields (i.e., system productivity) of the cropping patterns (Table 75 and 78), which is consistent with previous studies in acidic soil (Islam et al., 2021a, b, c). In the acidic soil of Nalitabari, Sherpur, Islam et al. (2021a, b) reported that combined application of lime, organic amendment and chemical fertilizer increased yield and nutrient uptake of the T. Aman-Maize-Fallow and Wheat-Mungbean- T. Aman cropping patterns. In another study at the same site of the present study, Islam et al. (2021c) observed that combined application of lime, organic manure and chemical fertilizer significantly improved total system productivity and nutrient absorption of T. Aman-Mustard-Boro cropping pattern with subsequent improvement in the soil quality. The authors postulated the rise in soil pH and other soil physicochemical properties as the increase in crop productivity and nutrient uptake. Ikbal et al. (2019) reported that 30% PM + 70% chemical fertilizer increased rice grain yield by 95% and nutrient uptake and NUE. In a field experiment at Agronomic Research Farm, University of Agriculture Faisalabad, Pakistan, Mahmood et al. (2017) observed that NPK at 150-85-50 + 7 t ha^{-1} PM significantly increased maize yield with concurrent improvement in soil properties. Similarly, Bedada et al. (2014) found that combining compost and urea enhanced soil characteristics and maize production. Improved soil physical conditions and increased water availability increased the crop's nutrient-absorption capability, boosting biological output at a given quantity of fertilizer application (Liang et al., 2012). Hossain et al. (2010)

similarly found that FYM treatment increased N absorption in rice compared to no fertilizer and inorganic fertilizer applications. Chemical fertilizer alone reduced nutrient absorption due to poor availability and more significant nutritional loss (Puli et al., 2017). Crop N requirements must be synchronised with N supply to improve N usage efficiency. Crop type, availability of other nutrients, nutrient leaching, weather, and genotypic variations are all factors that influence crop NUE (De-shui et al., 2007; Takahashi and Anwar, 2007). In rice, Dawe et al. (2003) discovered that N losses reduce as yield and NUE increase, while Fofana et al. (2005) observed comparable effects in maize crops. In two-year field research, Rehim et al. (2020) reported a 98% increase in N absorption of wheat grains and a 200% increase in NUE when 75% urea+25% farm yard manure was applied instead of urea alone. These findings showed that combining organic and inorganic sources to improve NUE in crops is more effective (Zhang et al., 2016).

Treatment effects on microbial biomass and microbial population

Soil microbial biomass is an important biomarker of tracking rapid changes in soil quality due to human influences as well as agricultural management methods (Suman et al., 2006). MBC and MBN account for 3–7% of SOC and 1–5% of STN (Wu, 2007). Our results demonstrated that IPNS treatments, especially biochar (PMB) and compost (OF)-based IPNS significantly elevated MBC in both soils and MBN in charland soil. This is consistent with other researches (Liu et al., 2021; Chaudhry et al., 2016; Zhang et al., 2014b, Lehmann et al., 2011; Liang et al., 2010). MBC and MBN increased by 8.8-50% and 20-180%, respectively, which was comparable with Al-Suhaibani et al. (2020) who observed 20.0-47.5% and 32.2-65.2% increases in MBC and MBN, respectively, as a result of IPNS treatments. However, other studies discovered that: firstly, biochar application had no effect on soil MBC (Zavalloni et al., 2011; Castaldi et al., 2011); and secondly, MBC significantly diminished with biochar application while MBN remained undistorted in a coarse textured soil (Zavalloni et al., 2011; Castaldi et al., 2011; Dempster et al., 2012; Deenik et al., 2010). The biochar itself as a carbon source might be the cause of the rise in MBC. The build-up of organic compounds on the surface of the soil offers a substrate for increased microbial activity, which leads to greater MBC rates (Balota et al., 2004). The fastest mineralizable C and N in organic additions are the most important factors in biomass increase (Hao et al., 2008; Liu et al., 2010). A mixture of charcoal and inorganic fertilizer is more efficient for beneficial microbes in soil (Wardle et al., 2008; Brunn et al., 2012). The benefits flowing from IPNS treatments on MBN in charland soil is consistent with Kiem's (1997) findings that biological activity is greatest in coarse textured soils.

Basal respiration is a measure of the fundamental turnover rates in soil that is thought to represent the availability of carbon for microbial maintenance (Dinesh et al., 2004; Vanhala et al., 2005). Our findings strongly suggested that applying organic and inorganic fertilizers together boosted BR by 16-429% in acidic and charland soils, and this echoes what prior research has documented (Li et al., 2019; Li et al., 2018; Salehi et al., 2017; Chang et al., 2008). According to Shrestha et al. (2013), cow manure had the highest BR, followed by compost, bare fallow, and cover crop treatments, yet Chang et al. (2008) detected no influence of soybean meal addition on BR. Increased BR is due to the application of organic manures, which increases the amount of organic matter available for soil respiration. Furthermore, it has the ability to significantly increase both the number and microbial activity, impacting both SOC transformation and CO_2 release, and subsequently raising the microbial respiration rate (Zang et al., 2015). As a result, the treatments with organic manure treatments in our study considerably enhanced soil CO_2 emissions and soil respiration rates.

Soil microbes are crucial for OM decomposition, nutrient recycling, soil structure maintenance, insect and disease control, and the production of plant growth stimulants (Kirchman, 2018). Organic manures with or without chemical fertilizer had a beneficial impact on both bacterial and fungal population in soil (Kamaa et al., 2011). Our results revealed that biochar-based IPNS increased the bacterial and fungal population in acidic soil which was similar to what Narendrula-Kotha and Nkongolo (2017) and Alkharabsheh et al. (2021) reported. It might be due to the higher pH, which encourages bacterial development

(Narendrula and Nkongolo, 2015), sugars, alcohols, acids, ketones, and water molecules trapped in biochar's mesopores and micropores. These can increase microbial activity and change microbial population and composition in soil (Adnan et al., 2020). It should be noted that the microbial population remained statistically similar or smaller compared to the control in charland soil which is a mystery that requires further investigation. In both soils, our findings revealed that the bacterial community population was frequently larger than the fungal community population in all treatments, as reported by Kamaa et al. (2011). Previous studies have shown that organic and chemical fertilizers can benefit PSB. (Richard and Ogunjobi, 2016; Kumar et al., 2012). In both acidic and charland soils, however, we found no influence of IPNS or chemical fertilizer on PSB.

Treatment effects on carbon pool and management indices

The application of organic amendment and chemical fertilizer increased SOC content by 0.9%-23.6% in acidic and charland soils. Our finding is consistent with other analyses reporting an increase of about 2.9%-46.7% in SOC content due to combined application of organic and inorganic sources of nutrient (Al-Suhaibani et al., 2020; Liu et al., 2020; Roy and Kashem, 2014). The rise in SOC content is the consequence of high carbon content in readily biodegradable organic manures and increased SOC supply via crop root exudation (Yanardağ et al., 2014). The POC fraction is a labile SOC pool mostly made up of partly degraded plant residues that are not linked with soil minerals (Six et al., 2002). We observed 6.0%-198% increase in POC content in the soils which is consistent with previous research (Zhang et al., 2020; Bongiorno et al., 2019; Liang et al., 2012). According to Liu et al. (2013) and Rudrappa et al. (2006), adding organic matter to the soil increased POC build-up. Increased POC is mostly due to increased subterranean biomass production, root exudation, and readily biodegradable organic input components (Purakayastha et al., 2008). According to Zhang et al. (2020), the POXc level in soil had risen after a decade of wheat cultivation using synthetic fertilizer and residue application. Previous research has shown similar results (Cheng et al., 2010; Purakayastha et al., 2008; Rudrappa et al., 2006). Nevertheless, after two years of field trials, our findings revealed that IPNS had no effect on the build-up of POXc in soil. It may be due to the duration of the field experiment indicating that further long-term investigation is required.

Many studies have shown that including organic material reduces soil bulk density (Oladele et al., 2019; Ramos, 2017; Yazdanpanah et al., 2016). Surprisingly, we did not find any effect of IPNS on soil bulk density in both the soils after two years. This may be attributable to the balance in soil bulk density due to IPNS treatments.

The carbon management index, which includes both soil organic C pool and C lability, may be used to assess the potential of management approaches to improve soil quality. Incorporation of IPNS treatments to the soils had no impact on the lability and management indices of POXC (active carbon). After a short-term (2-year) trial, the IPNS treatments seemed to have no influence on POXC content in the soil, as expected. In the previous studies, researchers reported an increased CLI and CMI after a long-term (11-32 years) combined fertilizer application (Tang et al., 2018; Kumara et al., 2017; Benbi et al., 2015). CLI and CMI of MBC increased as a result of the application of IPNS treatments that were consistent with other work (Tang et al., 2018; Kumara et al., 2017; Benbi et al., 2015). This outcome might be attributed to soil microorganisms gaining access to organic carbon and other necessary nutrients (Kumara et al., 2017). Our results demonstrated that SOC, POC and MBC stock increased significantly in both acidic and charland soils as a result of organic and inorganic inputs, which agreed with previous research (Maillard and Angers, 2014; Sun et al., 2013). This is due to the large C input through organic sources resulting in increased SOC, POC and MBC content in soil (Tang et al., 2018).

Activity 5: Study on the mineralization rate of commonly used organic materials in Bangladesh in the acidic and Charland soils under field capacity and continuous standing water (CSW) conditions (incubation study)

Mineralization rate and kinetics of soil organic carbon

Mineralization rate was lower in continuous standing water (CSW) than in field capacity (FC) at acidic soil site (Fig. 113) but was similar in FC and CSW in char land site (Fig. 114). Among different organic materials, poultry manure biochar and rice husk biochar had lower mineralization rate as well as the rate constant (Fig. 113). The SOC content was lower in both biochars than in other organic amendments. The predicted model for C mineralization rate fitted very well with the observed data showing strong coefficient of determination (adjusted) at both sites. The lower C releases in biochar treated soils suggest that biochars are comparatively stable in nature undergoes slower decomposition. The C release or mineralization potential (C_0) and mineralization rate kinetics (e.g., 0.0007% and 0.0004% in FC and CSW for poultry manure biochar at acidic soil site and 0.001 in both FC and CSW conditions in char land site; Table 98 and 99) also support that biochar is a stable compound. The poultry manure biochar had the highest SOC release which suggests that poultry manure has higher degradable C than the biochar. The SOC release in vermicompost treated soils were lower than the biochars but higher than the poultry manure which indicates that vermicompost has also slower mineralization rate of soil organic matter with low degradation or decomposition rate. Both biochar and vermicompost have good potential to sequester SOC in soils.

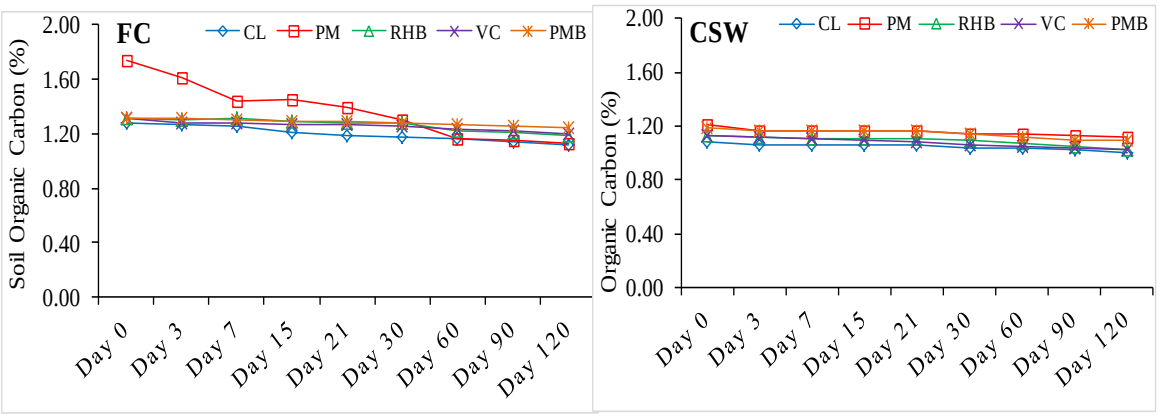


Figure 113. Carbon mineralization pattern over time at acid soil site (CL = control, PM = poultry manure, RHB = rice husk biochar, VC = vermicompost, PMB = poultry manure biochar)

Table 98. Carbon mineralization rate kinetics under different organic amendments at acid soil site

Treatments	C_0		k		F		R^2 Adjusted	
	FC	CSW	FC	CSW	FC	CSW	FC	CSW
CL	1.24	1.06	0.0010	0.0004	101.9	267	0.79	0.84
PM	1.56	1.56	0.0035	0.0004	30.0	155	0.75	0.62
RHB	1.31	1.17	0.0009	0.0007	245.6	246	0.94	0.94
VC	1.39	1.29	0.0008	0.0008	244.2	124	0.89	0.77
PMB	1.31	1.17	0.0007	0.0004	338.1	277	0.87	0.93

CL = control, PM = poultry manure, RHB = rice husk biochar, VC = vermicompost, PMB = poultry manure biochar)

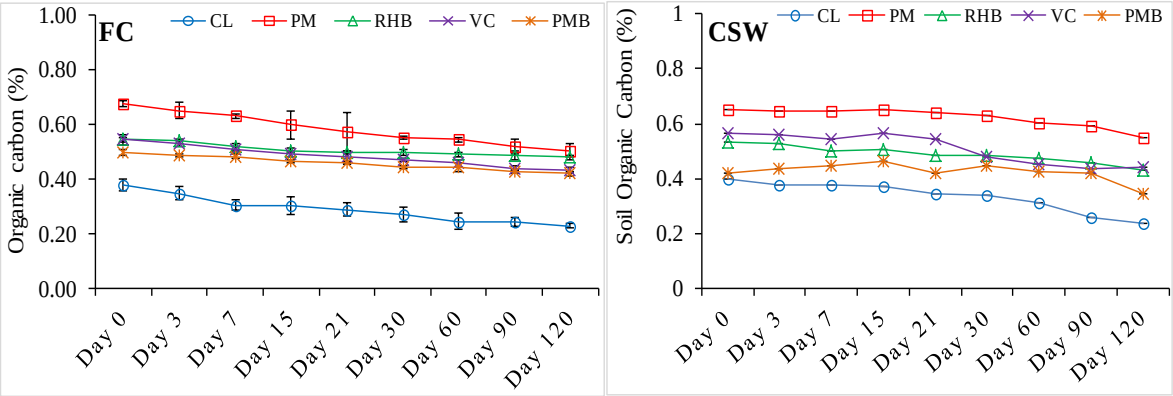


Figure 114. Carbon mineralization pattern during the incubation period at char land soil site (CL = control, PM = poultry manure, RHB = rice husk biochar, VC = vermicompost, PMB = poultry manure biochar)

Table 99. Carbon mineralization rate kinetics under different organic amendments at char land site

Treatments	C_0		k		F		R^2 Adjusted	
	FC	CSW	FC	CSW	FC	CSW	FC	CSW
CL	0.39	0.33	0.004	0.004	26.34	275.17	0.74	1.00
PM	0.66	0.66	0.002	0.002	43.63	38.53	0.74	0.57
RHB	0.53	0.52	0.001	0.002	77.84	91.90	0.63	0.86
VC	0.56	0.52	0.002	0.003	58.68	49.67	0.79	0.83
PMB	0.49	0.45	0.001	0.001	43.01	43.01	0.85	0.50

CL = control, PM = poultry manure, RHB = rice husk biochar, VC = vermicompost, PMB = poultry manure biochar)

Mineral N (NH_4^+-N + NO_3^--N) releases

The availability of N (NH_4^+-N + NO_3^--N) was significantly influenced by soil types ($p<0.001$). The mean mineral N was higher in acidic soil (Fig. 115) than in char land soil (Fig. 116). N mineralization occurred more rapidly in soils under FC moisture than in soils with CSW of 1 cm. Mineral N content was significantly influenced by treatment combinations ($p<0.001$). The highest mean mineral N was observed in poultry manure in both FC and CSW conditions while the lowest was found in the control at both sites. Except the control biochars, both rice husk biochar and poultry manure biochar had the lowest mineral N releases indicating that biochars have the potential to reduce N mineralization rate which can build up soil TN content.

The lowest mineral N was found in PMB which was similar to RHB and vermicompost where the later two were also similar with each other (Fig. 115 and 116). The order of mean mineral N mineralization was as follows: poultry manure > RHB > PMB > vermicompost. The trend of mineral N showed that the mineral N content reached its maximum at day 7, and remained more or less constant in case of acidic soil incubated at FC, and decreased thereafter with time in charland soil with FC and continuous standing water condition in both the soil types (Fig. 115 and 116).

The interactions effect of the soil type and soil moisture status was significant. The highest mineral N was observed in either soil type than CSW. Considering the soil type and treatment combination interactions, mean mineral N was significantly higher in acidic soil treated with vermicompost which was statistically similar to RHB, whereas the lowest value was observed in the either soil with PMB. Likewise, treatment combination and soil moisture status interactions had a significant effect on mean mineral N exhibiting the highest mineral N content in soil with vermicompost in FC which was identical to RHB in the same moisture status and lowest value in PMB with either moisture level.

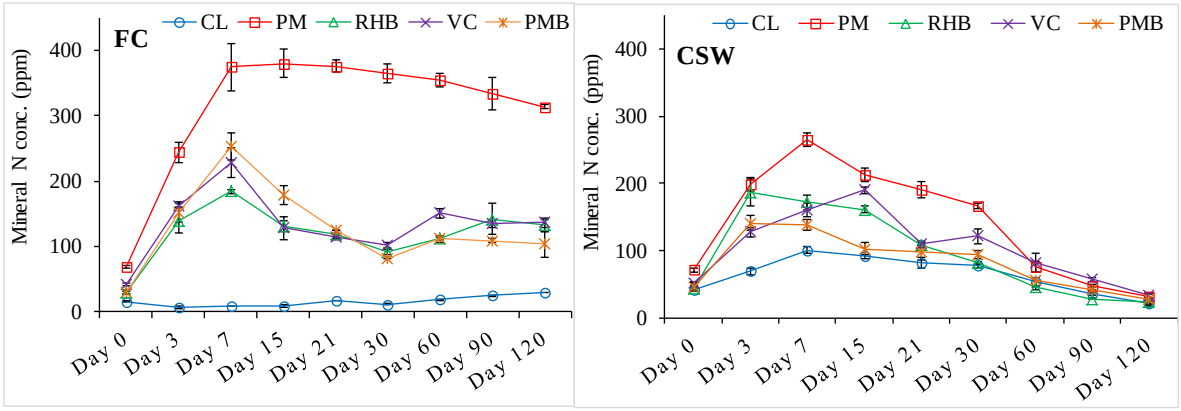


Figure 115. Trend of net mineral N (NH_4^+-N + NO_3^--N) mineralization from different treatments in acidic soil with field capacity and continuous standing water moisture status. Net mineralization is calculated as the difference in amount between amended soil and control. Error bars represent standard errors of the means (n=3)
CL = control, PM = poultry manure, RHB = rice husk biochar, VC = vermicompost, PMB = poultry manure biochar)

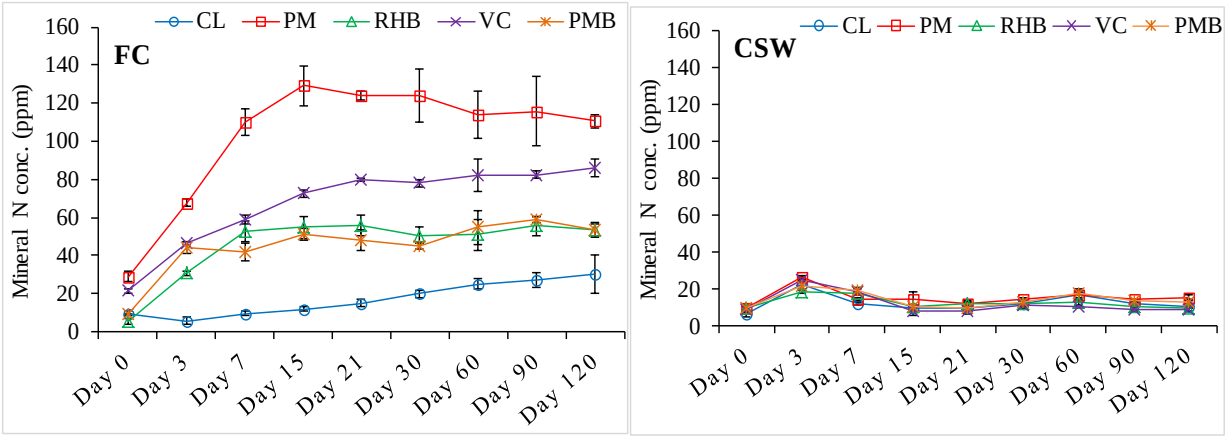


Figure 116. Trend of net mineral N (NH_4^+-N + NO_3^--N) mineralization from different treatments in charland soil with field capacity and continuous standing water moisture status. Net mineralization is calculated as the difference in amount between amended soil and control. Error bars represent standard errors of the means (n=3)
CL = control, PM = poultry manure, RHB = rice husk biochar, VC = vermicompost, PMB = poultry manure biochar)

Mineralization of TN

Changes in TN in acidic soil site

Soil type had a significant effect on the change in TN ($p<0.001$, Figure 117). More TN was retained after 120 days of incubation in char land soil compared to acidic soil, indicating less mineralization in charland soil. TN was significantly influenced by soil moisture status ($p<0.05$) exhibiting the highest total N remained in soils incubated at CSW compared to FC after 120 days of incubation. All the N sources significantly increased TN compared to the control in both soil types ($p<0.001$) (Figure 117). The pattern of changes in TN over different incubation periods was decreasing over time in both soil types (Figure 117). The highest total N at different incubation timings was observed in the treatments under PMB compared to any other treatment combination in both the soil type and soil moisture status. In acidic soil, TN was relatively increased from 10.22 to 13.64% and 10.11 to 12.36% compare to the control under FC and CSW, respectively. Similarly, it ranged from 20.83 to 25.0% and 20.41 to 22.5% in charland soil. The results indicated a significant negative correlation between mineral N and TN (r = 0.67 and 0.64 in acidic soil and charland soil, respectively),

demonstrating that soil N content was associated with the N release potential of the treatments (Fig. 118). All the interaction effects were non-significant. Percentage mineralization of TN was the lowest in PBM while the highest was found in CSW (Fig. 118). The changes in TN in were lower in FC than in CSW. Percentage change in TN ranged from 1.2 % in PMB to 12.5 % in PM in FC, while it ranged from 0.9 % in PMB to 11.4 % in PM (Fig. 118).

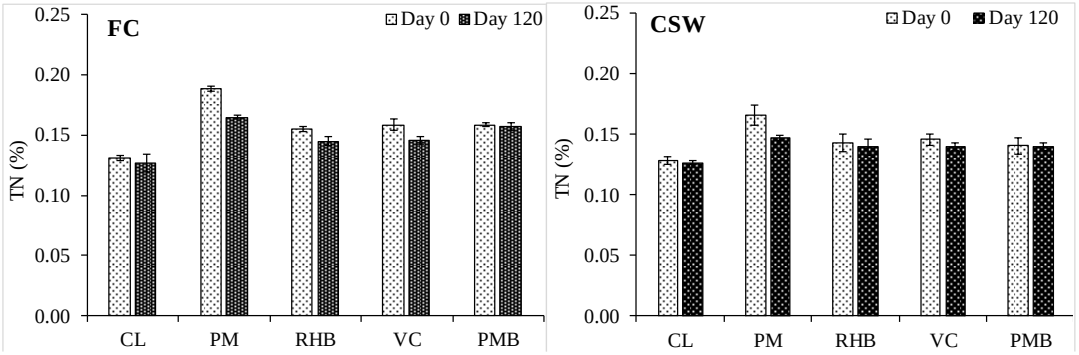


Figure 117. Changes in TN contents in the incubated soil between day 0 and 120 at acidic soil site (CL = control, PM = poultry manure, RHB = rice husk biochar, VC = vermicompost, PMB = poultry manure biochar)

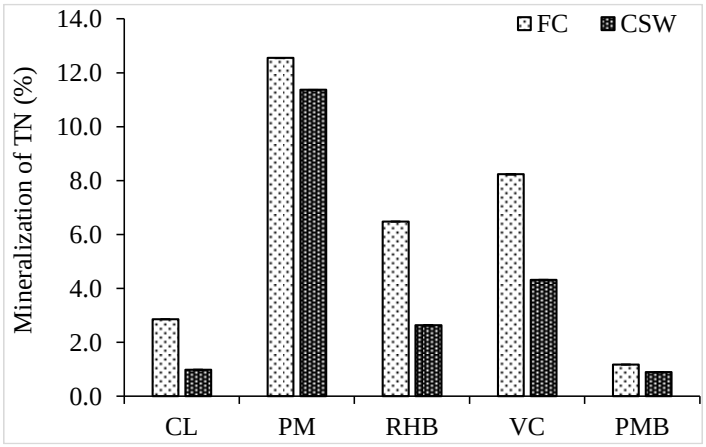


Figure 118. Percentage of TN mineralization in the incubated during the whole incubation period in FC and CSW conditions (CL = control, PM = poultry manure, RHB = rice husk biochar, VC = vermicompost, PMB = poultry manure biochar)

Changes in TN in char land site

Changes in TN during the incubation period were lower in PMB and vermicompost than in RHB and PM where the PMB and vermicompost were equal to the control (Fig. 119). The changes in TN in were higher in FC than in CSW. Percentage change in TN ranged from 11.3 % in PMB to 27 % in PM in FC, while it ranged from 9.4 % in PMB to 20.0 % in PM (Fig. 120).

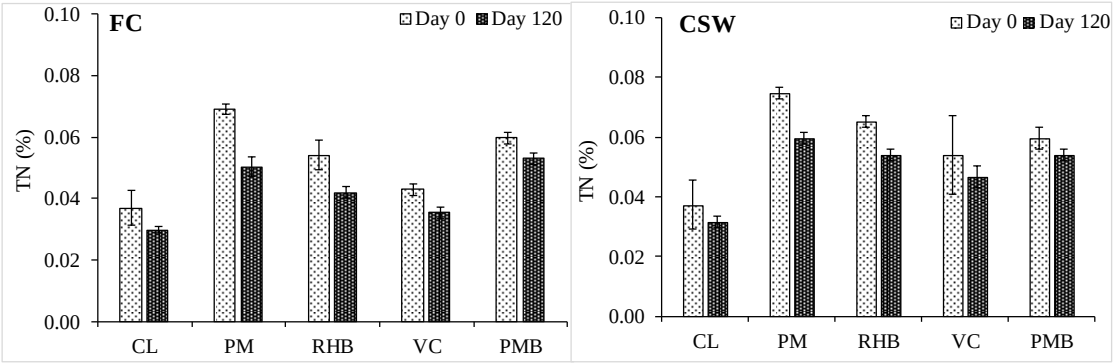


Figure 119. Changes in TN contents in the incubated soil between day 0 and 120 at acidic soil site (CL = control, PM = poultry manure, RHB = rice husk biochar, VC = vermicompost, PMB = poultry manure biochar)

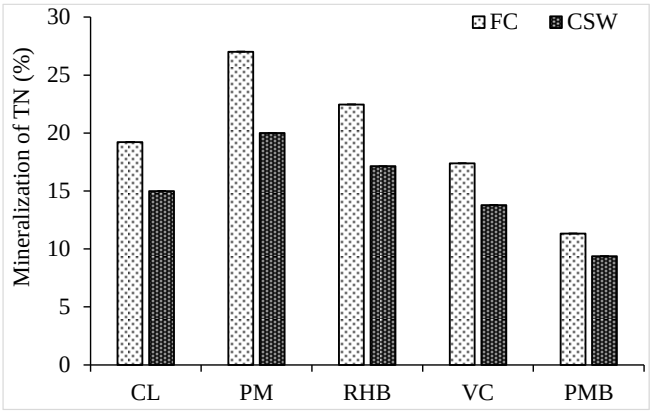


Figure 120. Percentage of TN mineralization in the incubated during the whole incubation period in FC and CSW conditions (CL = control, PM = poultry manure, RHB = rice husk biochar, VC = vermicompost, PMB = poultry manure biochar)

Discussion

Nitrogen mineralization in acidic and char land soils

The amount of N released by mineralization depends on the chemical composition of organic materials (e.g., N content, C:N ratio, and contents of cellulose and hemicelluloses, lignin, and polyphenols) (Calderón et al., 2005; Mohanty et al., 2011) application rate of manures (Haque et al., 2015) and on the physicochemical and biological properties of soil microbes (Manojlović et al., 2010). In acid soil, NH_4^+-N was substantially greater than in char land soil. This is attributed to the increased loss of NH_4^+ as NH_3 in char land soil as a result of the negative relationship between ammonia volatilization and clay concentration (Zhenghu and Honglang, 2000). Another factor is the higher pH of charland soil, which favors urease activity and ammonia volatilization (Sommer et al., 2004). Our results revealed that NH_4^+-N was found to be the dominating form of N under CSW conditions compared to FC conditions, as submergence increased NH_4^+-N concentration (Duhan et al., 2005), which is in line with Haque et al. (2015) and Calderon et al (2004). The lowest mineral NH_4^+-N was reported in the biochar treatment combinations because of the less amount urea N in the combination as biochar had high N content and biochar is more stable and less susceptible to mineralization (Lehmann et al., 2011). N-enriched biochar, on the other hand, may be utilized as a slow-release nitrogen fertiliser (Sarkhot et al., 2012). Furthermore, biochar may include bioavailable N components, whose mineralization and release will be influenced by the biochar's recalcitrance (Clough et al., 2013).

The NO_3^--N levels in acidic soil were greater than in char land soil. This might be due to the rapid nitrification of the available NH_4^+-N in sandy loam soil. The nitrification process was unaffected by soil pH, as nitrifying bacteria typically function in soil with a pH ranging from 5.5 to around 10.0, with an optimum around 8.5 (Sahrawat, 2008). However, nitrification has been reported to occur in soils with pH as low as 3.8 (Tisdale and Nelson, 1970). Aeration, moisture condition, and the quantity of ammonium ions are the most critical environmental variables that impact nitrification in soil (Allen et al., 2005). The concentration of NO_3^--N in the FC condition was considerably greater than in the CSW condition. Haque et al. (2015) reported a similar result. Soil moisture and aeration, or soil oxygen levels, are inversely linked in the soil system. Greater soil moisture reduces oxygen content in the soil because most pore spaces are filled by water, and higher soil moisture also inhibits atmospheric air diffusion into the soil. Because of the possible loss of mineral N owing to volatilization and denitrification under CSW conditions, N release potential was substantially higher in FC than in CSW. The rate constant was greater in char land soil because the mineral stability was lower due to fast mineral N loss by volatilization and denitrification. For the same reason, the mineralization rate constant in FC was greater than in CSW.

Phosphorus and S mineralization

Like, C and N, mineralization of P was higher in FC and CSW at both acidic soil site (Fig. 121) and char land site (Fig. 122). Overall, available P increased in soil over the incubation period in FC but in CSW they declined. Mean available S content was far lower in CSW than in FC at both acidic and char land site (Fig. 25 and 26). In acidic soil site, available S ranged from 8 to 17 ppm in FC while it ranged from 14 to 35 ppm in CSW. In the char land site at FC, available S was lower in control than all other organic treatments where it was higher in poultry manure and PMB than in in vermicompost and RHB. In FC, available S ranged from 12 ppm in control to 36 ppm in poultry manure. Among the organic amendments, RHB had lower available S than vermicompost and PMB where the later two were alike. In CSW, available S ranged from 13 ppm in control to 20 ppm in poultry manure and vermicompost. However, available S was higher in poultry manure than in all other treatments.

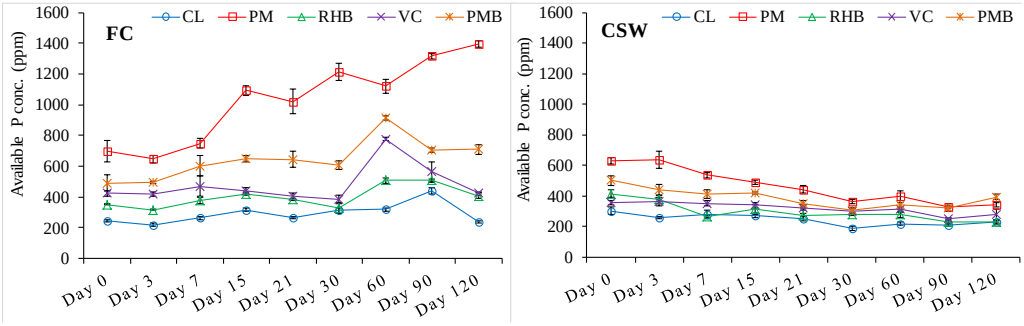


Figure 121. Trend of P mineralization from different treatments in charland soil with field capacity and continuous standing water moisture status. Error bars represent standard errors of the means (n=3). (CL = control, PM = poultry manure, RHB = rice husk biochar, VC = vermicompost, PMB = poultry manure biochar)

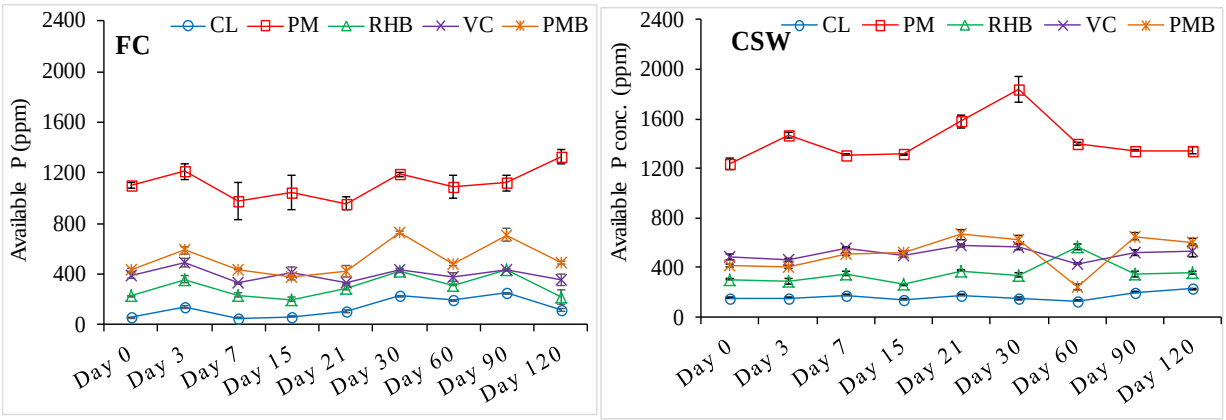


Figure 122. Trend of S mineralization from different treatments in charland soil with field capacity and continuous standing water moisture status. Error bars represent standard errors of the means (n=3)
(CL = control, PM = poultry manure, RHB = rice husk biochar, VC = vermicompost, PMB = poultry manure biochar)

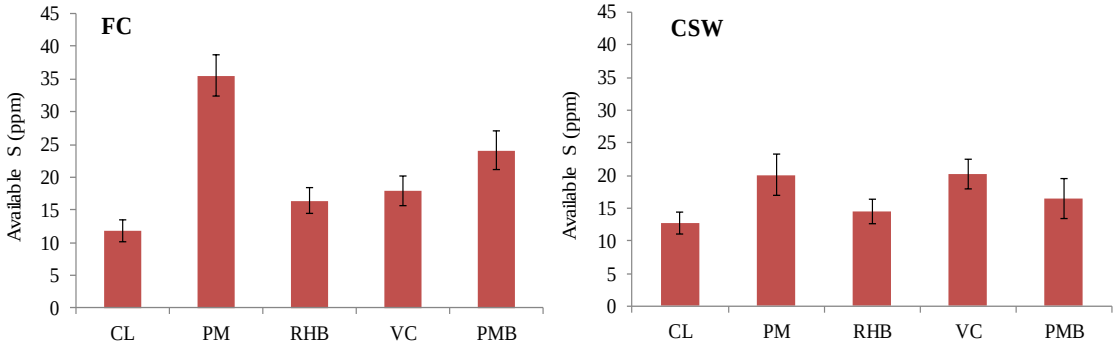


Figure 123. Mean available S in soil in FC and CSW conditions in acidic soil site ((CL = control, PM = poultry manure, RHB = rice husk biochar, VC = vermicompost, PMB = poultry manure biochar)

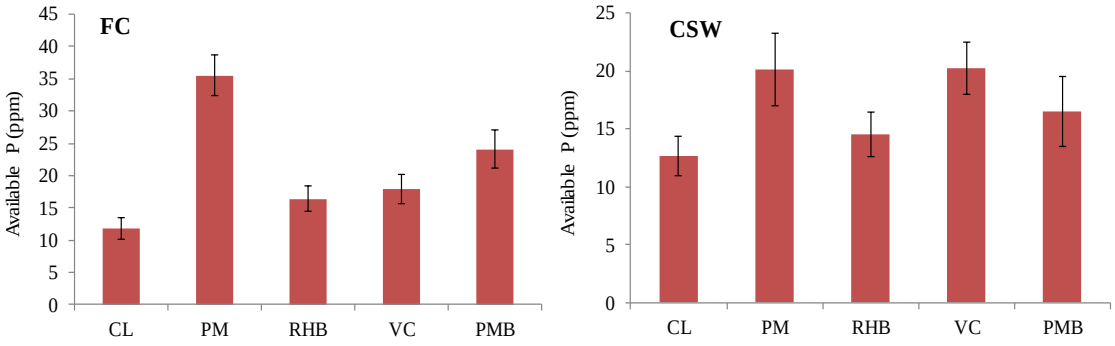


Figure 124. Mean available S in soil in FC and CSW conditions in acidic soil site (CL = control, PM = poultry manure, RHB = rice husk biochar, VC = vermicompost, PMB = poultry) manure biochar)

BSMRAU Component

The list of experiments under each objective are given below:

Objective I: Characterize the bio-physicochemical properties of soil in the climate vulnerable Dekar haor areas of Sunamganj, arsenic area of Faridpur sadar, saline areas of Batiaghata and heavy metal polluted areas of Bhaluka using different organic amendments

Expt. I. Physicochemical characteristics of the climate vulnerable Dekar haor of Sunamganj.

Expt. II. Assessment and Improvement of Bio-physicochemical characteristics of different soils of the climate vulnerable arsenic area of Faridpur sadar, saline areas of Batiaghata and heavy metal polluted areas of Bhaluka using different organic amendments.

Objective II: Evaluate the adsorption and desorption isotherms of heavy metals using organic materials including biochar for amending heavy metals in Bhaluka.

Expt. III. Study on mechanisms of the adsorption-desorption of heavy metal using different organic materials in contaminated soils heavy metal polluted areas of Bhaluka.

Objective III: Mineralization study of organic materials and their effects of climate vulnerable and arsenic and heavy metal polluted areas on soil properties and crop productivity and carbon sequestration in the selected areas

Expt. IV. Nitrogen and carbon mineralization dynamics using different organic materials in different climate vulnerable soils of arsenic area of Faridpur sadar and saline areas of Batiaghata.

Expt. V. Pot experiment on nitrogen and carbon mineralization dynamics using different organic materials in climate vulnerable soils of heavy metal polluted area of Bhaluka.

Expt. VI. Field study on nitrogen and carbon mineralization dynamics using different organic materials in climate vulnerable soils of heavy metal polluted area of Bhaluka.

Expt. VII. Impact of different organic materials on crop productivity in Rice-Rice cropping pattern of the climate vulnerable arsenic area of Faridpur sadar, saline areas of Batiaghata and heavy metal polluted areas of Bhaluka using different organic amendments.

Expt. VIII. Soil aggregate stability, storage of organic carbon and carbon sequestration in different climate vulnerable soils using different organic materials at Dekar haor areas of Sunamganj, arsenic area of Faridpur sadar, saline areas of Batiaghata and heavy metal polluted areas of Bhaluka.

2. Expt. I. Physicochemical characteristics of the climate vulnerable Dekar haor of Sunamganj (Under objective 1).

2.1 Experimental site

The study area Dekar haor belongs to Sunamganj district of Bangladesh. It is under the agro-ecological zone (AEZ) Sylhet Basin (AEZ 21) which is situated at the lower western side of the Surma-Kusiyara Floodplain. The experimental site is mainly smooth, broad basins with narrow rims of higher land along rivers. The site lies between latitude 24°34´N to 25°12´N and longitude 90°56´E to 91°49´E with an elevation of <10 meter from sea level (Kamal *et al*., 2018).

2.2 Soil characteristics

Soils of the area are grey, silty clay loams in the ridges and clay loam in the basins. Noncalcareous Grey Floodplain soils are the only general type (BARC, 2018). Soil pH value is about 5.7, which revealed that the soil is slightly acidic.

2.3 Weather condition of the experimental site

The experiment area has tropical climate. Most of the months in a year are marked by significant rainfall. The greatest amount of precipitation occurs in June, with an average of 712 mm and the driest month is December, with 6 mm. August is the warmest month of the year with temperature 28.4°C. The lowest average temperature occurs in January, around 18.4°C. Average temperature 25.0°C. Humidity 71%.

2.4 Experimental design and treatments

The study was carried out in factorial randomized complete block design with twenty replications. There were two treatments factors comprised of three locations (ridge, middle and basin) and three soil depths (0-15 cm, 15-30 cm and 30-45 cm).

2.5 Soil collection and sampling

Soil samples were collected from twenty locations from each of upper ridge, middle point and basin areas of the Dekar haor. From each point soil samples were collected considering three depths (0-15, 15-30 and 30-45 cm) using core sampler. Thus a total of 180 soil samples from Dekhar haor were collected from ridge, middle and basin part of the haor to evaluate the physico-chemical characterization of haor soils.

2.6 Soil sample analysis

2.6.1 Bulk density

Bulk density of soil was determined by Core Sampler Method described by Blake and Hartge (1986). Cores of 5 cm diameter and 5 cm height were used for taking the undisturbed soil. The samples were oven dried at 105^0 c to a constant weight. Bulk density was calculated by the following formula:

$$\text{Bulk density } (pb) = \frac{\text{Weight of oven dry soil}}{\text{Total volume of soil}} \quad \text{g/cc}$$

2.6.2 Soil pH

Soil pH was measured by a glass electrode pH meter using a soil water suspension ratio of 1:2.5 as described by Jackson (1973).

2.6.3 Soil organic carbon

Soil organic carbon was estimated by Walky and Black's (1934) wet oxidation method as described by Jackson (1973). One gram of air dried soil was taken in a conical flask and added 10 ml 1N KCr_2O_7 solution and 10 ml conc.H_2SO_4 (32N) and then it was heated on a sand bath at 150^0 C. After cooling, this was titrated against 0.2N ammonium ferrous sulphate (AFS) with the addition of phenyl Anthranilic Acid (PAA) indicator.
Organic carbon (OC) was calculated by using the following formula:

% OC = 0.6 × (B-V) ×f × 100/sample weight (mg)

Where,
B= Volume of AFS required in titration of blank samples
V= Volume of AFS required in the titration of sample
f= Correction factor of AFS

2.6.4 Total Nitrogen (N)

Total nitrogen was determined by micro-Kjeldahl method by Jackson (1958) following H_2SO_4 digestion using a mixture of $CuSO_4$ and K_2SO_4 (1:9) as catalyst and steam distillation with 40% NaOH solution. The distillate was collected in 4% H_3B0_3 and finally titrated against 0.02N (N/50) H_2SO_4.The nitrogen content of a soil is determined by heating to a temperature of at least 9000 C in the presence of oxygen gas. Mineral and organic nitrogen compounds are oxidized and/or volatilized .The combustion products are oxides of nitrogen (NO_X) and molecular nitrogen (N_2). After transforming all nitrogen into N_2 the content of total nitrogen was measured using thermal conductivity.

2.6.5 Available phosphorus (P)

The available phosphorus was determined by Olsen's method (Olsen *et a*l., 1954) when pH was >6.8 and when pH was <6.8 phosphorus was determined by Bray and Kurtz method (Bray and kurtz, 1945).

2.6.6 Exchangeable potassium (K)

The exchangeable potassium was determined by ammonium acetate extraction method (Christian and Feldman, 1970).

2.6.7 Available sulphur (S)

Available sulphur was determined by turbidimetric method.

2.6.8 Exchangeable Ca and Mg

Exchangeable Ca and Mg were determined by ammonium acetate extraction method (Christian and Feldman, 1970).

2.6.9 Exchangeable Na

Thomas (1983) method was followed to determine exchangeable Na. Atomic absorption Spectrophotometer reading was taken at 285.2 nm wave-length.

Figure 125. Soil sampling from Dekhar Haor, Sunamgonj

2.6.10 Soil properties of the selected study areas:

A total of 20 different soil sampling points of Dekhar haor along with upper, middle and bottom ridge of the haor. A total 180 soil samples of Dekhar haor was collected at different depth (0-15, 15-30, 30-45 cm) from upper, middle and bottom part of the haor to evaluate the bio-physicochemical characterization of haor soils.

2.7 Results

Table 1 showed the depth-wise disparity of soil chemical properties of the upper ridge of Dekhar haor site Sunamgonj. Data revealed that the soil of the topsoil (0-15cm) of upper ridge areas having strong acidity to neutral soil, containing the pH ranges from 5.16- 6.92. At

15-30 cm depth the pH of the upper ridge soil varied from 5.32-6.40, denoting it's strong to slightly acidic in nature. Similarly, strong acidic to neutral soil (pH, 5.41- 6.62) was observed at soil depth 30-45 cm of upper ridge soils of the haor area. There was a wide range of variation found for the percent organic carbon content (0.16-1.63%) in the topsoil of upper ridge of haor area. The organic carbon content of the upper ridge soil of haor area at 15-30 cm depth was varied from 0.26-1.46%. Meanwhile at 30-45 cm the organic carbon content of the area was comparatively lower and varied from 0.09-0.94%. Soil nitrogen content of the top soil (0-15cm) of upper ridge of studied haor area was shown a wide inconsistency (0.029-0.606%). The nitrogen content of the upper ridge soil of haor area at 15-30 cm depth was varied from 0.027-0.375%. Similarly a wide variation of N content (0.020-0.362%) was summarized in the upper ridge soil at 30-45 cm depth. While the phophorus content of the top soil (0-15cm) of upper ridge haor area was very low to low (0.17 to 8.80 ppm). Similarly at 15-30 and 30-45cm depth of the upper ridge area was also presented very low to low amount of phosphorus 0.19-9.05 and 0.21-10.96 ppm respectively. Potassium content of the upper ridge soil was varied from 0.167-0.432 me/100g for 0-15cm depth, for 15-30cm depth 0.113-0.345 me/100g and for 30-45 cm depth 0.116-0.435 me/100g soil. On the other hand, sulphur content of the upper ridge of haor soils showed a wide range of variability with a range of 38.50 to 243.50 ppm for 0-15cm depths. The sulphur content of upper ridge soil at 15-30cm and 30-40 cm depth was reviewed with a range of 43.74-254.80 ppm and 48.40-235.60 ppm respectively.

Table 100. Depth-wise soil chemical properties of the upper ridge of Dekhar haor site Sunamgonj

Sampling Point	Upper Ridge																	
	Soil Depth (0-15cm)						Soil Depth (15-30 cm)						Soil Depth (30-45 cm)					
	pH	**OC (%)**	**N (%)**	**P (ppm)**	**K (me/ 100g)**	**S (ppm)**	**pH**	**OC (%)**	**N (%)**	**P (ppm)**	**K (me /100g)**	**S (ppm)**	**pH**	**OC (%)**	**N (%)**	**P (ppm)**	**K (me /100g)**	**S (ppm)**
1	5.32	1.34	0.029	4.63	0.280	135.24	5.48	0.78	0.029	3.64	0.217	164.84	5.80	0.42	0.029	3.77	0.194	145.51
2	5.16	1.30	0.029	4.03	0.244	38.50	5.99	0.33	0.058	2.63	0.173	45.60	5.96	0.27	0.058	5.17	0.179	48.40
3	6.01	0.68	0.087	0.93	0.189	112.32	5.93	0.64	0.231	0.36	0.181	115.30	5.87	0.72	0.154	0.25	0.174	92.50
4	6.92	1.10	0.346	3.21	0.308	142.60	5.75	0.38	0.321	4.25	0.214	135.50	5.88	0.09	0.058	5.43	0.238	184.30
5	5.55	0.51	0.058	0.35	0.292	52.60	6.32	0.46	0.058	0.93	0.241	51.19	5.83	0.67	0.058	10.96	0.185	85.60
6	6.28	0.64	0.490	0.28	0.302	82.60	5.68	0.53	0.260	0.19	0.236	96.50	5.99	0.53	0.147	0.21	0.372	82.30
7	5.51	0.85	0.068	1.35	0.196	143.60	5.70	0.26	0.058	3.38	0.155	135.20	5.74	0.34	0.025	0.36	0.167	136.50
8	5.90	0.28	0.174	6.36	0.284	57.30	5.87	0.41	0.168	4.31	0.261	61.50	6.06	0.24	0.125	2.36	0.314	59.20
9	5.95	0.25	0.317	5.63	0.357	54.40	6.21	0.40	0.260	0.35	0.310	57.65	6.44	0.46	0.317	0.26	0.435	145.30
10	5.44	0.36	0.065	0.58	0.167	82.40	6.20	0.29	0.087	0.69	0.183	58.64	5.78	0.58	0.404	0.23	0.131	75.30
11	6.12	0.16	0.087	5.22	0.241	243.50	6.10	0.78	0.241	0.31	0.345	258.40	6.08	0.80	0.317	2.92	0.208	235.60
12	5.40	1.40	0.202	0.59	0.317	113.32	5.92	0.61	0.173	0.06	0.248	72.06	5.68	0.65	0.346	0.35	0.285	74.30
13	5.49	0.82	0.375	0.17	0.290	219.18	6.10	0.37	0.087	2.85	0.292	231.60	6.38	0.58	0.260	3.29	0.298	241.30
14	5.42	0.53	0.029	4.94	0.292	265.90	5.34	0.69	0.054	4.21	0.246	268.10	6.70	0.32	0.058	4.09	0.116	254.30
15	5.09	1.63	0.433	3.60	0.167	235.10	5.37	1.46	0.519	3.65	0.199	215.20	5.41	0.38	0.354	3.16	0.149	142.30
16	5.87	1.07	0.231	2.36	0.259	168.98	6.40	0.28	0.029	3.49	0.113	164.20	6.45	0.30	0.317	0.35	0.136	175.20
17	5.01	1.09	0.191	8.80	0.432	236.10	5.40	1.00	0.191	9.05	0.354	254.80	5.99	0.09	0.184	3.62	0.264	234.90
18	5.48	0.83	0.164	0.35	0.354	69.50	5.93	0.77	0.375	0.25	0.208	67.50	6.62	0.08	0.231	0.37	0.216	69.58
19	5.56	1.10	0.606	0.64	0.295	157.60	6.22	0.66	0.202	0.26	0.221	43.74	5.89	1.37	0.362	0.54	0.210	178.93
20	5.85	0.35	0.236	0.17	0.265	214.20	5.89	0.05	0.264	0.94	0.196	235.60	6.22	0.94	0.260	0.25	0.163	284.31

Table 2 showed the depth-wise disparity of soil chemical properties of the middle ridge of Dekhar haor site Sunamgonj. Data revealed that the soil of the topsoil (0-15cm) of upper ridge areas having strong acidity to slightly acidic, containing the pH ranges from 5.01- 6.30. At 15-30 cm depth the pH of the middle ridge soil varied from 5.08-6.62, denoting it's strong acidic to neutral in nature. Similarly, strong acidic to neutral soil (pH, 5.04-7.17) was observed at soil depth 30-45 cm of middle ridge soils of the haor area. There was a wide range of variation found for the percent organic carbon content (0.30-1.40%) in the topsoil of middle ridge of haor area. The organic carbon content of the middle ridge soil of haor area at 15-30 cm depth was varied from 0.46-2.20%. Meanwhile at 30-45 cm the organic carbon content of the area was comparatively lower and varied from (0.42-2.12%). Soil nitrogen content of the top soil (0-15cm) of middle ridge of studied haor area was shown a wide inconsistency (0.029-0.894%). The nitrogen content of the middle ridge soil of haor area at 15-30 cm depth was varied from 0.022-0.460%. Similarly a wide variation of N content (0.025-0.341%) was summarized in the upper ridge soil at 30-45 cm depth. While the phophorus content of the top soil (0-15cm) of middle ridge haor area was very low to low (0.19 to 4.36 ppm). Similarly at 15-30 and 30-45 cm depth of the middle ridge area was also presented very low to low amount of phosphorus (0.10-3.59; 0.10-4.35 ppm respectively). Potassium content of the middle ridge soil was varied from 0.124-0.364 me/100g for 0-15cm depths, for 15-30cm depth 0.149-0.421 me/100g and for 30-45 cm depth 0.075-0.431 me/100g soils. On the other hand, sulphur content of the middle ridge of haor soils showed a wide range of variability with a range of 39.50 to 258.80 ppm for 0-15cm depths. The potassium content of middle ridge soil at 15-30cm and 30-45 cm depth was reviewed with a range of 49.70-302.50 ppm and 25.34-308.50 ppm respectively.

Table 101. Depth-wise soil chemical properties of the middle ridge of Dekhar haor site Sunamgonj

Sampling Point	Middle Ridge																	
	Soil Depth (0-15cm)						Soil Depth (15-30 cm)						Soil Depth (30-45 cm)					
	pH	OC (%)	N (%)	P (ppm)	K (me/ 100g)	S (ppm)	pH	OC (%)	N (%)	P (ppm)	K (me /100g)	S (ppm)	pH	OC (%)	N (%)	P (ppm)	K (me /100g)	S (ppm)
1	6.06	0.68	0.055	1.25	0.248	136.50	6.08	0.72	0.058	0.34	0.247	112.33	6.05	0.78	0.029	0.35	0.431	66.60
2	6.12	0.77	0.894	2.35	0.208	39.50	6.62	0.72	0.029	0.34	0.183	35.79	5.88	0.60	0.058	0.10	0.243	25.34
3	6.30	0.58	0.087	0.38	0.124	94.93	6.27	0.59	0.173	0.45	0.154	68.40	6.32	0.57	0.029	0.78	0.075	29.82
4	5.78	0.38	0.068	2.36	0.258	163.50	5.72	0.47	0.094	1.54	0.149	158.40	5.69	0.35	0.247	1.68	0.341	127.60
5	5.67	0.48	0.136	2.34	0.321	54.80	5.66	0.46	0.254	2.34	0.421	67.30	5.58	0.42	0.341	2.54	0.249	69.40
6	5.87	0.68	0.241	2.17	0.384	59.30	5.86	0.62	0.134	2.35	0.284	83.10	5.98	0.64	0.144	4.78	0.295	84.60
7	5.45	0.45	0.029	0.19	0.216	123.26	5.63	0.73	0.029	0.09	0.183	60.13	6.06	0.75	0.029	0.36	0.183	52.1
8	6.19	1.26	0.135	4.36	0.264	56.30	6.25	0.61	0.126	3.25	0.183	56.16	6.23	0.87	0.284	3.26	0.254	123.80
9	5.05	1.40	0.314	1.64	0.341	263.40	6.29	1.21	0.144	0.11	0.248	216.70	7.17	1.12	0.125	0.35	0.264	214.30
10	5.01	0.28	0.248	0.34	0.354	59.40	5.08	0.37	0.321	0.64	0.264	56.40	5.04	0.34	0.025	0.54	0.239	85.30
11	5.76	0.60	0.264	1.36	0.294	254.80	5.69	0.57	0.234	2.54	0.264	302.50	5.75	0.53	0.236	2.35	0.418	308.50
12	5.58	0.46	0.341	0.26	0.341	59.40	5.61	0.50	0.258	0.35	0.258	66.80	5.56	0.42	0.354	0.64	0.264	69.10
13	5.35	1.34	0.029	0.19	0.264	258.94	5.35	1.70	0.404	0.19	0.245	235.10	5.37	1.40	0.214	0.35	0.254	236.50
14	5.40	0.53	0.035	3.64	0.147	198.50	5.38	0.56	0.125	3.59	0.148	138.50	5.34	0.64	0.184	2.65	0.126	292.50
15	5.20	2.26	0.184	3.65	0.354	243.10	5.14	2.20	0.462	2.69	0.264	258.30	5.08	2.12	0.204	1.25	0.254	264.90
16	5.43	0.52	0.236	0.26	0.364	153.60	5.48	0.56	0.354	3.26	0.260	142.50	5.45	0.57	0.258	1.35	0.284	125.80
17	5.42	1.36	0.169	2.67	0.358	235.60	5.34	1.28	0.125	2.94	0.269	245.80	5.45	1.34	0.134	4.35	0.358	264.60
18	5.49	0.30	0.173	0.26	0.232	95.92	5.97	0.68	0.029	0.10	0.216	49.70	6.28	0.67	0.058	0.35	0.189	85.49
19	5.31	1.21	0.341	0.64	0.284	164.50	5.24	1.18	0.264	0.36	0.264	163.20	5.16	1.14	0.254	0.39	0.235	154.20
20	5.78	0.96	0.115	0.29	0.364	82.50	5.83	0.97	0.354	0.35	0.194	123.50	5.60	1.03	0.202	0.85	0.155	324.20

Table 3 showed the depth-wise transformation of soil chemical properties of the lower ridge of Dekhar haor site Sunamgonj. The analytical data exposed that the soil of the topsoil (0-15cm) of lower ridge areas of Dekhar haor uphold strong acidity to slightly acidity, comprising the pH ranges from 4.85- 6.27. However, at the15-30 cm depth the pH of the lower ridge soil varied from 4.72- 6.14 and ensued it's strong to slightly acidic nature of soil. Similarly, strong acidic to slightly acidic soil (pH, 4.55- 6.30) was observed at soil depth 30-45 cm of upper ridge soils of the haor area. Lower ridge soil of Dekhar haor area had shown a wide range of variation found for the percent organic carbon content (0.52-1.71%) in the topsoil (0-15cm). The organic carbon content at 15-30 cm depth in the lower ridge area was varied from 0.46-2.30%. Meanwhile at 30-45 cm, the organic carbon content of the studied lower ridge area was varied from (0.41-2.15%). Soil nitrogen content of the top soil (0-15cm) of lower ridge of studied haor area was shown a wide inconsistency (0.036-0.364%). The nitrogen content at 15-30 cm depth of the lower ridge soil of haor area was varied from 0.094-0.421%. Similarly, at 30-45 cm depth of the lower ridge area had a variable range of N content (0.034-0.404%). The phophorus content of the top soil (0-15cm) of lower ridge haor area was very low to low (0.11 to 6.34 ppm). Similarly, at 15-30 and 30-45cm depth of the lower ridge area had exhibited very low to low amount of phosphorus 0.14-5.04 and 0.16-7.61 ppm respectively. Potassium content of the lower ridge soil of haor area was varied from 0.124-0.364 me/100g for 0-15cm depth, for 15-30cm depth 0.140-0.394 me/100g and for 30-45 cm depth 0.199-0.358 me/100g soil. The sulphur content of the lower ridge of haor soils showed a wide range of variability from 51.60 to 345.50 ppm for 0-15cm depths. The sulphur content at 15-30cm and 30-40 cm depth of the lower ridge area having a range of 53.50-349.40 ppm and 30.50-269.50 ppm respectively.

Table 102. Depth-wise soil chemical properties of the lower ridge of Dekhar haor site Sunamgonj

Sampling Point	Lower Ridge																	
	Soil Depth (0-15cm)						Soil Depth (15-30 cm)						Soil Depth (30-45 cm)					
	pH	OC (%)	N (%)	P (ppm)	K (me/ 100g)	S (ppm)	pH	OC (%)	N (%)	P (ppm)	K (me /100g)	S (ppm)	pH	OC (%)	N (%)	P (ppm)	K (me /100g)	S (ppm)
1	5.61	0.69	0.036	0.26	0.215	68.50	5.56	0.72	0.123	0.28	0.236	58.20	5.65	0.95	0.404	0.81	0.358	36.90
2	5.69	0.96	0.144	3.44	0.227	102.38	5.64	0.91	0.156	2.35	0.264	109.30	5.66	0.95	0.241	1.35	0.231	106.80
3	6.27	0.56	0.254	0.64	0.124	51.60	6.05	0.58	0.317	0.37	0.140	91.94	6.30	0.55	0.087	5.92	0.227	180.91
4	5.87	0.98	0.364	1.67	0.256	98.50	5.99	0.94	0.490	0.20	0.154	89.96	5.96	0.93	0.035	0.68	0.284	64.90
5	5.78	0.53	0.264	1.97	0.284	59.50	5.81	0.58	0.251	3.54	0.264	102.50	5.83	0.54	0.215	0.35	0.213	87.50
6	5.49	0.72	0.234	3.24	0.241	125.60	5.52	0.64	0.202	5.04	0.217	143.63	5.50	0.65	0.214	2.64	0.238	126.30
7	5.64	0.52	0.247	0.28	0.364	52.30	5.71	0.54	0.174	0.61	0.264	53.50	5.62	0.45	0.154	1.35	0.292	30.50
8	5.83	1.04	0.147	2.64	0.264	231.50	5.81	1.10	0.173	3.38	0.236	383.69	5.88	1.05	0.125	4.35	0.236	235.30
9	6.24	0.49	0.126	0.26	0.324	96.50	6.14	0.46	0.124	0.36	0.394	123.50	4.55	0.41	0.034	0.36	0.268	142.50
10	5.24	0.52	0.064	0.36	0.236	89.60	5.26	0.48	0.094	0.94	0.289	67.50	5.24	0.45	0.310	1.34	0.364	64.80
11	5.52	1.40	0.354	0.36	0.347	345.50	5.45	1.59	0.289	0.47	0.299	349.40	5.48	1.24	0.261	0.68	0.246	269.50
12	5.68	0.64	0.261	0.37	0.315	73.50	5.71	0.56	0.421	0.94	0.289	76.80	5.72	0.46	0.321	0.16	0.268	96.10
13	5.55	0.79	0.365	2.36	0.235	234.10	5.52	0.82	0.264	3.07	0.364	258.10	5.47	0.85	0.024	3.16	0.294	236.80
14	5.41	1.28	0.144	2.81	0.304	294.23	5.35	1.12	0.314	2.62	0.352	218.60	5.37	1.08	0.264	2.51	0.284	213.50
15	5.33	1.62	0.202	0.70	0.264	70.07	5.37	1.54	0.261	0.65	0.261	72.50	5.34	1.52	0.268	4.31	0.342	74.30
16	5.67	0.79	0.184	3.59	0.264	266.50	5.72	0.76	0.187	3.94	0.348	254.10	5.74	0.85	0.195	7.61	0.294	235.80
17	5.04	2.70	0.167	6.34	0.264	231.80	5.12	2.30	0.148	4.68	0.315	213.50	5.09	2.15	0.231	5.07	0.199	148.20
18	5.75	0.99	0.168	0.11	0.164	89.50	5.71	1.18	0.346	3.13	0.190	186.87	5.80	0.82	0.404	0.34	.272	154.30
19	4.85	1.71	0.260	0.98	0.318	184.50	4.72	2.20	0.173	0.14	0.204	123.60	5.89	1.80	0.099	0.31	0.345	128.30
20	5.42	0.92	0.325	0.62	0.435	269.50	5.58	0.97	0.317	3.21	0.210	374.75	5.27	0.82	0.375	0.69	0.227	262.92

2.7.1 Soil bulk density

The bulk density of soil varied non-significantly both in locations and depths. In case of location, bulk density was found more or less similar in ridge (1.36 g cc^{-1}) and middle soil (1.37 g cc^{-1}), which was higher than that of basin soil (1.15 g cc^{-1}) (Fig. 126). In case of depth bulk density was higher in 0-15 cm depth which was 1.33 g cc^{-1} (Fig. 127). In 15-30 cm and 30-45 cm depth bulk density were 1.26 g cc-^{1} and 1.28 g cc^{-1} respectively which were more or less similar. The lowest bulk density was found in basin areas. It might be due to higher moisture content and flocculent soft layer in the top soils of basin areas, which contributed to less dry mass compared to middle and ridge lands.

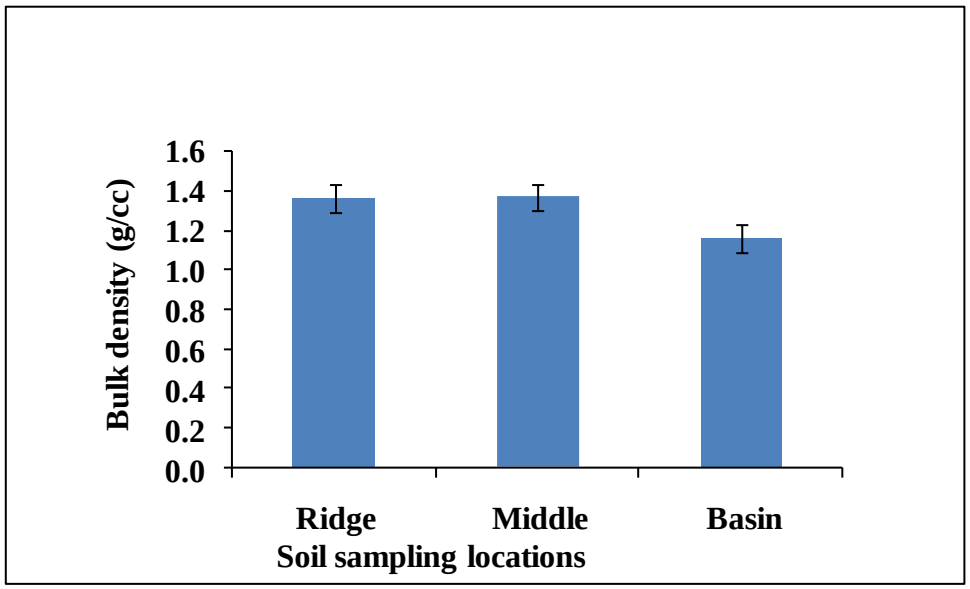


Figure 126. Soil bulk density in various locations of Dekar haor

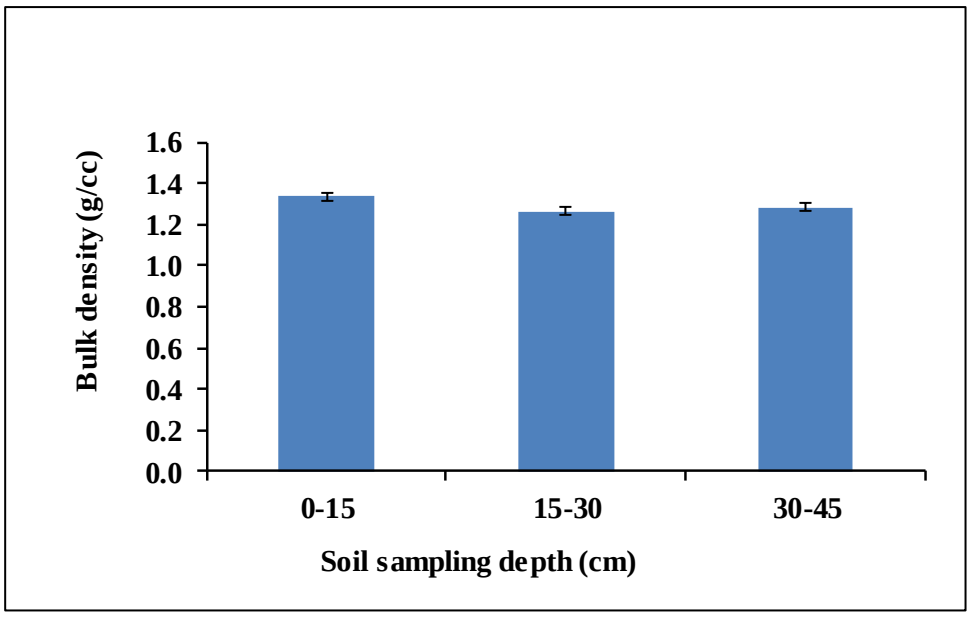


Figure 127. Soil bulk density in various depths of Dekar haor

Soil bulk density is a vital parameter for calculating weight of soil considering the depth of interest. In an ideal porosity (50% volume), bulk density of soil ranges from 1.30 to 1.35 g cc^{-1}, while in case of coarse-textured soil, it varies from 1.40 to 1.75 g cc^{-1}, and in fine-

textured one ranges from 1.10 to 1.40 g cc^{-1} (Phogat *et al*., 2015). Different factors affecting soil bulk density are soil texture, structure, moisture, OM content, and management practices. The lower bulk density indicates the higher OM and clay content of the soil. Different management practices like irrigation management, C sequestration and nutrient dynamics depends upon the bulk density of soil.

2.7.2 Soil pH

Soil pH was found slightly acidic in all three locations and depths which is shown in the Table 5. It was observed that in ridge, middle and basin soil pH were 5.86, 5.69 and 5.58 respectively. The pH of ridge soil was higher than that of middle and basin soils. In 0-15 cm, 15-30 cm and 30-45 cm depths pH were 5.62, 5.73 and 5.78, respectively. Soil pH was appeared little lower in top soils (0-15 cm) compared to other two depths. However, in all locations and depths pH values revealed that soils are moderately acidic (FRG, 2018).

Usually soil pH does not change easily because of buffering action of soils. Sometimes application of higher level of organic materials alone and in combination with inorganic fertilizers reduces soil pH (Sarwar *et al*., 2008). The reduction in pH might be due to release of hydrogen ions upon break down of organic materials, which replace calcium ions on the charged sites. Soil pH is an important factor that contributes to release of nutrients, their uptake by plants, and microbial activities in soils (Heggelund *et al*., 2014). The pH in agricultural soils best suited for most of the field crop ranges from 6.0 to 7.5. Slightly acidic, neutral and slightly alkaline soils are good for nutrient availability and crop productivity. The availability of macronutrients (N, P, K, Ca, Mg, S) plus Mo is increases at high pH. In contrast, micronutrient availability (Cl, Fe, Zn, Cu) minus Mo increases at lower soil pH. Soil nutrient availability is restricted when pH is <5.5 or >8.5.

2.7.3 Organic carbon (OC)

Organic carbon contents in ridge, middle and basin soils were 0.62, 0.82 and 0.97%, respectively (Table 4). As per fertility rankings given by Bangladesh Agricultural Research Council (BARC), status of OC contents in haor soils were observed low (FRG, 2018). Organic carbon contents were found higher in basin soils than that of ridge and middle soils. Because the low land is saucer shaped, which receive runoff materials and organic constituents and thus upon time it becomes enriched with organic matter. Organic carbon contents were 0.87, 0.79 and 0.74% in 0-15 cm, 15-30 cm, 30-45 cm depths, respectively which are also rated as low (Table 103). Generally, soil OC contents in the top soils are higher because of inputs like composts, manures, crop residues are applied to the surface soils. Surface soil is the most biologically active soil which logically contains higher amount of nutrients and carbon (Wells *et al*., 2011). According to FRG (2018), a good soil contains about 1.16% OC (2% OM), while in most of the soils of Bangladesh have less than 0.87% OC, and some soils have even less than 0.58% OC (<1% OM).

Solitary application of chemical fertilizers without replenishment of OM for crop cultivation, utilization of high yielding crop varieties, and removal of crop residues from crop fields, use of less or no organic fertilizers, etc. have created remarkable influences on soil nutrient removal and thus led to the deterioration of soil health (Rahman, 2013). Organic matter is the life of a soil, while its deficiency might be a threat to the sustainability of agriculture and the environment. Therefore, the improvement of soil fertility is a must for sustainable crop production. Different organic sources viz. crop residues, poultry manure, cowdung, vermicompost, farmyard manure, are good source of soil C which can be applied to soils especially in the ridge areas of haors.

Table 103. Effects of topography and depth on soil properties

Soil characteristics					
Treatments Factor	**pH**	**OC (%)**	**N (%)**	**P (mg kg^{-1})**	**S (mg kg^{-1})**
Location:					
Ridge	5.86 a	0.62 c	0.199	2.46 a	141.73
Middle	5.69 b	0.82 b	0.191	1.46 b	140.72
Basin	5.58 b	0.97 a	0.223	1.91 ab	157.04
S.E (±)	0.059	0.061	0.022	0.287	9.699
Soil depth (cm):					
0-15	5.62 b	0.87 a	0.210	1.96	144.30
15-30	5.73 ab	0.79 ab	0.207	1.89	145.42
30-45	5.78 a	0.74 b	0.195	1.99	149.76
S.E (±)	0.059	0.061	0.022	0.287	9.699
Location × depth	NS	NS	NS	NS	NS
CV%	5.6	41.42	61.23	80.79	36.27

BD - bulk density, OC- organic carbon, N- nitrogen, P- phosphorus, S- sulphur

2.7.4 Total nitrogen (N)

No significant variation was recorded in the total N content among the ridge, middle, basin soils and the soils of 0-15 cm, 15-30 cm and 30-45 cm depths. The N content in ridge soil was 0.199% and in middle it was 0.191% while in basin soil it was slightly higher 0.223% (Table 103). However, as per soil fertility ranking given by BARC (FRG, 2018), N contents in the ridge, middle and basin soils were rated as medium. In case of depths, N contents were 0.210, 0.207 and 0.195% in 0-15, 15-30 and 30-45 cm depths, respectively, which were also rated as medium. Results revealed that total N content decreased significantly with the increase of soil depths. Nitrogen is very reactive and mobile in soils, it subjected to losses through volatilization, de-nitrification, leaching and surface runoff (Delgado, 2002). Farmers in the haor areas generally apply all fertilizers as a basal dose to crop fields, which encourages higher N loss and contributes to lower efficiency. Therefore, a full dose of N fertilizer should be applied on a split basis to satisfy N requirement of each crop during the growing season.

2.7.5 Available phosphorous (P)

Available P in ridge, middle and basin soils were 2.46, 1.46 and 1.91 mg kg^{-1}, respectively (Table 103). In case of soil depths, P contents were found 1.96, 1.89 and 1.99 mg kg^{-1} in 0-15, 15-30 and 30-45 cm depth, respectively. Phosphorous was higher in ridge soils compared to middle and basin soils. According to BARC (FRG, 2018) available P was very low in all types of soils. It may be occurred due to the presence of acidic soil and low OM content, and more specifically imbalanced and less amount of inorganic fertilizer application by the farmers in the haor areas. Ali *et al*. (2017) reported that average P application rate by farmers of the haor areas was only 8.6 kg P ha^{-1}, while BARC recommended dose is 20 kg P ha^{-1}. It is revealed that the actual P application rate was much lower than that of recommended dose. The soils of the study area also contain very high level of calcium (Table 104), which might have fixed available P in haor soils. Lower rates of P application and P fixation by calcium might attributed to lower available P in haor soils. Therefore, soil test-based fertilizers application could be a solution of P management in the haor soils.

2.7.6 Available sulphur (S)

Available S contents in the ridge and middle soils were 141.73 and 140.72 mg kg^{-1} which were lower than that of basin soil which contained 157.04 mg S kg^{-1} (Table 103). In 30-45 cm depth, S content was 149.76 mg kg^{-1} which was higher than other two depths. In 0-15 cm and 15-30 cm depths, S contents were 144.30 and 145.42 mg kg^{-1}, respectively. Overall status of S contents in haor soils were very high according to fertility ranking of BARC (FRG, 2018). Sulphur contents increased with the increase of soil depths because of leaching of SO_4^{2-} from top soils to sub-soils. As the test results exposed that S contents in the haor soils were very high, therefore, application of sulphur-containing fertilizer must not be needed unless the subsequent soil test revealed its deficiency in soils.

2.7.7 Exchangeable potassium (K)

The potassium contents in ridge, middle and basin soils were 0.24, 0.25 and 0.26 cmol (+) kg^{-1}, respectively (Table 104). Potassium was present little higher in basin soil than that of middle and ridge soils. Potassium was higher in the top soils (0-15 cm) containing 0.27 cmol (+) K kg^{-1} soil. In the lower depths (15-30 cm and 30-45 cm) K content was found same, which was 0.24 cmol (+) kg^{-1}. However, as per BARC soil fertility ranking, K status were rated optimum for all locations and depths of soils at Dekar haor (FRG, 2018). If the soil contains K at optimum level, extra application using inorganic potassium fertilizer might not be needed. However, a maintenance dose of K can be recommended for farmers in the study area. Potassium ion (K^+) may fix with negatively charged soil colloidal particles viz. humus and clay and thereby loss of K from soil is minimum (Silva *et al*., 2002).

2.7.8 Exchangeable sodium (Na), calcium (Ca) and magnesium (Mg)

No significant variation was recorded in exchangeable Na in soils for both of locations and depths. In the ridge, middle and basin soils, Na contents were 0.21, 0.20 and 0.19 cmol (+) kg^{-1}, respectively (Table 104). In all three types of depth Na contents were 0.20 cmol (+) kg^{-1}, i.e. there was no variations in Na contents in three different soil depths. Calcium contents in middle and basin soils were more or less similar where the values were 20.65 and 19.20 cmol (+) kg^{-1}, respectively which were higher than that of ridge soil. In ridge soils, Ca contents was 13.67 cmol (+) kg^{-1}. In case of soil depths, Ca contents in 0-15, 15-30 and 30-45 cm were 17.02, 19.18 and 17.31 cmol (+) kg^{-1}, respectively. The fertility status of Ca in haor soils were high according to fertility ranking (FRG, 2018). Magnesium contents were more or less similar in middle and basin soils which were lower than that of ridge soil. Magnesium contents in ridge, middle and basin soil were 0.35, 0.32 and 0.30 cmol (+) kg^{-1}, respectively. In both of 0-15 and 30-45 depths, Mg contents were 0.33 cmol (+) kg^{-1}, while in 15-30 cm depth it was 0.32 cmol (+) kg^{-1} (Table 104). The fertility status of Mg in haor soil was very low according to fertility ranking of BARC (FRG, 2018). Magnesium is very mobile in soil, because it is less bound to the soil charges. This results in a relatively high abundance of this element in the soil solution and thus a higher risk of leaching (Maguire and Cowan, 2002). However, such leaching may not occur in the study area because of lower amount of Mg content in haor soils.

Table 104. Effects of topography and depths on basic cations

Treatments factors	Basic cations (Cmol (+) kg^{-1})			
	K	Na	Ca	Mg
Location:				
Ridge	0.24 b	0.22	13.67 b	0.36 a
Middle	0.26 ab	0.20	20.65 a	0.32 b
Basin	0.27 a	0.20	19.20 a	0.30 b
S.E (±)	0.011	6.23	1.26	0.01
Soil depth (cm):				

Treatments factors	Basic cations (Cmol (+) kg^{-1})			
	K	Na	Ca	Mg
0-15	0.28 a	0.21	17.02	0.33
15-30	0.24 b	0.20	19.18	0.32
30-45	0.25 b	0.20	17.31	0.33
S.E (±)	0.011	6.23	1.26	0.01
Location × depth	NS	NS	NS	NS
CV%	24.24	16.62	38.68	17.52

k- potassium, Na- sodium, Mg- magnesium, Ca- calcium, CV- Co-efficient of Variation, S.E- standard Error

3 Expt. II. Assessment and Improvement of Bio-physicochemical characteristics of different soils of the climate vulnerable arsenic area of Faridpur sadar, saline areas of Batiaghata and heavy metal polluted areas of Bhaluka using different organic amendments (Under objective I).

Chemical properties like pH, N (%), OC (%), P (mg/kg), S (mg/kg), K (cmol/kg), Zn (mg/kg), CEC (cmol/kg), NH_4-N (mg/kg), NO_3-N (mg/kg), physical properties like bulk density (g/cm3), carbon sequestration (t/ha) and biological properties like biomass C (mg /kg), biomass N (mg/kg) were analyzed using standard methods.

Arsenic contaminated area of Faridpur sadar

Bio-physicochemical properties of initial soil samples of arsenic contaminated area of Faridpur Sadar are presented in the Table 105. The chemical properties of studied soil such as, pH, N, OC, P, S, K, Zn, Fe, CEC, NH_4-N, NO_3-N, As were 6.56, 0.159%, 0.95%, 18.87 mg/kg, 24.28 mg/kg, 0.19 cmol/kg, 0.24 mg/kg, 115.2 ppm, 14.38 cmol/kg, 9.36 mg/kg, 3.72 mg/kg, 38.2 ppm, respectively. Meanwhile, the study area have on an average bulk density (1.39 g/cm^3) and carbon sequestration (10.12 t/ha). The average biomass C and biomass N content of the arsenic contaminated area were 32.67 mg /kg and 4.72 mg/kg, respectively.

Table 105. Average values of bio-physicochemical properties of initial soil samples in arsenic contaminated area of Faridpur sadar

Soil properties	Analytical Value
pH	6.56
Total N (%)	0.159
OC (%)	0.95
Available P (mg/kg)	18.87
Available S (mg/kg)	24.28
Exchangeable K (cmol/kg)	0.19
Zn (mg/kg)	0.24
Fe (ppm)	115.2
CEC (cmol/kg)	14.38
NH_4-N (mg/kg)	9.36
NO_3-N (mg/kg)	3.72
As concentration (ppm)	38.2
Bulk density (g/cm^3)	1.39
Carbon stock (t/ha)	19.81
Biomass C (mg /kg)	32.67
Biomass N (mg/kg)	4.72

3.1 The effect of different organic amendment on soil chemical properties in Faridpur Sadar

3.1.1 Soil pH

The effects of different treatments on soil pH in the arsenic contaminated research field of Faridpur Sadar is presented in 106. After three-year judicious application of organic fertilizers, soil pH did not significantly influenced by different treatments. The soil pH ranged from 6.58 to 6.92. The maximum soil pH (6.92) was in the T_3 treatment (biochar + recommended fertilizer), while the lowest soil pH value (6.58) was in T_1 treatment (control).

Table 106. Effect of different organic matters on post-harvest soil pH content in arsenic contaminated area of Faridpur sadar

Treatments	pH value
T_1	6.58a
T_2	6.67a
T_3	6.92a
T_4	6.77a
T_5	6.74a
T_6	6.68a
CV (%)	5.28
SE (±)	0.25

Legends, T_1 = Control, T_2 = Recommended Fertilizer, T_3 = Biochar + Recommended Fertilizer, T_4 = Poultry Manure + Chemical Fertilizer, T_5 = Vermicompost + Chemical Fertilizer, T_6 = Standard Organic Fertilizer + Chemical Fertilizer

3.1.2 Soil Total Nitrogen (%)

Soil total N content was significantly increased by different treatments after three-year application with organic fertilizers (Table 107). The soil total N was varied from 0.157 to 0.293 (%). The significantly highest soil total N content (0.293%) was found in the T3 treatment which was statistically similar with T_4 treatment. The lowest soil total N content (0.157%) was recorded in T_1 treatment.

Table 107. Effect of different organic matters on post-harvest soil total N (%) content in arsenic contaminated area of Faridpur sadar

Treatments	Total N (%)
T_1	0.157d
T_2	0.166cd
T_3	0.293a
T_4	0.288a
T_5	0.194bc
T_6	0.205b
CV (%)	8.68
SE (±)	0.013

Legends, T_1 = Control, T_2 = Recommended Fertilizer, T_3 = Biochar + Recommended Fertilizer, T_4 = Poultry Manure + Chemical Fertilizer, T_5 = Vermicompost + Chemical Fertilizer, T_6 = Standard Organic Fertilizer + Chemical Fertilizer

3.1.3 Soil Organic Carbon (%)

The OC content of the contaminated soil was significantly increased by different organic amendment treatments after three-year application (Table 108). The soil OC was extended from 0.98 to 1.25 (%). The significantly highest soil OC content (1.25%) was observed in the T_3 treatment which was statistically similar to T_4, T_5 and T_6 treatments. The lowest soil OC content (0.98%) was noted in T_1 treatment.

Table 108. Effect of different organic matters on post-harvest soil OC (%) content in arsenic contaminated area of Faridpur sadar

Treatments	OC (%) content
T_1	0.98c
T_2	1.02bc
T_3	1.25a
T_4	1.23a
T_5	1.16ab
T_6	1.10abc
CV (%)	9.87
SE (±)	0.078

Legends, T_1 = Control, T_2 = Recommended Fertilizer, T_3 = Biochar + Recommended Fertilizer, T_4 = Poultry Manure + Chemical Fertilizer, T_5 = Vermicompost + Chemical Fertilizer, T_6 = Standard Organic Fertilizer + Chemical Fertilizer

3.1.4 Soil Available Phosphorus (mg/kg)

The soil available P was remarkably influenced by different treatments after three-year application of organic fertilizers (Table 109). The soil available P was ranged from 18.41 to 25.92 (mg/kg). The significantly highest soil available P (25.92mg/kg) was found in the T_4 treatment which was statistically similar to T_3 and T_6 treatments. The lowest soil available P (18.41mg/kg) was noted in T_1 treatment.

Table 109. Effect of different organic matters on post-harvest soil available P (mg/kg) content in arsenic contaminated area of Faridpur sadar

Treatments	Available Phosphorus (mg/kg)
T_1	18.41c
T_2	19.53c
T_3	25.63a
T_4	25.92a
T_5	22.17b
T_6	24.70a
CV (%)	3.59
SE (±)	0.57

Legends, T_1 = Control, T_2 = Recommended Fertilizer, T_3 = Biochar + Recommended Fertilizer, T_4 = Poultry Manure + Chemical Fertilizer, T_5 = Vermicompost + Chemical Fertilizer, T_6 = Standard Organic Fertilizer + Chemical Fertilizer

3.1.5 Soil Available Sulphur (mg/kg)

Three-year application of organic fertilizers had significant effect on the available S content in the contaminated soil (Table 110). The soil available S was ranged from 24.20 to 46.50 (mg/kg). Among the treatments, T_4 (poultry manure + chemical fertilizer) gave the significantly highest soil available S (46.50mg/kg) content. The lowest soil available S (24.20mg/kg) was detected in T_1 treatment.

Table 110. Effect of different organic matters on post-harvest soil available S (mg/kg) content in arsenic contaminated area of Faridpur sadar

Treatments	Available S (mg/kg)
T_1	24.20f
T_2	32.22e
T_3	43.14b
T_4	46.50a
T_5	37.81c
T_6	35.23d
CV (%)	2.8
SE (±)	0.72

Legends, T_1 = Control, T_2 = Recommended Fertilizer, T_3 = Biochar + Recommended Fertilizer, T_4 = Poultry Manure + Chemical Fertilizer, T_5 = Vermicompost + Chemical Fertilizer, T_6 = Standard Organic Fertilizer + Chemical Fertilizer

3.1.6 Soil Exchangeable Potassium (cmol/kg)

Table 111 represents that three years judicious application of different organic fertilizer treatments significantly affected the exchangeable K content in contaminated soil. The range of soil exchangeable potassium was 0.17 to 0.35 (cmol/kg). In the T_3 treatment, the maximum soil exchangeable K was 0.35 (cmol/kg). The lowest soil exchangeable K recorded in the T_1 treatment was 0.17 (cmol/kg).

Table 111. Effect of different organic matters on post-harvest soil exchangeable K (cmol/kg) content in arsenic contaminated area of Faridpur sadar

Treatments	Exchangeable Potassium (cmol/kg)
T_1	0.17d
T_2	0.21c
T_3	0.35a
T_4	0.23b
T_5	0.22bc
T_6	0.22bc
CV (%)	4.14
SE (±)	0.006

Legends, T_1 = Control, T_2 = Recommended Fertilizer, T_3 = Biochar + Recommended Fertilizer, T_4 = Poultry Manure + Chemical Fertilizer, T_5 = Vermicompost + Chemical Fertilizer, T_6 = Standard Organic Fertilizer + Chemical Fertilizer

3.1.7 Soil Zinc (mg/kg)

Three-year application of organic fertilizers significantly increased the Zn content in contaminated soil (Table 112). Organic amendments were varied the Zn content from 0.27 to 1.48 (mg/kg). Among the treatments, the biochar treated treatment T_3 showed the maximum Zn content (1.48mg/kg) and the minimum Zn content (0.27mg/kg) in T_1 treatment.

Table 112. Effect of different organic matters on post-harvest soil Zn (mg/kg) content in arsenic contaminated area of Faridpur sadar

Treatments	Zn (mg/kg) content
T_1	0.27e
T_2	0.64d
T_3	1.48a
T_4	0.93b
T_5	0.81c
T_6	0.90bc
CV (%)	7.67
SE (±)	0.045

Legends, T_1 = Control, T_2 = Recommended Fertilizer, T_3 = Biochar + Recommended Fertilizer, T_4 = Poultry Manure + Chemical Fertilizer, T_5 = Vermicompost + Chemical Fertilizer, T_6 = Standard Organic Fertilizer + Chemical Fertilizer

3.1.8 Soil cation exchange capacity (cmol/kg)

Three-year incorporation of organic amendment had significant effects on CEC of arsenic contaminated soil (Table 113). The CEC was ranged from 14.34 to 28.37 (cmol/kg). The maximum CEC (28.37 cmol/kg) of the amended soil was noted in the T_3 treatment which was statistically similar with T4 treatment. The lowest CEC was 14.34 (cmol/kg) recorded in T_1 treatment.

Table 113. Effect of different organic matters on post-harvest soil CEC (cmol/kg) in arsenic contaminated area of Faridpur sadar

Treatments	CEC (cmol/kg)
T_1	14.34d
T_2	18.13c
T_3	28.37a
T_4	28.25a
T_5	23.67b
T_6	19.50c
CV (%)	10.88
SE (±)	1.69

Legends, T_1 = Control, T_2 = Recommended Fertilizer, T_3 = Biochar + Recommended Fertilizer, T_4 = Poultry Manure + Chemical Fertilizer, T_5 = Vermicompost + Chemical Fertilizer, T_6 = Standard Organic Fertilizer + Chemical Fertilizer

3.1.9 Soil ammonium nitrogen (mg/kg)

The soil NH_4-N was significantly increased by three-year application of different organic fertilizers (Table 114). The range of NH_4-N significantly varied from 9.39 to 18.46 (mg/kg). The significantly highest soil NH_4-N (18.46 mg/kg) was in the T_3 treatment. The lowest soil NH_4-N (9.39 mg/kg) was recorded in T_1 treatment.

Table 114. Effect of different organic matters on post-harvest soil NH_4-N (mg/kg) content in arsenic contaminated area of Faridpur sadar

Treatments	NH_4-N (mg/kg)
T_1	9.39e
T_2	11.45d
T_3	18.46a
T_4	16.03b
T_5	13.45c
T_6	12.57cd
CV (%)	8.66
SE (±)	0.83

Legends, T_1 = Control, T_2 = Recommended Fertilizer, T_3 = Biochar + Recommended Fertilizer, T_4 = Poultry Manure + Chemical Fertilizer, T_5 = Vermicompost + Chemical Fertilizer, T_6 = Standard Organic Fertilizer + Chemical Fertilizer

3.1.10 Soil nitrate nitrogen (mg/kg)

The effects of different treatments on soil NO_3-N in the study area are presented in Table 115. The soil NO_3-N remarkably influenced by different treatments after three-year application of organic fertilizers. The soil NO_3-N ranged from 3.67 to 5.57 (mg/kg). The significantly highest NO_3-N (5.57 mg/kg) was found in the T_3 treatment and the lowest NO_3-N (3.67 mg/kg) content in T_1 treatment.

Table 115. Effect of different organic matters on post-harvest soil NO_3-N (mg/kg) content in arsenic contaminated area of Faridpur sadar

Treatments	NO_3-N (mg/kg)
T_1	3.67d
T_2	3.73d
T_3	5.57a
T_4	4.42b
T_5	4.41b
T_6	4.11c
CV (%)	4.13
SE (±)	0.126

Legends, T_1 = Control, T_2 = Recommended Fertilizer, T_3 = Biochar + Recommended Fertilizer, T_4 = Poultry Manure + Chemical Fertilizer, T_5 = Vermicompost + Chemical Fertilizer, T_6 = Standard Organic Fertilizer + Chemical Fertilizer

3.2 The effect of different organic amendment on soil physical properties in Faridpur Sadar

3.2.1 Soil bulk density (g/cm^3)

The effects of different treatments on bulk density in the experimental site are presented in Table 116. After three-year incorporation of different organic materials the bulk density of the soil was significantly decreased. The range of bulk density was found between 1.28 and 1.37 (g/cm^3). The maximum bulk density (1.37 g/cm^3) was recorded in the T_1 treated plot. The lowest bulk density (1.28 g/cm^3) was assessed in the T_3 treatment.

Table 116. Effect of different organic matters on post-harvest soil bulk density (g/cm^3) in arsenic contaminated area of Faridpur sadar

Treatments	Bulk density (g/cm^3)
T_1	1.37a
T_2	1.36a
T_3	1.28d
T_4	1.32c
T_5	1.35ab
T_6	1.33bc
CV (%)	1.07
SE (±)	0.01

Legends, T_1 = Control, T_2 = Recommended Fertilizer, T_3 = Biochar + Recommended Fertilizer, T_4 = Poultry Manure + Chemical Fertilizer, T_5 = Vermicompost + Chemical Fertilizer, T_6 = Standard Organic Fertilizer + Chemical Fertilizer

3.3 The effect of different organic amendment on soil biological properties in Faridpur Sadar

3.3.1 Soil biomass carbon (mg /kg)

Three-year application of organic fertilizers had significant effect on the biomass carbon content in the contaminated soil (Table 117). The soil biomass carbon was ranged from 32.42 to 196.27 (mg/kg). Among the treatments, T_3 gave the significantly highest soil biomass carbon (196.27mg/kg) content. The lowest soil biomass carbon (32.42 mg/kg) was detected in T_1 treatment.

Table 117. Effect of different organic matters on post-harvest soil Biomass C (mg /kg) content in arsenic contaminated area of Faridpur sadar

Treatments	Biomass C (mg /kg)
T_1	32.42e
T_2	69.92d
T_3	196.27a
T_4	167.93b
T_5	142.56c
T_6	136.35c
CV (%)	6.75
SE (±)	5.93

Legends, T_1 = Control, T_2 = Recommended Fertilizer, T_3 = Biochar + Recommended Fertilizer, T_4 = Poultry Manure + Chemical Fertilizer, T_5 = Vermicompost + Chemical Fertilizer, T_6 = Standard Organic Fertilizer + Chemical Fertilizer

3.3.2 Soil biomass nitrogen (mg /kg)

Table 118 represents that three years judicious application of different organic fertilizer treatments significantly affected the biomass nitrogen content in contaminated soil. The range of soil biomass nitrogen was 4.70 to 23.19 (mg/kg). In the T_3 treatment, the maximum soil biomass nitrogen was 23.19 mg/kg. The lowest soil biomass nitrogen recorded in the T_1 treatment was 4.70 mg/kg.

Table 118. Effect of different organic matters on post-harvest soil Biomass N (mg /kg) content in arsenic contaminated area of Faridpur sadar

Treatments	Biomass N (mg /kg)
T_1	4.70e
T_2	14.77d
T_3	23.19a
T_4	19.54b
T_5	18.47b
T_6	16.43c
CV (%)	6.1
SE (±)	0.69

Legends, T_1 = Control, T_2 = Recommended Fertilizer, T_3 = Biochar + Recommended Fertilizer, T_4 = Poultry Manure + Chemical Fertilizer, T_5 = Vermicompost + Chemical Fertilizer, T_6 = Standard Organic Fertilizer + Chemical Fertilizer

Saline areas of Batiaghata

Figure 128. Soil samples collection from Saline area of Batiaghata upazila, Khulna

Table 119. represents the bio-physicochemical properties of initial soil samples of saline affected area of Batiaghata, Khulna. The soil had a pH (7.73), N (0.221%), OC (0.72%), P (13.96 mg/kg), S (30.07 mg/kg), K (0.18 cmol/kg), Zn (0.25 mg/kg), NH_4-N (9.39 mg/kg), NO_3-N (3.41 mg/kg), CEC (19.76 cmol/kg) and 7.28 dS/m of EC content. The study soil had a bulk density of 1.45 g/cm^3 and 15.66 t/ha of carbon stock. The biomass C and N were 27.45 mg /kg and 4.68 mg/kg, respectively.

Table 119. Average values of bio-physicochemical properties of initial soil samples in saline areas of Batiaghata, Khulna

Soil properties	Analytical value
pH	7.73
Total N (%)	0.221
OC (%)	0.72
Available P (mg/kg)	13.96
Available S (mg/kg)	30.07
Exchangeable K (cmol/kg)	0.18
Zn (mg/kg)	0.25
CEC (cmol/kg)	19.76
EC (dS/m)	7.28
NH_4-N (mg/kg)	9.39
NO_3-N (mg/kg)	3.41
Bulk density (g/cm3)	1.45
Carbon stock (t/ha)	15.66
Biomass C (mg /kg)	27.45
Biomass N (mg/kg)	4.68

3.4 The effect of different organic amendment on soil chemical properties in Batiaghata

3.4.1 Soil pH

There was no significant effects on the soil pH in post-harvest soil after three years intensive application of different organic fertilizers (Table 120). The range of soil pH was varied between 7.83 and 8.46. The highest soil pH (8.46) was found in the T_3 treatment (biochar + recommended fertilizer). Alike pH value was found in T4, T5 and T6 treatments. The lowest soil pH value (7.83) was exhibited in T_1 treatment (control).

Table 120. Effect of different organic matters on post-harvest soil pH of the salinity affected experimental sites Batiaghata, Khulna

Treatments	soil pH
T_1	7.83c
T_2	8.26b
T_3	8.46a
T_4	8.40ab
T_5	8.33ab
T_6	8.36ab
CV (%)	1.27
SE (±)	0.075

Legends, T_1 = Control, T_2 = Recommended Fertilizer, T_3 = Biochar + Recommended Fertilizer, T_4 = Poultry Manure + Chemical Fertilizer, T_5 = Vermicompost + Chemical Fertilizer, T_6 = Standard Organic Fertilizer + Chemical Fertilizer

3.4.2 Soil nitrogen (%)

Total N (TN) content in salinity affected soil was significantly varied by the three year intensive application of different organic fertilizer treatments (Table 121). Organic amendments were varied the TN content from 0.223 to 0.263%. Among the treatments the biochar treated treatment T_3 was shown the highest TN content (0.263%) and the lowest TN content 0.223% in T_1 treatment.

Table 121. Effect of different organic matters on post-harvest soil N (%) content of the salinity affected experimental sites Batiaghata, Khulna

Treatments	N (%)
T_1	0.223c
T_2	0.223c
T_3	0.263a
T_4	0.242b
T_5	0.229bc
T_6	0.235bc
CV (%)	4.37
SE (±)	0.0072
LSD (0.05)	0.0155

Legends, T_1 = Control, T_2 = Recommended Fertilizer, T_3 = Biochar + Recommended Fertilizer, T_4 = Poultry Manure + Chemical Fertilizer, T_5 = Vermicompost + Chemical Fertilizer, T_6 = Standard Organic Fertilizer + Chemical Fertilizer

3.4.3 Soil organic carbon (%)

The OC content of saline-affected soil was significantly increased by the three years intensive addition of different organic fertilizers treatments (Table 122). The soil OC was ranged from 0.70 to 0.83 %.The significantly highest soil OC (0.83%) was found in the T_3 treatment which was statistically similar to T_2, T_4, T_5 and T_6 treatments. The lowest soil OC (0.70 %) was noted in T_1 treatment.

Table 122. Effect of different organic matters on post-harvest soil OC (%) content of the salinity affected experimental sites Batiaghata, Khulna

Treatments	OC (%)
T_1	0.70b
T_2	0.76ab
T_3	0.83a
T_4	0.79a
T_5	0.78a
T_6	0.77a
CV (%)	6.51
SE (±)	0.035

Legends, T_1 = Control, T_2 = Recommended Fertilizer, T_3 = Biochar + Recommended Fertilizer, T_4 = Poultry Manure + Chemical Fertilizer, T_5 = Vermicompost + Chemical Fertilizer, T_6 = Standard Organic Fertilizer + Chemical Fertilizer

3.4.4 Soil available Phosphorus (mg/kg)

The effects of different organic amendment treatments on soil available P content in the saline-affected research field of Batiaghata, Khulna is presented in Table 123. Three year intensive application of different organic fertilizer treatments had pose a significant positive change of soil available P in salinity affected soil and having a range of 13.82 to 24.12 (mg/kg). The highest available P content (24.12 mg/kg) was found in the T_4 treatment (Poultry Manure + Chemical Fertilizer) and a proximate data was found in T_3 treatment. The lowest soil available P value 13.82 (mg/kg) was in T_1 treatment (control).

Table 123. Effect of different organic matters on post-harvest soil P (mg/kg) content of the salinity affected experimental sites Batiaghata, Khulna

Treatments	Available P (mg/kg)
T_1	13.82d
T_2	14.28d
T_3	24.12a
T_4	25.49a
T_5	21.22b
T_6	19.14c
CV (%)	6.81
SE (±)	0.94

Legends, T_1 = Control, T_2 = Recommended Fertilizer, T_3 = Biochar + Recommended Fertilizer, T_4 = Poultry Manure + Chemical Fertilizer, T_5 = Vermicompost + Chemical Fertilizer, T_6 = Standard Organic Fertilizer + Chemical Fertilizer

3.4.5 Soil available Sulphur (mg/kg)

The effects of different treatments on soil available S in the study area are presented in Table 124. The soil available S remarkably influenced by different treatments after three years intensive application of organic fertilizers. The soil available S ranged from 30.01 to 54.49 (mg/kg). The significantly highest available S (54.49 mg/kg) was found in the T_4 treatment and the lowest available S (30.01 mg/kg) content in T_1 treatment.

Table 124. Effect of different organic matters on post-harvest soil available S (mg/kg) content of the salinity affected experimental sites Batiaghata, Khulna

Treatments	Available S (mg/kg)
T_1	30.01d
T_2	36.60c
T_3	46.15b
T_4	54.49a
T_5	45.93b
T_6	39.29c
CV (%)	4.34
SE (±)	1.29

Legends, T_1 = Control, T_2 = Recommended Fertilizer, T_3 = Biochar + Recommended Fertilizer, T_4 = Poultry Manure + Chemical Fertilizer, T_5 = Vermicompost + Chemical Fertilizer, T_6 = Standard Organic Fertilizer + Chemical Fertilizer

3.4.6 Soil exchangeable potassium (cmol/kg)

Three years intensive application of different organic fertilizers had significant effect on the exchangeable K content in the saline affected soil (Table 125). The soil exchangeable K was ranged from 0.18 to 0.34 (cmol/kg). Among the treatments, T_3 (Biochar + Recommended Fertilizer) gave the significantly highest soil exchangeable K (0.34 cmol/kg) content. The lowest soil exchangeable K (0.34 cmol/kg) content was detected in T_1 treatment.

Table 125. Effect of different organic matters on post-harvest soil exchangeable K (cmol/kg) content of the salinity affected experimental sites Batiaghata, Khulna

Treatments	Exchangeable K (cmol/kg)
T_1	0.18c
T_2	0.26b
T_3	0.34a
T_4	0.28b
T_5	0.26b
T_6	0.27b
CV (%)	12.61
SE (±)	0.024

Legends, T_1 = Control, T_2 = Recommended Fertilizer, T_3 = Biochar + Recommended Fertilizer, T_4 = Poultry Manure + Chemical Fertilizer, T_5 = Vermicompost + Chemical Fertilizer, T_6 = Standard Organic Fertilizer + Chemical Fertilizer

3.4.7 Soil zinc (mg/kg)

The effects of different organic amendment treatments on Zn content in the studied soil are presented in Table 126. The Zn content of the salt-affected soil was significantly increased by the three years intensive application of different organic fertilizer treatments. The Zn content was ranged from 0.24 to 1.25 mg/kg. The significantly highest Zn content (1.25 mg/kg) was found in the T_3 treatment and the lowest Zn (0.24 mg/kg) content in T_1 treatment.

Table 126. Effect of different organic matters on post-harvest soil Zn (mg/kg) content of the salinity affected experimental sites Batiaghata, Khulna

Treatments	Zn (mg/kg)
T_1	0.24d
T_2	0.60c
T_3	1.25a
T_4	0.96b
T_5	0.88b
T_6	0.59c
CV (%)	9.71
SE (±)	0.052

Legends, T_1 = Control, T_2 = Recommended Fertilizer, T_3 = Biochar + Recommended Fertilizer, T_4 = Poultry Manure + Chemical Fertilizer, T_5 = Vermicompost + Chemical Fertilizer, T_6 = Standard Organic Fertilizer + Chemical Fertilizer

3.4.8 Soil cation exchange capacity (CEC) (cmol/kg)

A significant positive change on CEC of salt-affected soil was detected by the three years intensive application of different organic fertilizer treatments (Table 127). The CEC of saline soil was ranged 19.72 to 28.27 (cmol/kg). In the T_3 treatment, the maximum soil CEC was 28.27 (cmol/kg). The lowest soil CEC was recorded in the T_1 treatment (19.72 cmol/kg).

Table 127. Effect of different organic matters on post-harvest soil CEC (cmol/kg) content of the salinity affected experimental sites Batiaghata, Khulna

Treatments	CEC (cmol/kg)
T_1	19.72b
T_2	19.98b
T_3	28.27a
T_4	26.99a
T_5	20.37b

T_6	20.67b
CV (%)	8.81
SE (±)	1.41

Legends, T_1 = Control, T_2 = Recommended Fertilizer, T_3 = Biochar + Recommended Fertilizer, T_4 = Poultry Manure + Chemical Fertilizer, T_5 = Vermicompost + Chemical Fertilizer, T_6 = Standard Organic Fertilizer + Chemical Fertilizer

3.4.9 Soil EC (dS/m)

The effects of different organic amendment treatments on soil EC in the study area are presented in Table 128. The soil EC was significantly influenced by the different treatments after three-year application of organic fertilizers. The soil EC ranged from 5.71 to 7.29 (dS/m). The significantly highest EC (7.29 dS/m) was found in the T_1 treatment and the lowest EC (5.71dS/m) content in T_3 treatment.

Table 128. Effect of different organic matters on post-harvest soil EC (dS/m) content of the salinity affected experimental sites Batiaghata, Khulna

Treatments	EC (dS/m)	
T_1	7.29a	
T_2	6.09bc	
T_3	5.71d	
T_4	6.11bc	
T_5	6.03c	
T_6	6.33b	
CV (%)	6.23	
SE (±)	0.13	

Legends, T_1 = Control, T_2 = Recommended Fertilizer, T_3 = Biochar + Recommended Fertilizer, T_4 = Poultry Manure + Chemical Fertilizer, T_5 = Vermicompost + Chemical Fertilizer, T_6 = Standard Organic Fertilizer + Chemical Fertilizer

3.4.10 Soil ammonium nitrogen (mg/kg)

The effects of different organic amendment treatments on soil NH_4-N in the experimental site are presented in Table 129. After three years intensive incorporation of different organic materials treatments, NH_4-N content of saline soil was significantly increased. The range of soil NH_4-N was found between 9.34 and 18.62 (mg/kg). The maximum soil NH_4-N (18.62 mg/kg) was recorded in the T_3 treated plot. The lowest soil NH_4-N (9.34 mg/kg) was assessed in the T_1 treatment.

Table 129. Effect of different organic matters on post-harvest soil NH_4-N (mg/kg) content of the salinity affected experimental sites Batiaghata, Khulna

Treatments	NH_4-N (mg/kg)
T_1	9.34d
T_2	11.04cd
T_3	18.62a
T_4	15.81b
T_5	15.77b
T_6	12.31c
CV (%)	8.78
SE (±)	0.85

Legends, T_1 = Control, T_2 = Recommended Fertilizer, T_3 = Biochar + Recommended Fertilizer, T_4 = Poultry Manure + Chemical Fertilizer, T_5 = Vermicompost + Chemical Fertilizer, T_6 = Standard Organic Fertilizer + Chemical Fertilizer

3.4.11 Soil nitrate nitrogen (mg/kg)

Table 130 represents that three years rigorous application of different organic fertilizer treatments had a significant affect on NO_3-N content in saline soil. The range of soil NO_3-N content was 3.46 to 5.60 mg/kg. The T_3 treatment was exhibited the maximum NO_3-N content (5.60 mg/kg), while the minimum NO_3-N content (3.46 mg/kg) was noted in the T_1 treatment.

Table 130. Effect of different organic matters on post-harvest soil NO_3-N (mg/kg) content of the salinity affected experimental sites Batiaghata, Khulna

Treatments	NO_3-N (mg/kg)
T_1	3.46e
T_2	3.72d
T_3	5.60a
T_4	4.64b
T_5	4.14c
T_6	4.35c
CV (%)	3.71
SE (±)	0.11

Legends, T_1 = Control, T_2 = Recommended Fertilizer, T_3 = Biochar + Recommended Fertilizer, T_4 = Poultry Manure + Chemical Fertilizer, T_5 = Vermicompost + Chemical Fertilizer, T_6 = Standard Organic Fertilizer + Chemical Fertilizer

3.5 The effect of different organic amendment on soil physical properties in Batiaghata

3.5.1 Soil bulk density (g/cm^3)

Three years intensive application of different organic fertilizer treatments had played a significant positive role on bulk density of salinity affected soil (Table 131). The bulk density of the soil was ranged from 1.29 to 1.47 (g/cm^3). The treatments T_1 had provided the significantly highest soil bulk density (1.47 (g/cm3). Meanwhile Biochar + Recommended Fertilizer treated treatment T_3 exhibited the lowest soil bulk density (1.28 g/cm^3).

Table 131. Effect of different organic matters on post-harvest soil Bulk density (g/cm^3) of the salinity affected experimental sites Batiaghata, Khulna

Treatments	Bulk density (g/cm3)
T_1	1.47a
T_2	1.36b
T_3	1.29c
T_4	1.34b
T_5	1.35b
T_6	1.36b
CV (%)	1.21
SE (±)	0.011

Legends, T_1 = Control, T_2 = Recommended Fertilizer, T_3 = Biochar + Recommended Fertilizer, T_4 = Poultry Manure + Chemical Fertilizer, T_5 = Vermicompost + Chemical Fertilizer, T_6 = Standard Organic Fertilizer + Chemical Fertilizer

3.6 The effect of different organic amendment on soil biological properties in Batiaghata

3.6.1 Soil biomass carbon (mg /kg)

The effects of different treatments on biomass C in the experimental site are presented in Table 132. The biomass C of the post-harvest soil was significantly increased by the three year intensive incorporation of different organic materials. The range of biomass C was found between 27.37 and

198.36 (mg/kg). The maximum biomass C (198.36 mg/kg) was recorded in the T_3 treated plot. The lowest biomass C (27.37 mg/kg) was assessed in the T_1 treatment.

Table 132. Effect of different organic matters on post-harvest soil Biomass C (mg /kg) content of the salinity affected experimental sites Batiaghata, Khulna

Treatments	Biomass C (mg /kg)
T_1	27.37e
T_2	63.23d
T_3	198.36a
T_4	175.55b
T_5	142.35c
T_6	128.95c
CV (%)	7.53
SE (±)	6.53

Legends, T_1 = Control, T_2 = Recommended Fertilizer, T_3 = Biochar + Recommended Fertilizer, T_4 = Poultry Manure + Chemical Fertilizer, T_5 = Vermicompost + Chemical Fertilizer, T_6 = Standard Organic Fertilizer + Chemical Fertilizer

3.6.2 Soil biomass nitrogen (mg /kg)

Three years intensive application of different organic fertilizers treatment had significant effect on the biomass N content in the post-harvest saline affected soil (Table 133). The biomass N content of saline soil was ranged from 4.63 to 21.22 mg/kg. Among the treatments, T_3 gave the significantly highest soil biomass N (21.22 mg/kg) content. The lowest soil biomass N (4.63 mg/kg) was detected in T_1 treatment.

Table 133. Effect of different organic matters on post-harvest soil Biomass N (mg /kg) content of the salinity affected experimental sites Batiaghata, Khulna

Treatments	Biomass N (mg /kg)
T_1	4.63d
T_2	14.75c
T_3	21.22a
T_4	19.03b
T_5	18.25b
T_6	15.58c
CV (%)	8.05
SE (±)	0.88

Legends, T_1 = Control, T_2 = Recommended Fertilizer, T_3 = Biochar + Recommended Fertilizer, T_4 = Poultry Manure + Chemical Fertilizer, T_5 = Vermicompost + Chemical Fertilizer, T_6 = Standard Organic Fertilizer + Chemical Fertilizer

Heavy metal polluted area of Bhaluka

Figure 129. Soil samples collection from heavy metal polluted area of Bhaluka, Mymensingh

Table 134 represents the bio-physicochemical properties of initial soil samples of heavy metal polluted area of Bhaluka, Mymensingh. The polluted soil was acidic (pH 4.95) in nature having total N content (0.125%), OC (1.14 %), P (11.12 mg/kg), S (24.32 mg/kg), K (0.08 cmol/kg), Zn (0.25 mg/kg), NH_4-N (11.58 mg/kg), NO_3-N (3.38 mg/kg), CEC (9.97 cmol/kg), Pb (41.48 mg/kg), Cd (4.95 mg/kg) and Ni (35.94 mg/kg). The study soil had a bulk density of 1.45 g/cm^3 and 24.79 t/ha of carbon stock. The biomass C and N were 32.52 mg /kg and 4.53 mg/kg, respectively.

Table 134. Average values of bio-physicochemical properties of initial soil samples in heavy metal polluted areas of Bhaluka, Mymensingh

Soil properties	Analytical value
pH	4.95
Total N (%)	0.125
OC (%)	1.14
Available P (mg/kg)	11.12
Available S (mg/kg)	24.32
Exchangeable K (cmol/kg)	0.08
Zn (mg/kg)	0.25
CEC (cmol/kg)	9.97
NH_4-N (mg/kg)	11.58
NO_3-N (mg/kg)	3.38
Pb (mg/kg)	41.48
Cd (mg/kg)	4.95
Ni (mg/kg)	35.94
Bulk density (g/cm3)	1.45
Carbon stock	24.79
Biomass C (mg /kg)	32.52
Biomass N (mg/kg)	4.53

3.7 The effect of different organic amendment on soil chemical properties in heavy metal polluted area of Bhaluka, Mymensingh

3.7.1 Soil pH

The effects of different treatments on soil pH in the heavy metal polluted research field of Bhaluka is presented in Table 135. After three-year judicious application of organic fertilizers, soil pH was significantly influenced by different treatments. The soil pH ranged from 4.92 to 5.33. The maximum soil pH (5.33) was noted in the T_3 treatment (biochar + recommended fertilizer), while the minimum soil pH value (4.92) was in T_1 treatment (control).

Table 135. Effect of different organic matters on post-harvest soil pH content of heavy metal polluted area of Bhaluka, Mymensingh

Treatments	Soil pH
T_1	4.92e
T_2	5.01d
T_3	5.33a
T_4	5.21b
T_5	5.12c
T_6	5.11c
CV (%)	0.44
SE (±)	0.016

Legends, T_1 = Control, T_2 = Recommended Fertilizer, T_3 = Biochar + Recommended Fertilizer, T_4 = Poultry Manure + Chemical Fertilizer, T_5 = Vermicompost + Chemical Fertilizer, T_6 = Standard Organic Fertilizer + Chemical Fertilizer

3.7.2 Soil total nitrogen (%)

Soil total N content was significantly increased by different organic fertilizers treatments after three years rigorous application (Table 136). The soil total N was varied from 0.122 to 0.183 (%). The significantly highest soil total N content (0.183 %) was found in the T3 treatment. The lowest soil total N content (0.122%) was recorded in T_1 treatment.

Table 136. Effect of different organic matters on post-harvest soil total N (%) content of heavy metal polluted area of Bhaluka, Mymensingh

Treatments	Total N (%)
T_1	0.122b
T_2	0.122b
T_3	0.183a
T_4	0.128b
T_5	0.122b
T_6	0.124b
CV (%)	5.77
SE (±)	0.0054
LSD (0.05)	0.0116

Legends, T_1 = Control, T_2 = Recommended Fertilizer, T_3 = Biochar + Recommended Fertilizer, T_4 = Poultry Manure + Chemical Fertilizer, T_5 = Vermicompost + Chemical Fertilizer, T_6 = Standard Organic Fertilizer + Chemical Fertilizer

3.7.3 Soil organic carbon (%)

After three years continuous application of different organic fertilizers a significant positive change of soil OC was observed (Table 137). The soil OC was ranged from 1.13 to 1.31 %.The significantly highest soil OC (1.31%) was found in the T_3 treatment which was statistically similar to T_4, T_5 and T_6 treatments. The lowest soil OC (1.13 %) was noted in T_1 treatment.

Table 137. Effect of different organic matters on post-harvest soil OC (%) content of heavy metal polluted area of Bhaluka, Mymensingh

Treatments	OC (%)
T_1	1.13c
T_2	1.19bc
T_3	1.31a
T_4	1.30a
T_5	1.25ab
T_6	1.26ab
CV (%)	4.07
SE (±)	0.035

Legends, T_1 = Control, T_2 = Recommended Fertilizer, T_3 = Biochar + Recommended Fertilizer, T_4 = Poultry Manure + Chemical Fertilizer, T_5 = Vermicompost + Chemical Fertilizer, T_6 = Standard Organic Fertilizer + Chemical Fertilizer

3.7.4 Soil available phosphorus (mg/kg)

Available P content in the post-harvest soil of heavy metal polluted experimental site showed a significant positive change after three years judicious application of organic fertilizers (Table 138). The soil available P content was ranged from 11.34 to 23.47 (mg/kg). The highest soil available P content (23.47 mg/kg) was observed in T_4 treatment (poultry manure + chemical fertilizer), while the lowest soil available P content (11.34 mg/kg) was in T_1 treatment (control).

Table 138. Effect of different organic matters on post-harvest soil available P (mg/kg) content of heavy metal polluted area of Bhaluka, Mymensingh

Treatments	Available P (mg/kg)
T_1	11.34e
T_2	11.89de
T_3	17.21b
T_4	23.47a
T_5	14.34c
T_6	12.31d
CV (%)	4.23
SE (±)	0.45

Legends, T_1 = Control, T_2 = Recommended Fertilizer, T_3 = Biochar + Recommended Fertilizer, T_4 = Poultry Manure + Chemical Fertilizer, T_5 = Vermicompost + Chemical Fertilizer, T_6 = Standard Organic Fertilizer + Chemical Fertilizer

3.7.5 Soil available sulphur (mg/kg)

Three years application of organic fertilizers had significant positive effect on the available S content in the heavy metal polluted soil (Table 139). The soil available S was ranged from 24.28 to 53.71 (mg/kg). Among the treatments, T_4 (poultry manure + chemical fertilizer) gave the significantly highest soil available S (53.71 mg/kg) content. The lowest soil available S (24.28 mg/kg) was detected in T_1 treatment.

Table 139. Effect of different organic matters on post-harvest soil available S (mg/kg) content of heavy metal polluted area of Bhaluka, Mymensingh

Treatments	Available S (mg/kg)
T_1	24.28e
T_2	34.12d
T_3	44.92b

T_4	53.71a
T_5	35.72cd
T_6	37.76c
CV (%)	6.03
SE (±)	1.63

Legends, T_1 = Control, T_2 = Recommended Fertilizer, T_3 = Biochar + Recommended Fertilizer, T_4 = Poultry Manure + Chemical Fertilizer, T_5 = Vermicompost + Chemical Fertilizer, T_6 = Standard Organic Fertilizer + Chemical Fertilizer

3.7.6 Soil exchangeable potassium (cmol/kg)

Table 140 summarized that three years judicious application of different organic fertilizer treatments had a significant effect on the exchangeable K content in polluted soil. The range of soil exchangeable potassium was 0.09 to 0.41 (cmol/kg). In the T_3 treatment, the maximum soil exchangeable K was (0.41 cmol/kg). The lowest soil exchangeable K content (0.09 cmol/kg) was recorded in the T_1 treatment.

Table 140. Effect of different organic matters on post-harvest soil exchangeable K (cmol/kg) content of heavy metal polluted area of Bhaluka, Mymensingh

Treatments	Exchangeable K (cmol/kg)
T_1	0.09d
T_2	0.21c
T_3	0.41a
T_4	0.32b
T_5	0.21c
T_6	0.24c
CV (%)	10.67
SE (±)	0.018

Legends, T_1 = Control, T_2 = Recommended Fertilizer, T_3 = Biochar + Recommended Fertilizer, T_4 = Poultry Manure + Chemical Fertilizer, T_5 = Vermicompost + Chemical Fertilizer, T_6 = Standard Organic Fertilizer + Chemical Fertilize

3.7.7 Soil zinc (mg/kg)

The Zn content of the polluted soil was significantly affected by three years intensive application of different organic fertilizer treatments (Table 141). The soil Zn content was ranged from 0.23 to 1.65 (mg/kg). The significantly highest soil Zn content was (1.65 mg/kg) in the T_3 treatment. The lowest soil Zn content (0.23 mg/kg) was recorded in T_1 treatment. The results revealed a dramatic increase of Zn content by the addition of different organic manures along with recommended fertilizers in polluted area.

Table 141. Effect of different organic matters on post-harvest soil Zn (mg/kg) content of heavy metal polluted area of Bhaluka, Mymensingh

Treatments	Zn (mg/kg)
T_1	0.23d
T_2	0.90c
T_3	1.65a
T_4	1.27b
T_5	0.92c
T_6	0.88c
CV (%)	7.28
SE (±)	0.05

Legends, T_1 = Control, T_2 = Recommended Fertilizer, T_3 = Biochar + Recommended Fertilizer, T_4 = Poultry Manure + Chemical Fertilizer, T_5 = Vermicompost + Chemical Fertilizer, T_6 = Standard Organic Fertilizer + Chemical Fertilizer

3.7.8 Soil cation exchange capacity (cmol/kg)

Three years intensive incorporation of organic amendment had significant effects on CEC of heavy metal polluted soil (Table 142). The CEC was ranged from 9.92 to 17.05 (cmol/kg). The significantly highest CEC (17.05 cmol/kg) was noted in Biochar + Recommended Fertilizer amended T_3 treatment which was statistically similar with T_4 and T_6 treatments. The lowest CEC (9.92 cmol/kg) was recorded in T_1 treatment.

Table 142. Effect of different organic matters on post-harvest soil CEC (cmol/kg) content of heavy metal polluted area of Bhaluka, Mymensingh

Treatments	CEC (cmol/kg)
T_1	9.92d
T_2	15.71c
T_3	17.05a
T_4	16.65ab
T_5	15.95bc
T_6	16.37abc
CV (%)	3.31
SE (±)	0.35

Legends, T_1 = Control, T_2 = Recommended Fertilizer, T_3 = Biochar + Recommended Fertilizer, T_4 = Poultry Manure + Chemical Fertilizer, T_5 = Vermicompost + Chemical Fertilizer, T_6 = Standard Organic Fertilizer + Chemical Fertilizer

3.7.9 Soil ammonium nitrogen (mg/kg)

The effects of different organic amendment treatments on NH_4-N content in the experimental site of heavy metal polluted area are presented in Table 143. Soil NH_4-N content in the polluted soil was significantly increased by the three years incorporation of different organic materials. The range of NH_4-N content was exist between 11.54 and 18.26 (mg/kg). The highest NH_4-N content (18.26 mg/kg) was noted in the T_3 treated plot. The lowest NH_4-N content (11.54 mg/kg) was assessed in the T_1 treatment.

Table 143. Effect of different organic matters on post-harvest soil NH_4-N (mg/kg) content of heavy metal polluted area of Bhaluka, Mymensingh

Treatments	NH_4-N (mg/kg)
T_1	11.54b
T_2	12.15b
T_3	18.26a
T_4	16.78a
T_5	12.18b
T_6	12.43b
CV (%)	11.8
SE (±)	1.15

Legends, T_1 = Control, T_2 = Recommended Fertilizer, T_3 = Biochar + Recommended Fertilizer, T_4 = Poultry Manure + Chemical Fertilizer, T_5 = Vermicompost + Chemical Fertilizer, T_6 = Standard Organic Fertilizer + Chemical Fertilizer

3.7.10 Soil nitrate nitrogen (mg/kg)

The effects of different organic amendment treatments on NO_3-N content in the experimental site of heavy metal polluted area are presented in Table 144. The NO_3-N content in the polluted soil was significantly increased by the three years incorporation of

different organic materials. The NO_3-N content was ranged from 3.34 to 5.63 (mg/kg). The significantly highest NO_3-N content (5.63 mg/kg) was found in the T_3 treatment and the lowest NO_3-N content (3.34 mg/kg) was found in T_1 treatment.

Table 144. Effect of different organic matters on post-harvest soil NO_3-N (mg/kg) content of heavy metal polluted area of Bhaluka, Mymensingh

Treatments	NO_3-N (mg/kg)
T_1	3.34d
T_2	3.80c
T_3	5.63a
T_4	4.28b
T_5	4.11b
T_6	4.17b
CV (%)	3.89
SE (±)	0.11

Legends, T_1 = Control, T_2 = Recommended Fertilizer, T_3 = Biochar + Recommended Fertilizer, T_4 = Poultry Manure + Chemical Fertilizer, T_5 = Vermicompost + Chemical Fertilizer, T_6 = Standard Organic Fertilizer + Chemical Fertilizer

3.7.11 Soil Pb (mg/kg)

The Pb content was significantly decreased by different treatments after three years intensive application with organic fertilizers in polluted soil (Table 145). The Pb content was varied from 31.31 to 42.26 (mg/kg). The significantly highest Pb content 42.26 (mg/kg) was found in the T_1 treatment. The lowest Pb content (31.31 mg/kg) was recorded in T_3 treatment.

Table 145. Effect of different organic matters on post-harvest soil Pb (mg/kg) content of heavy metal polluted area of Bhaluka, Mymensingh

Treatments	Pb (mg/kg)
T_1	42.26a
T_2	41.39b
T_3	31.31f
T_4	34.29e
T_5	34.74d
T_6	36.51c
CV (%)	1.17
SE (±)	0.0448

Legends, T_1 = Control, T_2 = Recommended Fertilizer, T_3 = Biochar + Recommended Fertilizer, T_4 = Poultry Manure + Chemical Fertilizer, T_5 = Vermicompost + Chemical Fertilizer, T_6 = Standard Organic Fertilizer + Chemical Fertilizer

3.7.12 Soil Cd (mg/kg)

The Cd content of polluted soil was significantly declined by the different organic fertilizers treatments after three years continuous application (Table 146). The soil Cd content was ranged from 3.71 to 4.91 (mg/kg). The significantly highest soil Cd content (4.91 mg/kg) was found in the T_1 treatment. The lowest soil Cd content (3.71 mg/kg) was noted in T_3 treatment.

Table 146. Effect of different organic matters on post-harvest soil Cd (mg/kg) content of heavy metal polluted area of Bhaluka, Mymensingh

Treatments	Cd (mg/kg)
T_1	4.91a
T_2	4.82b
T_3	3.71f
T_4	4.25e
T_5	4.45d
T_6	4.64c
CV (%)	1.69
SE (±)	0.0217

Legends, T_1 = Control, T_2 = Recommended Fertilizer, T_3 = Biochar + Recommended Fertilizer, T_4 = Poultry Manure + Chemical Fertilizer, T_5 = Vermicompost + Chemical Fertilizer, T_6 = Standard Organic Fertilizer + Chemical Fertilizer

3.7.13 Soil Ni (mg/kg)

The effects of different organic amendment treatments on soil Ni content in the research field of Bhaluka upazila, Mymensingh was presented in Table 147. After three years judicious application of different organic fertilizer treatments soil Ni content was significantly decreased. The soil Ni content was ranged from 26.66 to 35.80 (mg/kg). The maximum soil Ni 35.80 (mg/kg) was in the T_1 treatment (Biochar + Chemical Fertilizer), while the minimum soil Ni content 26.66 (mg/kg) was in T_3 treatment (control). Thus organic amendment played a significant role on reduction of Ni content in heavy metal polluted soil.

Table 147. Effect of different organic matters on post-harvest soil Ni (mg/kg) content of heavy metal polluted area of Bhaluka, Mymensingh

Treatments	Ni (mg/kg)
T_1	35.80a
T_2	35.17b
T_3	26.66f
T_4	30.60e
T_5	31.32d
T_6	32.27c
CV (%)	1.13
SE (±)	0.029

Legends, T_1 = Control, T_2 = Recommended Fertilizer, T_3 = Biochar + Recommended Fertilizer, T_4 = Poultry Manure + Chemical Fertilizer, T_5 = Vermicompost + Chemical Fertilizer, T_6 = Standard Organic Fertilizer + Chemical Fertilizer

3.8 The effect of different organic amendment on soil physical properties in Bhaluka

3.8.1 Soil bulk density (g/cm^3)

Three years application of different organic fertilizer treatments had significant effect on the bulk density in the polluted soil (Table 148). The soil bulk density was ranged from 1.28 to 1.43 (g/cm^3). Among the treatments, T_1 gave the significantly highest soil bulk density (1.43 (g/cm^3) content. The lowest soil bulk density (1.28 g/cm^3) was detected in T_3 treatment. Thus, bulk density was significantly improved by the addition of different organic amending substances in polluted soil.

Table 148. Effect of different organic matters on post-harvest soil bulk density (g/cm^3) of heavy metal polluted area of Bhaluka, Mymensingh

Treatments	Bulk density (g/cm^3)
T_1	1.43a
T_2	1.35b
T_3	1.28c
T_4	1.34b
T_5	1.35b
T_6	1.34b
CV (%)	2.17
SE (±)	0.02

Legends, T_1 = Control, T_2 = Recommended Fertilizer, T_3 = Biochar + Recommended Fertilizer, T_4 = Poultry Manure + Chemical Fertilizer, T_5 = Vermicompost + Chemical Fertilizer, T_6 = Standard Organic Fertilizer + Chemical Fertilizer

3.9 The effect of different organic amendment on soil biological properties in Bhaluka

3.9.1 Soil biomass carbon (mg /kg)

Three years application of different organic fertilizer treatments had significant effect on the biomass C content in the polluted soil (Table 149). The soil biomass carbon was ranged from 32.32 to 197.94 (mg/kg). Among the treatments, T_3 gave the significantly highest soil biomass C content (197.94 mg/kg). The lowest soil biomass C content (32.32 mg/kg) was detected in T_1 treatment.

Table 149. Effect of different organic matters on post-harvest soil Biomass C (mg /kg) content of heavy metal polluted area of Bhaluka, Mymensingh

Treatments	Biomass C (mg /kg)
T_1	32.32e
T_2	67.43d
T_3	197.94a
T_4	168.17b
T_5	136.57c
T_6	128.62c
CV (%)	5.73
SE (±)	4.93

Legends, T_1 = Control, T_2 = Recommended Fertilizer, T_3 = Biochar + Recommended Fertilizer, T_4 = Poultry Manure + Chemical Fertilizer, T_5 = Vermicompost + Chemical Fertilizer, T_6 = Standard Organic Fertilizer + Chemical Fertilizer

3.9.2 Soil biomass N (mg /kg)

The biomass N content of polluted soil was significantly influence by the different organic fertilizers' treatments after three years continuous application (Table 150). The range of biomass N content was found between 4.56 and 21.25 (mg/kg). The highest biomass N content (21.25 mg/kg) was recorded in the T_3 treated plot. The lowest biomass N content (4.56 mg/kg) was assessed in the T_1 treatment. Thus, biomass N was significantly improved by the addition of different organic amending substances in polluted soil.

Table 150. Effect of different organic matters on post-harvest soil Biomass N (mg /kg) content of heavy metal polluted area of Bhaluka, Mymensingh

Treatments	Biomass N (mg /kg)
T_1	4.56d
T_2	14.73c
T_3	21.25a

T_4	19.27b
T_5	19.04b
T_6	15.97c
CV (%)	6.13
SE (±)	0.68

Legends, T_1 = Control, T_2 = Recommended Fertilizer, T_3 = Biochar + Recommended Fertilizer, T_4 = Poultry Manure + Chemical Fertilizer, T_5 = Vermicompost + Chemical Fertilizer, T_6 = Standard Organic Fertilizer + Chemical Fertilizer

4 **Expt. III.** Study on mechanisms of the adsorption-desorption of heavy metal using different organic materials in contaminated soils heavy metal polluted areas of Bhaluka (PhD student's study partial completed under objective II).

4.2 Adsorption-desorption of heavy metal in different organic materials

4.2.1 Estimation of heavy metals

Heavy metals (Pb, Cd and Ni) of industrial polluted samples were estimated directly with the help of an atomic absorption spectrometer (Varian 55B) using acetylene gas according to their respective wavelength (Lindsay and Norvell, 1978).

4.2.2 Estimation of extractable heavy metals

Extractable heavy metals (Pb, Cd and Ni) of industrial polluted samples were estimated DTPA with the help of an atomic absorption spectrometer (Varian 55B) using acetylene gas according to their respective wavelength (Lindsay and Norvell, 1978).

4.2.3 Chemical properties of organic materials

The pH, organic carbon (OC), cadmium (Cd), lead (Pb) and nickel (Ni) content in the experimental used cowdung, cowdung slurry, vermicompost, tricocompost and rice husk biochar are presented in Table 151. The organic substances were neutral to slightly alkaline in nature having a pH value of cowdung (6.84), cowdung slurry (7.78), vermicompost (6.97), tricocompost (7.81) and rice husk biochar (7.62).
The organic carbon content of cowdung, cowdung slurry, vermicompost, tricocompost and rice husk biochar were 28.89, 32.75, 27.88, 26.19 and 40.72% respectively. The Pb, Cd and Ni content of studied substance were cowdung (9.64, 0.33 and 3.01 mg kg^{-1} respectively), cowdung slurry (8.78, 0.35 and 3.05 mg kg^{-1} respectively), vermicompost (28.21, 2.02 and 5.23 mg kg^{-1} respectively), tricocompost (26.43, 1.95 and 5.62 mg kg^{-1} respectively) and rice husk biochar (14.60, 0.96 and 6.70 mg kg^{-1} respectively).

Table 151. The pH, organic carbon (OC) and nitrogen status in cowdung, cowdung slurry, rice husk biochar, vermicompost and tricocompost

Organic materials	**Parameters**				
	pH	**OC (%)**	**Cd (mg kg^{-1})**	**Pb(mg kg^{-1})**	**Ni(mg kg^{-1})**
CD	6.84	28.89	0.33	9.64	3.01
CDS	7.78	32.75	0.35	8.78	3.05
VC	6.97	27.88	2.02	28.21	5.23
TC	7.81	26.19	1.95	26.43	5.62
RHB	7.62	40.72	0.96	14.60	6.70

CD = Cowdung, CDS = cowdung slurry, RHB = rice husk biochar, VC = vermicompost and TC = tricocompost

4.2.4 Adsorption percentage

The adsorption percentage of the heavy metals content with different organic materials is presented in Figure 130, 131 and 132. The study indicate that adsorption percentage of Cd^{2+}, Pb^{2+} and Ni^{2+} was increased by addition of different organic materials in polluted soil up to 21 days incubation period. After that, a static data was prevailed from 30 DAI to 120 DAI. During the incubation period the adsorption percentage of Cd^{2+}, Pb^{2+} and Ni^{2+} by different organic materials showed a linear increasing trends. RHB showed the highest Cd^{2+}, Pb^{2+} and Ni^{2+} adsorption rate as compared to all other organic materials. The adsorption rate has followed a trends of RHB>VC>CD>CDS>TC.

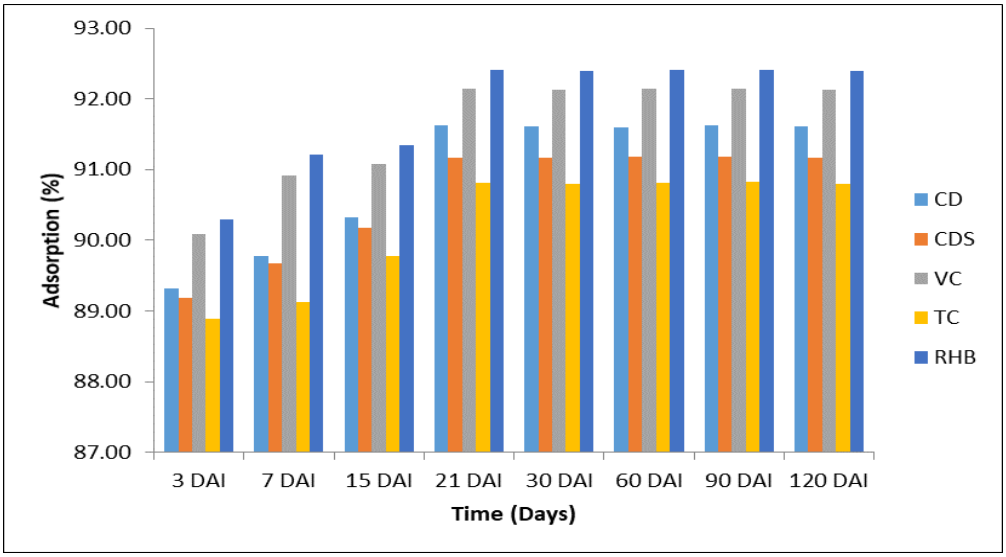


Figure 130. Adsorption percentage of Cd^{2+} by different organic materials in heavy metal polluted soil. CD = Cowdung, CDS = cowdung slurry, RHB = rice husk biochar, VC = vermicompost and TC = tricocompost, DAI = Days after incubation

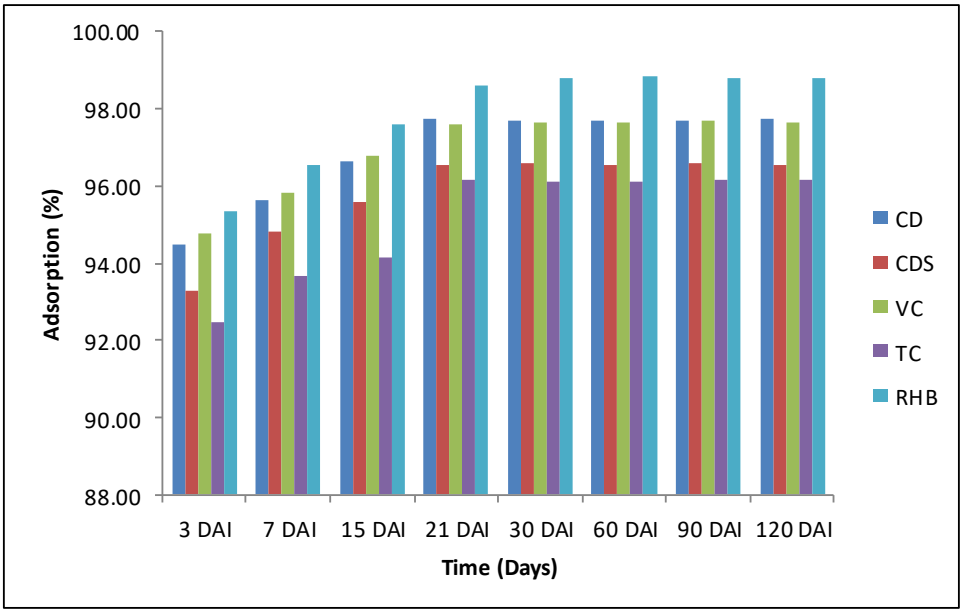


Figure 131. Adsorption percentage of Pb^{2+} by different organic materials in heavy metal polluted soil. CD = Cowdung, CDS = cowdung slurry, RHB = rice husk biochar, VC = vermicompost and TC = tricocompost

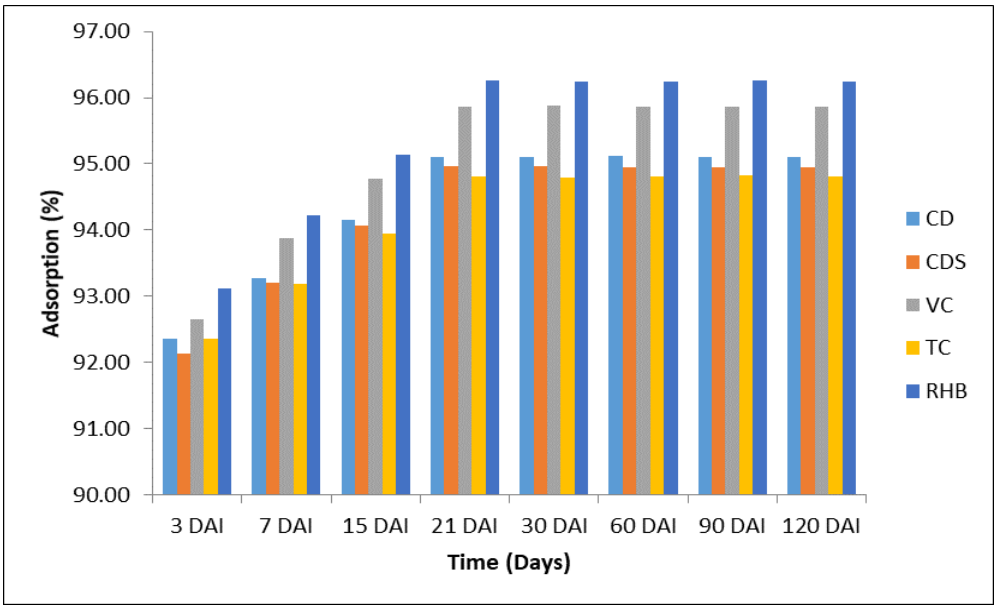


Figure 132. Adsorption percentage of Ni^{2+} by different organic materials in heavy metal polluted soil. CD = Cowdung, CDS = cowdung slurry, RHB = rice husk biochar, VC = vermicompost and TC = tricocompost

4.2.5 Desorption percentage

The desorption percentage of the heavy metals content with different organic materials is presented in Fig. 133, 134 and 135. Desorption rate of Cd^{2+}, Pb^{2+} and Ni^{2+} by different organic materials in polluted soil showed a decreasing trend up to 21 days incubation period. At 30 DAI the desorption rate of Cd^{2+}, Pb^{2+} and Ni^{2+} by different organic materials reached an equilibrium state. After that, almost static data was prevailed from 30 DAI to 120 DAI.

The desorption percentage of Cd^{2+}, Pb^{2+} and Ni^{2+} by different organic materials in polluted soil showed a decline trends during the 120 days incubation period. TC showed the highest Cd^{2+}, Pb^{2+} and Ni^{2+} adsorption rate as compared to all other organic materials. The desorption rate has followed a trends of TC>CDS>CD>VC>RHB.

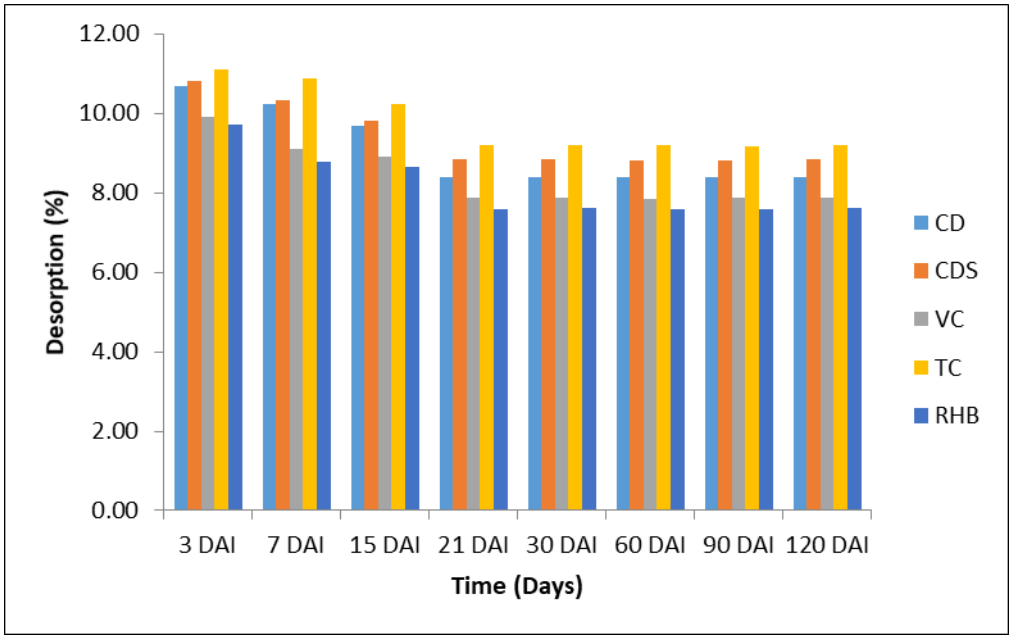


Figure 133. Desorption percentage of Cd^{2+} by different organic matter. CD = Cowdung, CDS = cowdung slurry, RHB = rice husk biochar, VC = vermicompost and TC = tricocompost

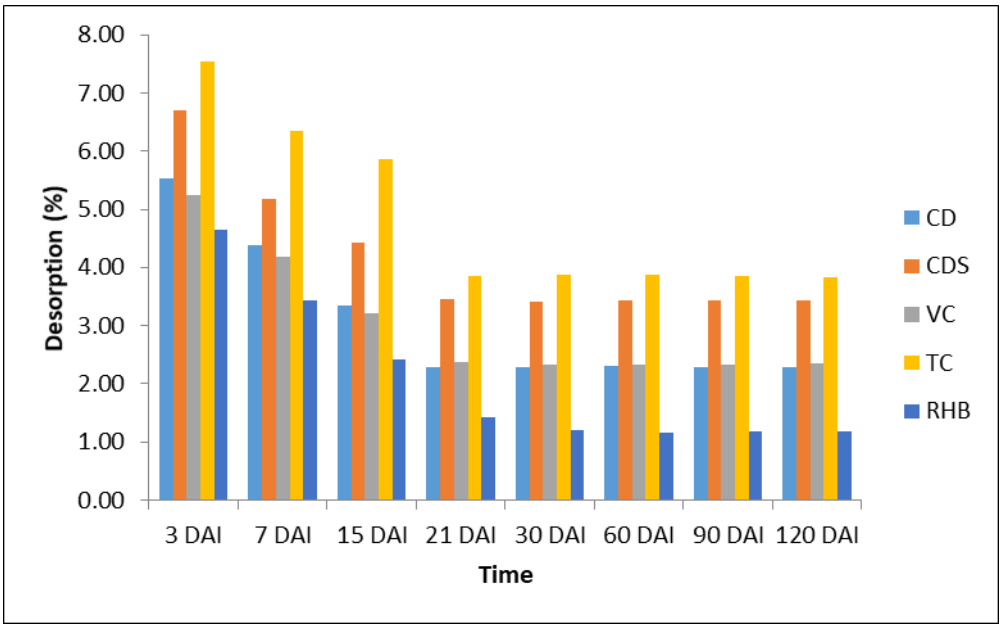


Figure 134. Desorption percentage of Pb^{2+} by different organic matter. CD = Cowdung, CDS = cowdung slurry, RHB = rice husk biochar, VC = vermicompost and TC = tricocompost

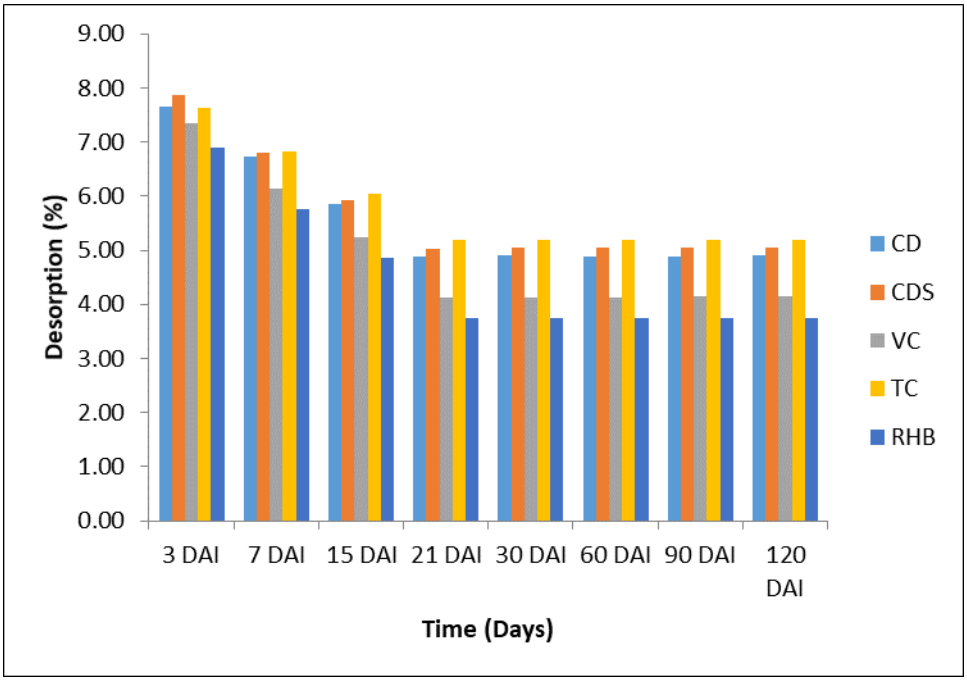


Figure 135. Desorption percentage of Ni^{2+} by different organic matter. CD = Cowdung, CDS = cowdung slurry, RHB = rice husk biochar, VC = vermicompost and TC = tricocompost

5 **Expt. IV.** Nitrogen and carbon mineralization dynamics using different organic materials in different climate vulnerable soils of arsenic area of Faridpur sadar and saline areas of Batiaghata (Under objective III).

5.2 Arsenic contaminated area of Faridpur sadar

5.2.1 Soil organic carbon (%) mineralization at different incubation periods

The effects of different treatments on soil OC (%) mineralization in the arsenic contaminated research field at different incubation periods i.e., 0, 15, 30, 45, 60, 75 and 90 days are presented in Figure 136. The soil OC (%) mineralization remarkably influenced by different treatments after three years application of organic fertilizers. Mineralized OC was maximum at 30 DAT for all organic matter treatments. At 30 days after transplanting the highest soil OC (1.82%) mineralization was observed in the T_2 (Recommended Fertilizer) treatment and the lowest soil OC mineralization 1.18 (%) was recorded in T_1 treatment. After 30 DAT the trends of OC (%) decreased until 75 DAT and then almost static data was prevailed from 75 DAT to 90 DAT. The OC (%) mineralization rate has followed a trend of $T_2>T_4>T_6>T_5>T_3>T_1$.

5.2.2 Soil total N (%) content at different incubation period

Three years intensive application of different organic fertilizers showed a remarkable change on soil total N (%) mineralization at different incubation periods i.e. 0, 15, 30, 45, 60, 75 and 90 DAT (Figure 137). The highest mineralized total N (%) was observed at 45 DAT in all of the incorporated organic matter treatments. At 45 DAT the highest soil total N (0.175%) mineralization was observed in the T_2 (Recommended Fertilizer) treatment and the lowest soil total N mineralization 0.11 (%) was recorded in T_1 treatment. After that organic amended soil showed a decline of mineralized N (%) and continued up to 90 DAT. The total N (%) mineralization rate has followed a trend of $T_2>T_4>T_5>T_6>T_3>T_1$.

5.2.3 Soil Biomass C (mg /kg) at different incubation period

The effects of different organic amendment treatments after three years intensive application on soil biomass C (mg/kg) content in the arsenic contaminated research field at different incubation periods i.e., 0, 15, 30, 45, 60, 75 and 90 days are presented in Figure 14. The soil biomass C (mg/kg) content increased in all organic amendment treatment and the control during the whole incubation

experiment (90DAT). The range was 27.35-75.60 mg/kg in the control treatment and 28.75-201.37 mg/kg in the organic amendment treatments. The soil biomass C content during the entire incubation period was the lowest in the control treatment (75.60 mg/kg) and highest in biochar amended soil (T_3) treatment (201.37 mg/kg). The biomass C (mg/kg) mineralization rate has followed a trend of $T_3>T_4>T_5>T_6>T_2>T_1$.

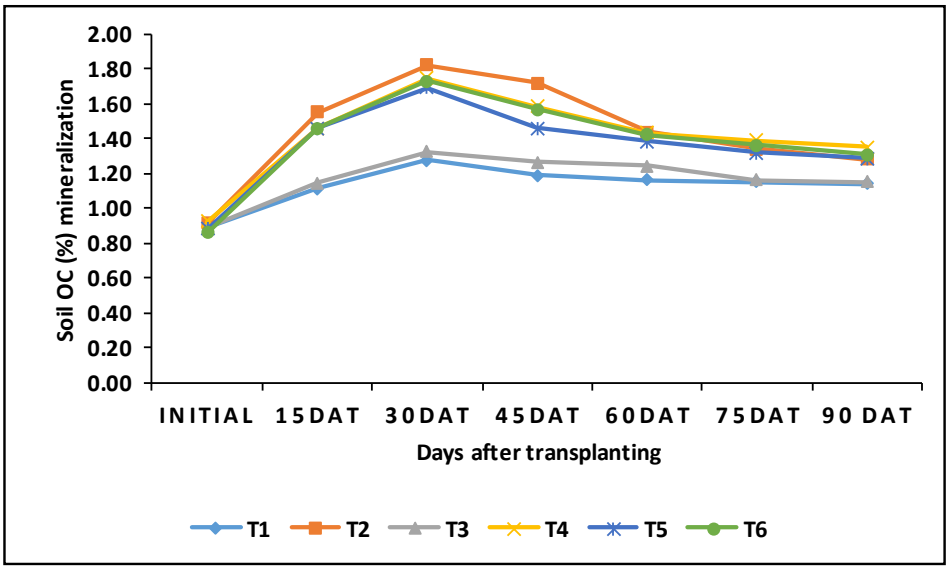


Figure 136. Effect of different organic matters on organic carbon (%) mineralization of soil (Faridpur), at different incubation period. T_1 = Control, T_2 = Recommended Fertilizer, T_3 = Biochar + Recommended Fertilizer, T_4 = Poultry Manure + Chemical Fertilizer, T_5 = Vermicompost + Chemical Fertilizer, T_6 = Standard Organic Fertilizer + Chemical Fertilizer, DAT = Days After Transplanting

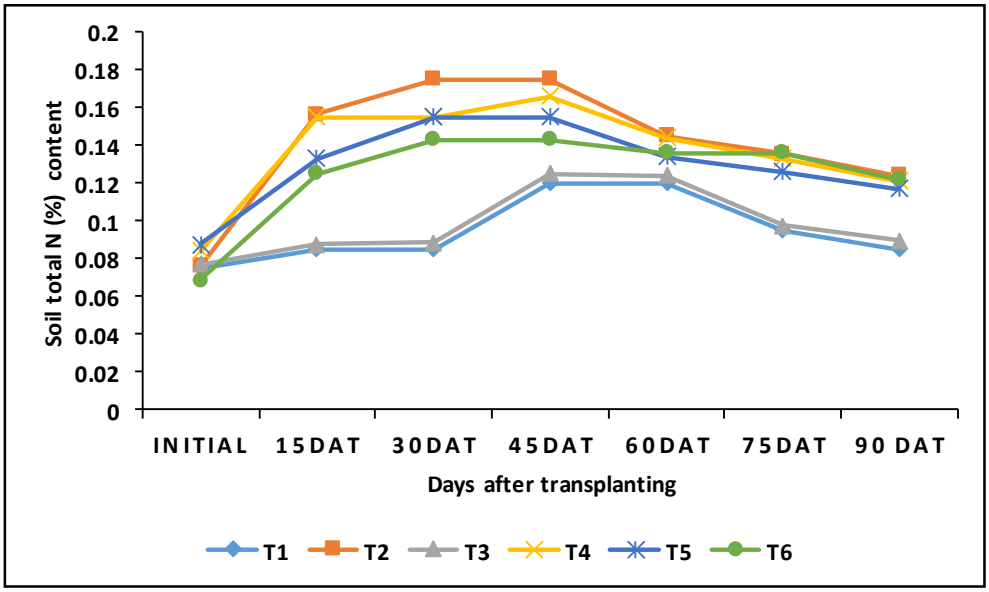


Figure 137. Effect of different organic matters on total N (%) of soil (Faridpur), at different incubation period. T_1 = Control, T_2 = Recommended Fertilizer, T_3 = Biochar + Recommended Fertilizer, T_4 = Poultry Manure + Chemical Fertilizer, T_5 = Vermicompost + Chemical Fertilizer, T_6 = Standard Organic Fertilizer + Chemical Fertilizer

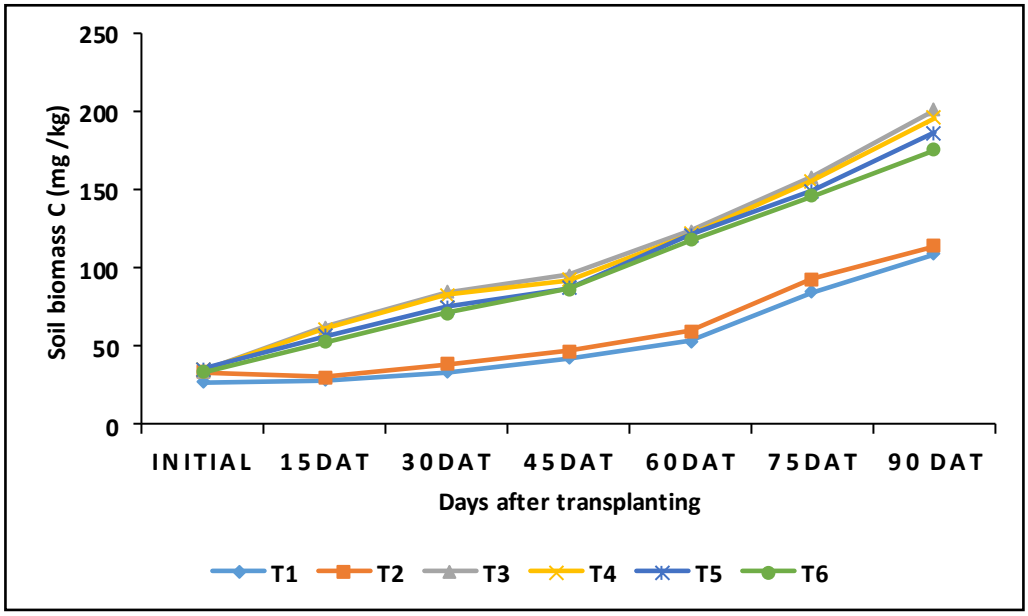


Figure 138. Effect of different organic matters on Biomass C (mg /kg) of soil (Faridpur), at different incubation period. T_1 = Control, T_2 = Recommended Fertilizer, T_3 = Biochar + Recommended Fertilizer, T_4 = Poultry Manure + Chemical Fertilizer, T_5 = Vermicompost + Chemical Fertilizer, T_6 = Standard Organic Fertilizer + Chemical Fertilizer

5.2.4 Soil Biomass N (mg/kg) at different incubation period

Figure 139 represent the effects of three years intensive management by different organic substances on soil biomass N (mg/kg) content in the arsenic contaminated research field at different incubation periods i.e., 0, 15, 30, 45, 60, 75 and 90 DAT. The soil biomass N (mg/kg) content increased in all organic amendment treatment and the control during the whole incubation experiment (90DAT). The range was 4.35-14.35 mg/kg in the control treatment and 4.75-24.37 mg/kg in the organic amendment treatments. The soil biomass N content during the entire incubation period was the lowest in the control treatment (4.35 mg/kg) and highest in biochar amended soil (T_3) treatment (24.37 mg/kg). The biomass N (mg/kg) mineralization rate has followed a trend of $T_3>T_4>T_5>T_6>T_2>T_1$.

5.2.5 Soil NO_3-N (mg/kg) at different incubation period

Third year mineralized data shows that NO_3-N (mg/kg) content was increased in all organic amendments and the control treatment during the incubation experiment at 0, 15, 30, 45, 60, 75 and 90 DAT (Figure 16). The highest mineralized NO_3-N (mg/kg) was observed at 45 DAT in all of the incorporated organic matter treatments. At 45 DAT the highest soil NO_3-N (4.86 mg/kg) mineralization was observed in the T_2 (Recommended Fertilizer) treatment and the lowest soil NO_3-N mineralization 3.50(mg/kg) was recorded in biochar treated T_3 treatment. After that organic amended soil showed a decline of mineralized NO_3-N (mg /kg) and continued up to 90 DAT. The NO_3-N (mg/kg) mineralization rate has followed a trend of $T_2>T_4>T_5>T_6>T_1>T_3$. Integrated over the whole incubation period the highest mineralized NO_3-N was in recommended fertilizer treated T_2 plot and the lowest in biochar amended soil.

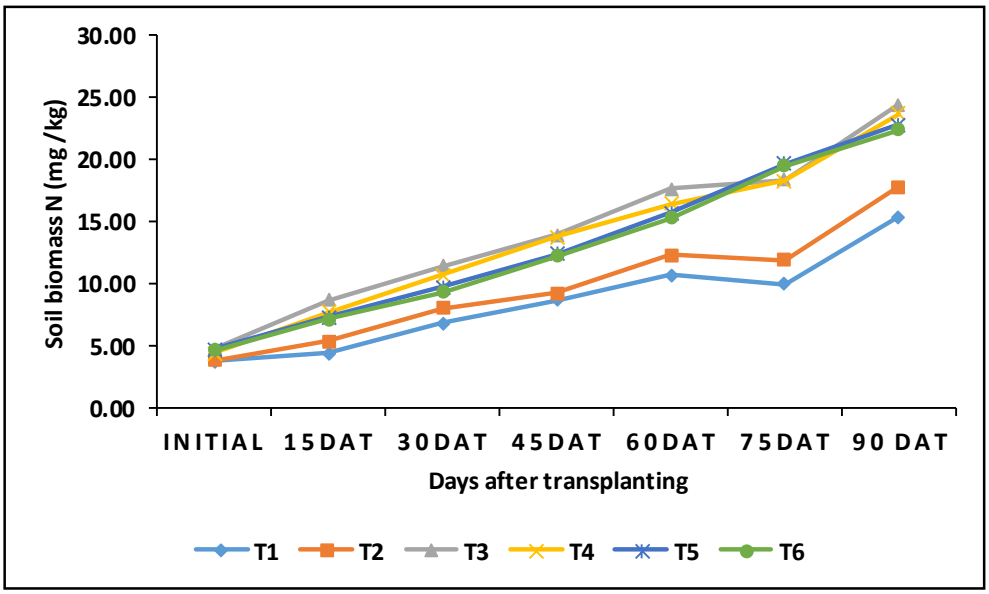


Figure 139. Effect of different organic matters on Biomass N (mg/kg) of soil (Faridpur), at different incubation period. T_1 = Control, T_2 = Recommended Fertilizer, T_3 = Biochar + Recommended Fertilizer, T_4 = Poultry Manure + Chemical Fertilizer, T_5 = Vermicompost + Chemical Fertilizer, T_6 = Standard Organic Fertilizer + Chemical Fertilizer

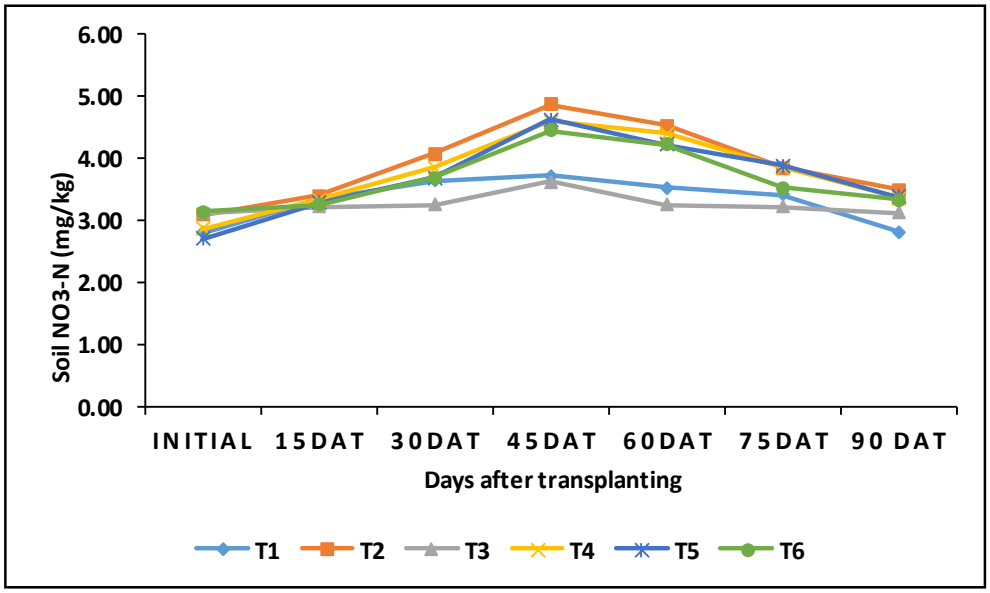


Figure 140. Effect of different organic matters on NO_3-N (mg/kg) of soil (Faridpur), at different incubation period. T_1 = Control, T_2 = Recommended Fertilizer, T_3 = Biochar + Recommended Fertilizer, T_4 = Poultry Manure + Chemical Fertilizer, T_5 = Vermicompost + Chemical Fertilizer, T_6 = Standard Organic Fertilizer + Chemical Fertilizer

5.2.6 Soil NH_4-N (mg/kg) at different incubation period

The effects of different organic amendment treatments after three years intensive application on soil NH4-N (mg/kg) content in the arsenic contaminated research field at different incubation periods i.e., 0, 15, 30, 45, 60, 75 and 90 days are presented in Figure 141. The highest mineralized NH_4-N (mg/kg) was observed at 45 DAT in all of the incorporated organic matter treatments. At 45 DAT the highest soil NH_4-N (16.87 mg/kg) mineralization was observed in the T_2 (Recommended Fertilizer) treatment and the lowest soil NH_4-N

mineralization 10.50(mg/kg) was recorded in biochar treated T_1 treatment. After that organic amended soil showed a decline of mineralized NH_4-N (mg /kg) and continued up to 90 DAT. The NH_4-N (mg/kg) mineralization rate has followed a trend of $T_2>T_4>T_5>T_6>T_3>T_1$. Integrated over the whole incubation period the highest mineralized NH_4-N was in recommended fertilizer treated T_2 soil and the lowest in control soil.

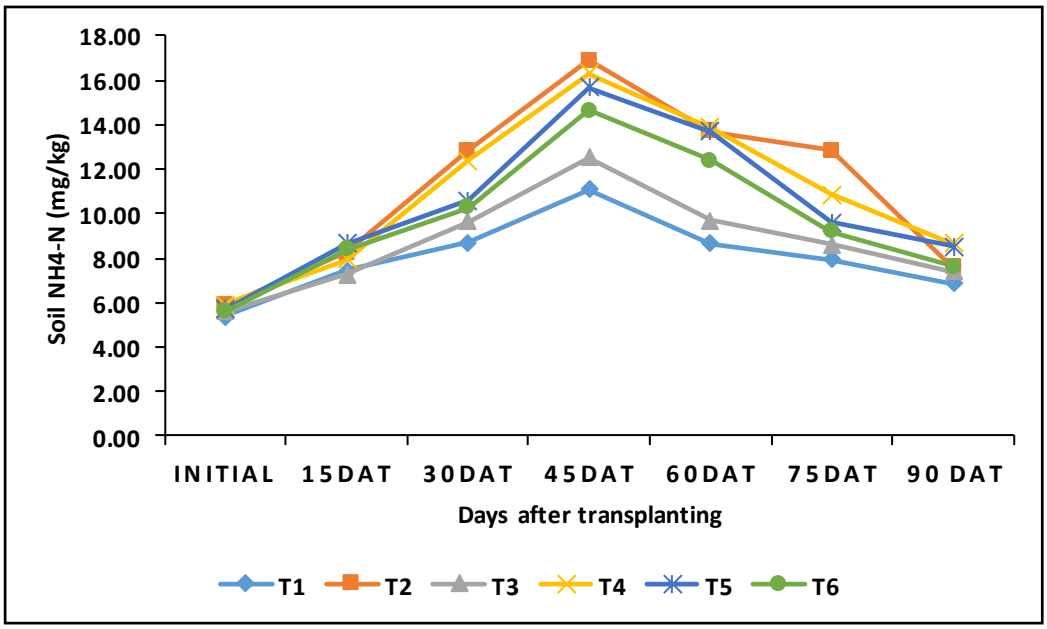


Figure 141. Effect of different organic matters on NH_4-N (mg/kg) of soil (Faridpur), at different incubation period. T_1 = Control, T_2 = Recommended Fertilizer, T_3 = Biochar + Recommended Fertilizer, T_4 = Poultry Manure + Chemical Fertilizer, T_5 = Vermicompost + Chemical Fertilizer, T_6 = Standard Organic Fertilizer + Chemical Fertilizer

5.3 Saline affected area of Batiaghata

The effects of different organic amendment treatments on soil OC (%) mineralization in the saline affected field at different incubation periods i.e. 0, 15, 30, 45, 60, 75 and 90 days are presented in Figure 142. The soil OC (%) mineralization remarkably influenced by different treatments after three years application of organic fertilizers. The maximum amount of mineralized OC was recorded at 30 DAT for all organic matter treatments. At 30 days after transplanting the highest soil OC (1.81%) mineralization was observed in the T_2 (recommended fertilizer) treatment and the lowest soil OC mineralization 1.18 (%) was recorded in T_1 treatment. Afterward net mineralization decreased in all organic substances and continued up to 60DAT and level off in those amended soil after 60DAT. The OC (%) mineralization rate has followed a trends of $T_2>T_4>T_6>T_5>T_3>T_1$.

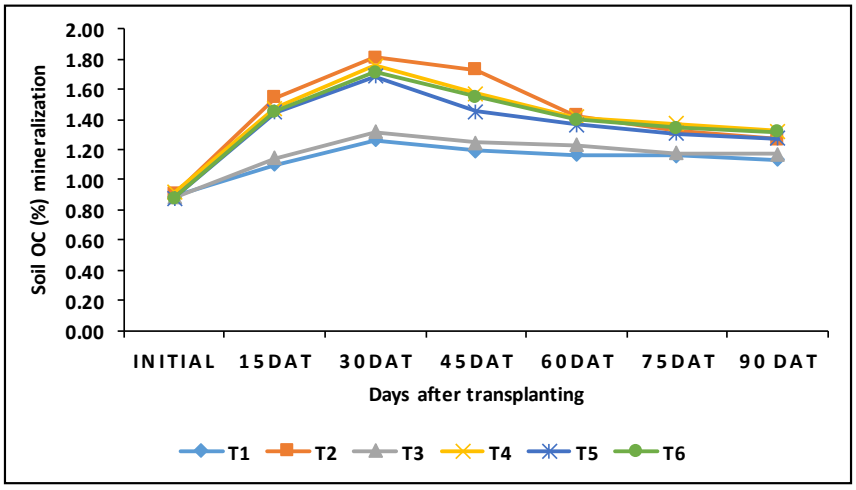


Figure 142. Effect of different organic matters on organic carbon (%) mineralization of soil (Batiaghata, Khulna), at different incubation period. T_1 = Control, T_2 = Recommended Fertilizer, T_3 = Biochar + Recommended Fertilizer, T_4 = Poultry Manure + Chemical Fertilizer, T_5 = Vermicompost + Chemical Fertilizer, T_6 = Standard Organic Fertilizer + Chemical Fertilizer

5.3.1 Soil total N (%) content at different incubation period

Three years intensive application of different organic fertilizers showed a remarkable change on soil total N (%) mineralization at different incubation periods i.e. 0, 15, 30, 45, 60, 75 and 90 DAT at saline affected field (Figure 19). The total N mineralized content increased in all organic amendment treatment and the control during the incubation period. The range was 0.069 -0.11 % in the control treatment and 0.071-0.172 % in the organic amendment treatments. The maximum amount of mineralized total N (%) was observed at 30 DAT in T_2 amended soil, at 45DAT in T4 and T6 treated soil and at 60DAT in biochar and control soil. After that organic amended soil showed a decline of mineralized N (%) and continued up to 90 DAT. The total N (%) mineralization rate has followed a trends of $T_2>T_4>T_5>T_6>T_3>T_1$.

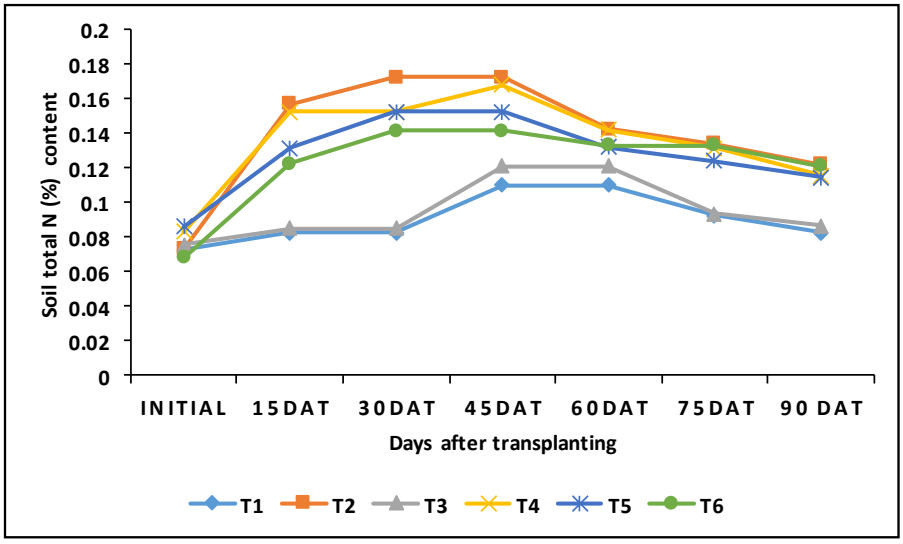


Figure 143. Effect of different organic matters on total N (%) of soil (Batiaghata, Khulna), at different incubation period. T_1 = Control, T_2 = Recommended Fertilizer, T_3 = Biochar + Recommended Fertilizer, T_4 = Poultry Manure + Chemical Fertilizer, T_5 = Vermicompost + Chemical Fertilizer, T_6 = Standard Organic Fertilizer + Chemical Fertilizer

5.3.2 Soil Biomass C (mg /kg) at different incubation period

The effects of different organic amendment treatments after three years intensive application on soil biomass C (mg/kg) content in the saline affected soil at different incubation periods i.e. 0, 15, 30, 45, 60, 75 and 90 days are presented in Figure 144. The soil biomass C (mg/kg) content increased in all organic amendment treatment and the control during the whole incubation experiment (90DAT). The range was 26.96 -54.38 mg/kg in the control treatment and 32.75-206.37 mg/kg in the organic amendment treatments. The soil biomass C content during the entire incubation period was the lowest in the control treatment (26.96 mg/kg) and highest in biochar amended soil (T_3) treatment (206.37 mg/kg). The biomass C (mg/kg) mineralization rate has followed a trends of $T_3>T_4>T_6>T_5>T_2>T_1$.

5.3.3 Soil Biomass N (mg/kg) at different incubation period

Figure 21 represent the effects of three years intensive management by different organic substances on soil biomass N (mg/kg) content in the saline affected soil at different incubation periods i.e. 0, 15, 30, 45, 60, 75 and 90 DAT. The soil biomass N (mg/kg) content increased progressively in all organic amendment treatments and the control during the whole incubation experiment (90DAT). The range was 4.25-14.35 mg/kg in the control treatment and 4.75-24.35 mg/kg in the organic amendment treatments. The soil biomass N content during the entire incubation period was the lowest in the control treatment (4.25 mg/kg) and highest in poultry manure amended soil (T_4) treatment (24.35mg/kg). The biomass N (mg/kg) mineralization rate has followed a trends of $T_4>T_5>T_6>T_3>T_2>T_1$.

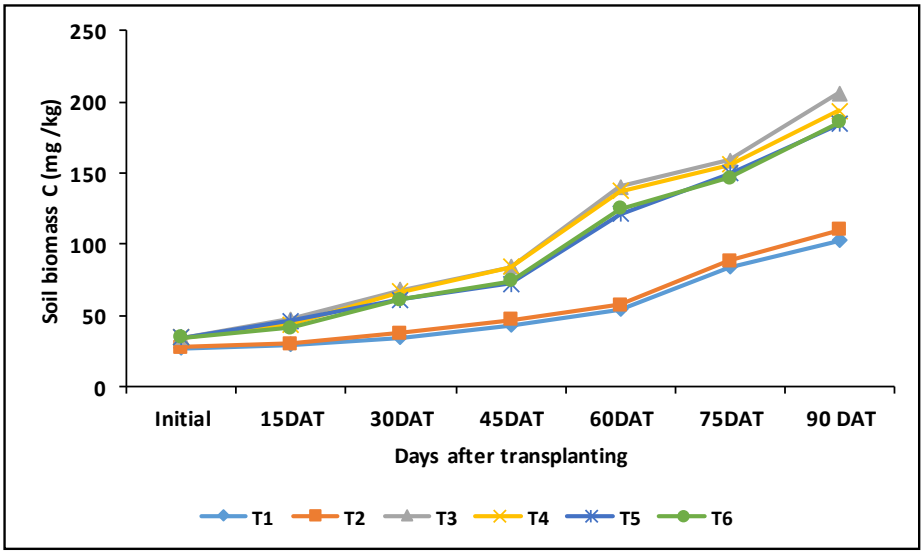


Figure 144. Effect of different organic matters on Biomass C (mg /kg) of soil (Batiaghata, Khulna), at different incubation period. T_1 = Control, T_2 = Recommended Fertilizer, T_3 = Biochar + Recommended Fertilizer, T_4 = Poultry Manure + Chemical Fertilizer, T_5 = Vermicompost + Chemical Fertilizer, T_6 = Standard Organic Fertilizer + Chemical Fertilizer

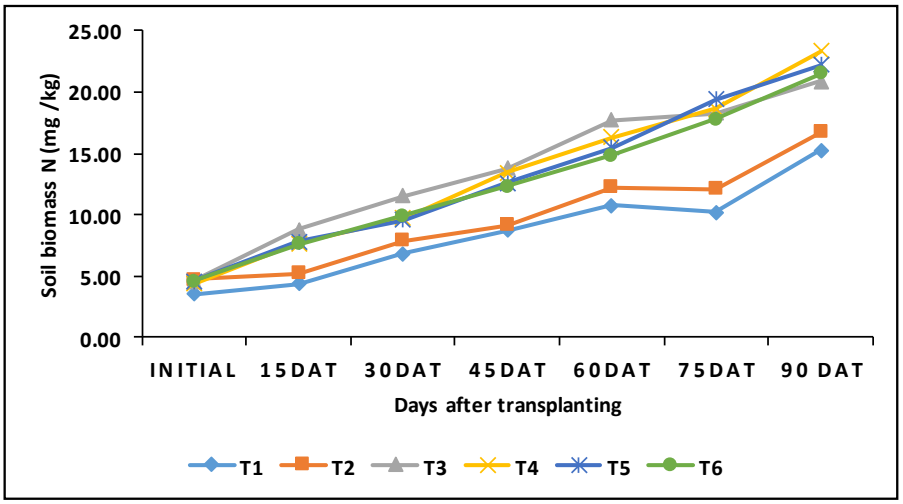


Figure 145. Effect of different organic matters on Biomass N (mg/kg) of soil (Batiaghata, Khulna), at different incubation period. T_1 = Control, T_2 = Recommended Fertilizer, T_3 = Biochar + Recommended Fertilizer, T_4 = Poultry Manure + Chemical Fertilizer, T_5 = Vermicompost + Chemical Fertilizer, T_6 = Standard Organic Fertilizer + Chemical Fertilizer

5.3.4 Soil NO_3-N (mg/kg) at different incubation period

The mineralized data shows that NO_3-N (mg/kg) content was increased in all organic amendments and the control treatment during the incubation experiment at 0, 15, 30, 45, 60, 75 and 90 DAT (Figure 146). The highest mineralized NO_3-N (mg/kg) was observed at 45 DAT in all of the incorporated organic matter treatments. At 45 DAT the highest soil NO_3-N (4.93 mg/kg) mineralization was observed in the T_2 (Recommended Fertilizer) treatment and the lowest soil NO_3-N mineralization 3.52(mg/kg) was recorded in biochar treated T_3 treatment. After that organic amended soil showed a decline of mineralized NO_3-N (mg /kg) and continued up to 90 DAT. The NO_3-N (mg/kg) mineralization rate has followed a trends of $T_2>T_4>T_5>T_6>T_1>T_3$. Integrated over the whole incubation period the highest mineralized NO_3-N was in recommended fertilizer treated T_2 plot and the lowest in biochar amended soil.

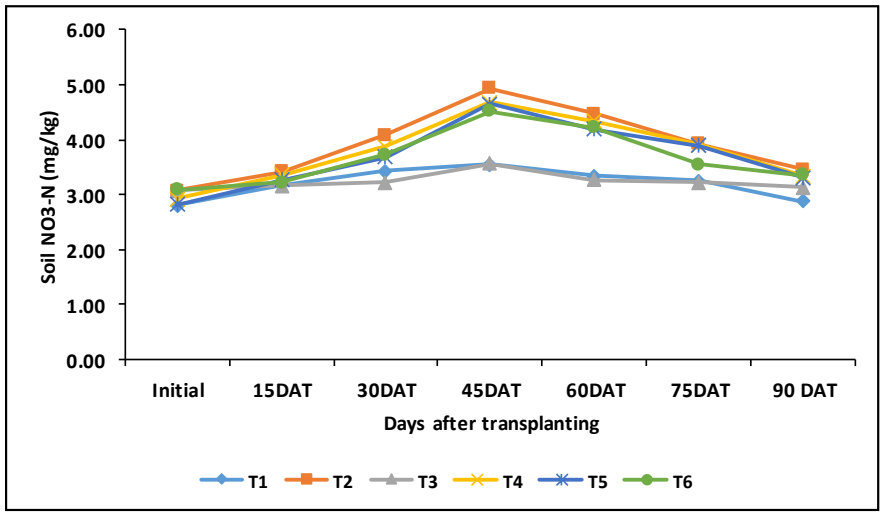


Figure 146. Effect of different organic matters on NO_3-N (mg/kg) of soil (Batiaghata, Khulna), at different incubation period. T_1 = Control, T_2 = Recommended Fertilizer, T_3 = Biochar + Recommended Fertilizer, T_4 = Poultry Manure + Chemical Fertilizer, T_5 = Vermicompost + Chemical Fertilizer, T_6 = Standard Organic Fertilizer + Chemical Fertilizer

5.3.5 Soil NH_4-N (mg/kg) at different incubation period

The effects of different organic amendment treatments after three years intensive application on soil NH_4-N (mg/kg) content in the arsenic contaminated research field at different incubation periods i.e. 0, 15, 30, 45, 60, 75 and 90 days are presented in **Figure** 23. The highest mineralized NH_4-N (mg/kg) was observed at 45 DAT in all of the incorporated organic matter treatments. At 45 DAT the highest soil NH_4-N (16.68 mg/kg) mineralization was observed in the T_2 (Recommended Fertilizer) treatment and the lowest soil NH_4-N mineralization 9.25(mg/kg) was recorded in biochar treated T_1 treatment. After that organic amended soil showed a decline of mineralized NH_4-N (mg /kg) and continued up to 90 DAT. The NH_4-N (mg/kg) mineralization rate has followed a trend of $T_2>T_4>T_5>T_6>T_3>T_1$. Integrated over the whole incubation period the highest mineralized NH_4-N was in recommended fertilizer treated T_2 soil and the lowest in control soil.

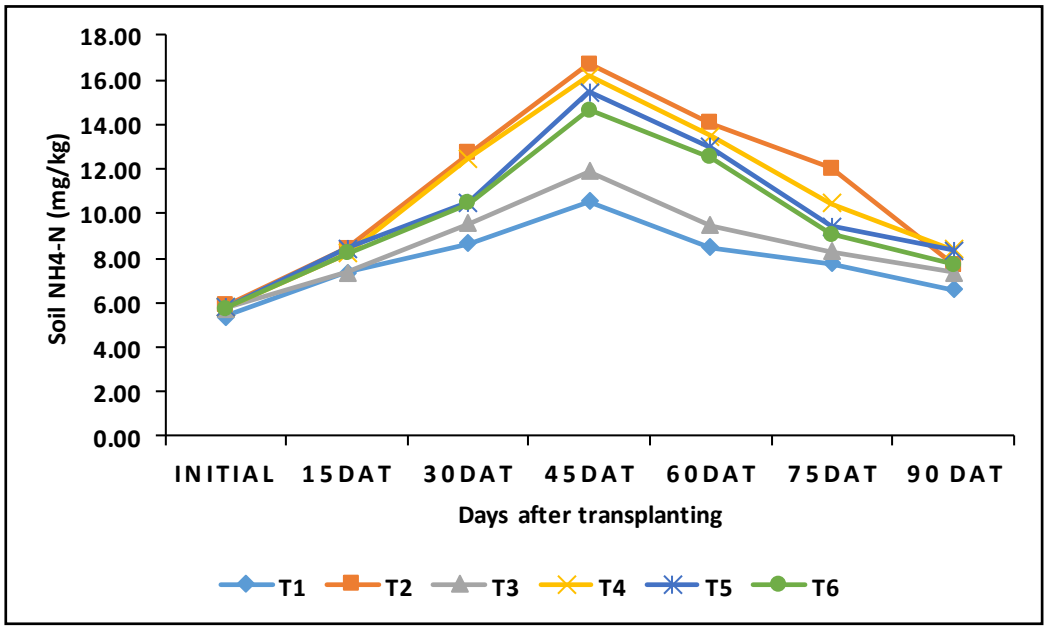


Figure 147. Effect of different organic matters on NH_4-N (mg/kg) of soil (Batiaghata, Khulna), at different incubation period. T_1 = Control, T_2 = Recommended Fertilizer, T_3 = Biochar + Recommended Fertilizer, T_4 = Poultry Manure + Chemical Fertilizer, T_5 = Vermicompost + Chemical Fertilizer, T_6 = Standard Organic Fertilizer + Chemical Fertilizer

6 **Expt. V.** Pot experiment on nitrogen and carbon mineralization dynamics using different organic materials in climate vulnerable soils of heavy metal polluted area of Bhaluka (PhD student's study under objective III)

Figure 148. Soil preparation for mineralization study of heavy metal polluted areas of Bhaluka

Figure 149. Mineralization Study under field capacity and CSW condition (Laboratory)

Mineralization and nutrient dynamics of organic materials under the field capacity and continuous standing water at laboratory condition

6.2 Materials and Methods

Study site description: Soil Science Laboratory of the Bangbandhu Sheikh Mujibur Rahman Agricultural University (BSMRAU), Gazipur, Bangladesh
Duration: November 2020 to March 2021.
Soil collection: Heavy metal polluted area Kathalia, Valuka, Mymensingh.
Experimental design: RCBD with 3 replications

Treatments:
T_1=control, T_2= cowdung, T_3= cowdung slurry, T_4= rice husk biochar, T_5= Vermicompost, T_6= Tricocompost and T_7= Bacteria inoculant
Organic carbon was applied @1.30g C Kg^{-1}

6.3 Physico-chemical properties of organic materials

Table 152. Physical and chemical properties of organic materials used in the experiment

Sample	Moisture (%)	OC (%)	Nitrogen (%)	P (%)	K (%)	Zn (%)	S (%)	C:N ratio
CD	14.87	28.89	2.31	0.32	0.49	0.19	3.32	12.50
CDS	17.13	30.75	2.52	0.64	0.30	0.38	3.22	12.30
RHB	9.31	40.72	0.50	0.14	0.52	0.05	3.99	81.44
VC	17.76	27.88	2.03	0.56	0.82	0.21	3.70	13.69
TC	16.94	26.19	2.01	0.51	1.61	0.19	4.65	13.02

CD=Cowdung, CDS= Cowdung slurry, RHB= Rice husk biochar, VC= Vermicompost, TC= Tricocompost, OC= Organic Carbon

6.4 Soil sampling and analysis

The experiment was continued for 120 days. Soil sample was collected from each pot considering (0, 3, 7, 15, 21, 30, 60, 90 and 120 days) and prepared for analysis.

Table 153. Physico-chemical characterization of mineralized soil sample

Soil properties	Methods	References
OC	Wet oxidation method	Walkley and Black (1935)
TN	Micro-Kjeldahl method	Jackson (1973)
Available P	Bray and Kurtz Method	Bray and Kurtz (1945)
Exchangeable K	Ammonium acetate extraction method	Christian and Feldman (1970)
Available Zn	DTPA extraction method	Christian and Feldman (1970)
Available S	Turbid metric method	David et al., (1989)
Ex. Ca	Atomic Absorption Spectrophotometer	Jackson (1973)
Ex. Mg	Atomic Absorption Spectrophotometer	Jackson (1973)
Mineral N (NH_4^+ + NO_3^-)	NH_4OAC extraction method	Maynard et al. (1993)
Biomass C	Chloroform fumigation extraction method	Jenkinson (1988)
Biomass N	Chloroform fumigation extraction method	Brookers et al. (1985)

Figure 150. Mineralization study of organic materials under field capacity and continuous standing water condition (Laboratory condition)

Different organic amendment had significant effects ($p < 0.05$) on total N, NO_3-N, NH_4-N, OC, biomass C, and biomass N of heavy metal polluted soil at different incubation period at laboratory condition (Figure 151).

The nitrogen percentage content at 0 days of organic amended polluted soil is the contributions of soil inherent capability and nature of organic amending substances. Compared to control condition, organic amendments led to a progressive increase in Total N, NO_3-N, and NH4-N content in polluted soil during the entire 120 days incubations periods. The significantly highest ($p < 0.05$) amounts of mineralized total N, and NH4-N contents (0.17% and 58.16 mg kg^{-1}, respectively) were found in CDS amended soil and NO_3^--N content (78.82 mg kg^{-1}) were in CD amended soil at 120 days after incubation (DAI) (Figure 151A, 151B, 151C). The lowest mineralized total N, NO_3-N, and NH4-N content were noted in the non-amended control soil. Nevertheless, among the amending substances the lowest mineralized total N, NH_4-N, and NO_3-N content (0.07%, 17.83 mg $kg^{-1}$and 18.88 mg kg^{-1}, respectively) was observed in RHB-amended soil.

At different incubation periods, organic amendments have significant effects on the organic carbon content in polluted soil (27D). The mineralized OC content increased in all organic amendment treatment and the control during the whole incubation experiment (120 DAI). The range was 0.72-0.92% in the control treatment and 0.76-1.72% in the organic amendment treatments. The OC content during the entire incubation period was the lowest

in the control treatment (0.72%) and highest in CDS amended soil (1.72%). The OC (%) mineralization rate has followed a trend of CDS>CD>VC>TC>BI> RHB>Co.

Soil biomass C and N were significantly influenced by different organic amending substances at different incubation periods (151E and 151F). The highest biomass C and N were observed at 7 DAI in all of the incorporated organic matter treatments. At 7 DAI, the highest soil biomass C (267.8 mg/kg) observed in the RHB treated soil and biomass N (41.46 mg/kg) in CD-treated soil. The lowest soil biomass C (38.56 mg/kg) and biomass N (8.63 mg/kg) was observed in untreated control soil. After that organic amended soil showed a decline of biomass C and N and continued up to 120 DAT. The biomass C enriched in soils in the order of RHB >CDS>VC>TC>BI> CD> Control (Figure 151E). The biomass N enriched in soils maintained the order of CD >CDS>VC>TC>BI> RHB> Control (Figure 151E). Integrated over the whole incubation period the highest biomass C observed in the RHB treated soil and biomass N in CD-treated soil and the lowest in control soil.

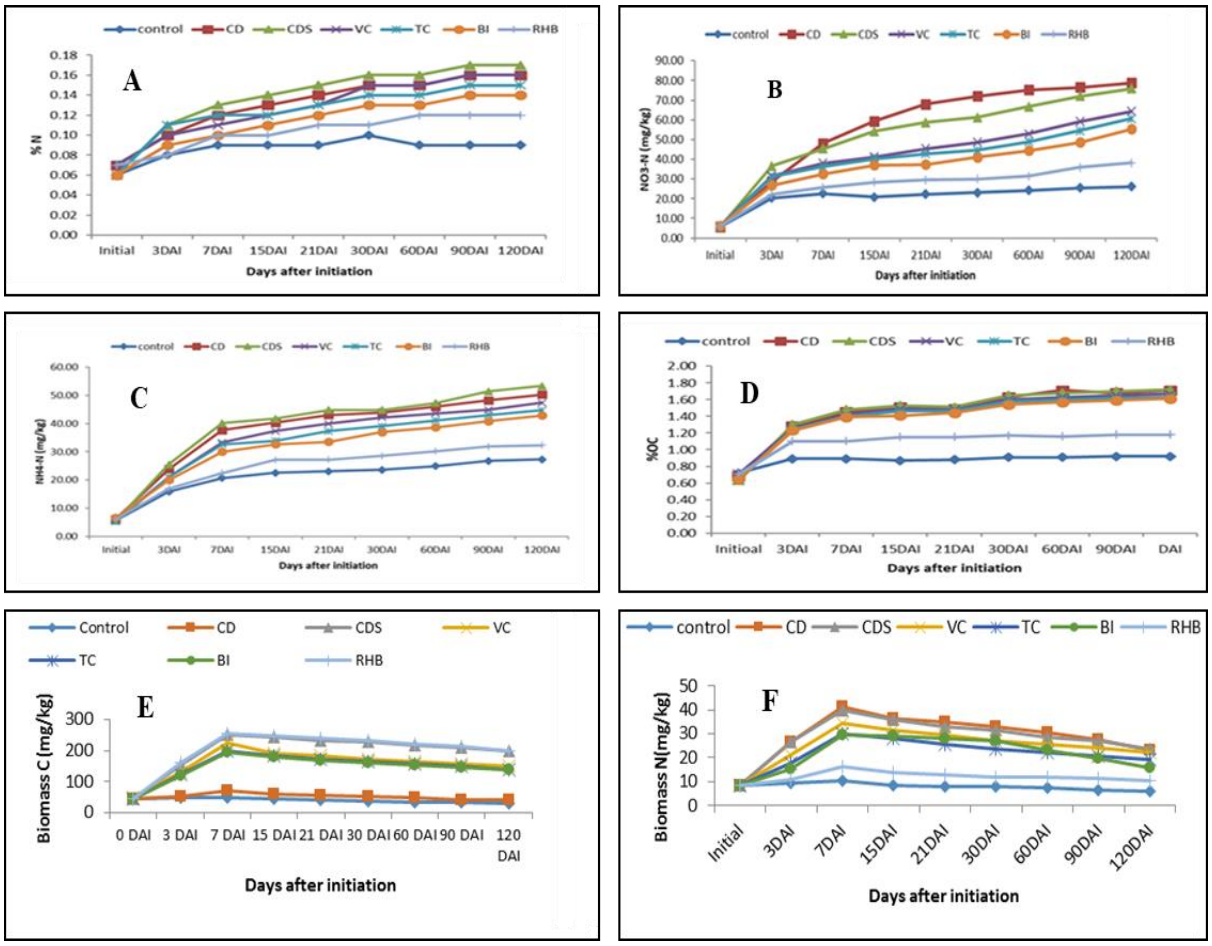


Figure 151. Effect of different organic amendment on (A.) Total N, (B.) NO_3-N, (C.) NH_4-N, (D.) OC, (E.) Biomass C, (F.) Biomass N of heavy metal polluted soil at different incubation period

Different organic amendment had significant effects ($p < 0.05$) on total N, NO_3-N, NH_4-N, OC, biomass C, and biomass N of heavy metal polluted soil at different incubation period at field capacity (FC) and continuous standing water (CSW) moisture regime (Figure 152). The result shows that the highest total N, NO_3-N, NH4-N, OC, biomass C and biomass N content in polluted soil was recorded in CSW water management condition than in FC condition in all incubation periods. The rate of mineralization in total N, NO_3-N, NH4-N and OC were from 0.05 to 0.15 %, 3.52 to 68.65 mg/kg, 4.80 to 46.85 mg/kg and 0.69 to 1.47 %,

respectively in both moisture conditions. However, biomass C and N mineralization rate was increased up to 7 DAI in both moisture regimes afterwards a declining trends was observed.

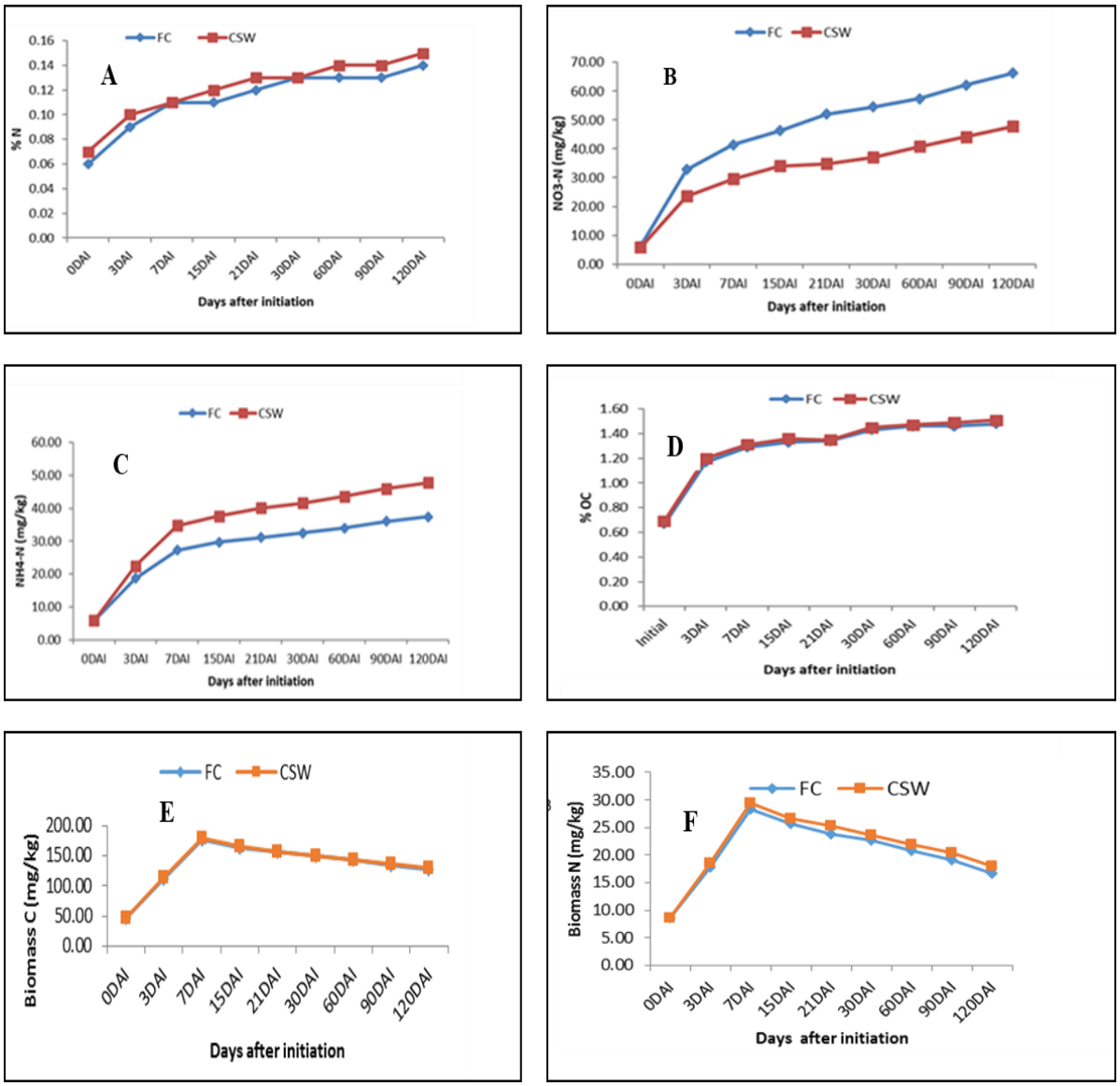


Figure 152. Effect of different moisture regimes on (A.) Total N, (B.) NO3-N, (C.) NH4-N, (D.) OC, (E.) Biomass C, (F.) Biomass N of heavy metal polluted soil at different incubation period

The interaction effects of organic materials and irrigation management practice on nitrogen content of industrial polluted soil at different days after incubation were presented in Table 154. The best combination for increasing the availability of total nitrogen release by mineralization was observed in cowdung slurry treated soil at CSW condition (0.18%) followed by CDSxFC and VCxCSW at 120 DAI. The lowest combination for mineralized total nitrogen content was observed in controlxFC condition.

Table 154. Interaction effect of different organic materials (OM) and irrigation management (IM) practice on total nitrogen content of industrial polluted soil at different days after incubation (DAI)

OM*IM	% Nitrogen								
	0 DAI	3 DAI	7 DAI	15 DAI	21 DAI	30 DAI	60 DAI	90DAI	120 DAI
Cont*FC	0.05c	0.07g	0.09e	0.09f	0.09i	0.10g	0.09f	0.08g	0.09e
CD*FC	0.07ab	0.09defg	0.12abcd	0.12abcd	0.14abc	0.15ab	0.15abc	0.16abc	0.16ab
CDS*FC	0.06bc	0.10cde	0.13ab	0.14a	0.14ab	0.15ab	0.16a	0.17a	0.17ab
VC*FC	0.07ab	0.10cdef	0.11bcde	0.12abcde	0.12def	0.14bc	0.15abc	0.15abc	0.16ab
TC*FC	0.06bc	0.11abc	0.11bcde	0.12abcd	0.13cde	0.14bcd	0.14abcd	0.14bcd	0.15bc
BI*FC	0.06bc	0.09defg	0.10cde	0.10cdef	0.12efg	0.12def	0.12de	0.13cde	0.13cd
RHB*FC	0.06abc	0.08fg	0.10de	0.09ef	0.11gh	0.11efg	0.12de	0.12def	0.12cd
Cont*CSW	0.06abc	0.07g	0.09e	0.10def	0.10hi	0.11fg	0.10ef	0.10fg	0.10de
CD*CSW	0.08a	0.10bcde	0.12abc	0.13ab	0.14abc	0.15ab	0.15ab	0.16ab	0.16ab
CDS*CSW	0.06abc	0.12a	0.14a	0.14a	0.15a	0.16a	0.16a	0.17ab	0.18a
VC*CSW	0.07abc	0.11abcd	0.11bcde	0.12abcde	0.13cde	0.15ab	0.15abc	0.16abc	0.17ab
TC*CSW	0.06bc	0.12ab	0.12abcd	0.13abc	0.13bcd	0.14bcd	0.14abcd	0.16ab	0.15bc
BI*CSW	0.06bc	0.09cdef	0.11bcde	0.11bcde	0.12defg	0.13cde	0.13bcd	0.14bcd	0.16ab
RHB*CSW	0.07ab	0.09efg	0.11bcde	0.10def	0.11fgh	0.11efg	0.13cd	0.11ef	0.12cd
CV(%)	13.40	11.89	12.99	12.60	7.51	7.68	10.70	11.86	12.20
LSD $_{(0.05)}$	0.015	0.019	0.024	0.024	0.016	0.017	0.024	0.028	0.029

Con = control, CDS= cowdung slurry, RHB = rice husk biochar, CD = cow dung,VC = vermicompost, TC =trico-compost and BI= bacteria inoculant, FC= Field Capacity and CSW= Continuous Standing Water.

The interaction effects of organic materials and irrigation management practice on nitrate nitrogen content of industrial polluted soil at different days after incubation were presented in Table 155. The best combination for increasing the availability of nitrate nitrogen release by mineralization was observed in cowdung treated soil at FC condition (96.46 mg/kg) followed by VCxFC and TCxFC at 120 DAI. The lowest combination for mineralized nitrate nitrogen content was observed in controlxFC condition.

Table 155. Interaction effect of different organic materials (OM) and irrigation management (IM) practice on nitrate nitrogen content of industrial polluted soil at different days after incubation

OM*IM	NO_3-N (mg kg^{-1})								
	0DAI	3 DAI	7 DAI	15 DAI	21 DAI	30 DAI	60 DAI	90DAI	120 DAI
Cont*FC	5.95a	22.71f	26.67fg	22.98gh	25.63gh	25.72i	26.21h	27.08i	27.74i
CD*FC	5.71a	33.60bc	53.40a	69.57a	82.01a	86.82a	90.51a	93.20a	96.46a
CDS*FC	6.24a	42.87a	55.62a	67.56a	73.91b	78.17b	84.21a	88.82a	94.10a
VC*FC	6.56a	37.65ab	44.56b	46.10bc	55.02c	58.59c	60.93b	70.31b	73.85b
TC*FC	6.22a	38.11ab	42.58bc	44.47bc	51.40cd	51.72de	55.37bc	63.39c	69.84bc
BI*FC	6.42a	31.53bcd	37.98cd	41.49cd	44.34de	47.42ef	49.97cd	54.58de	62.44cd
RHB*FC	6.24a	23.32ef	28.75f	31.78f	32.35fg	33.66h	34.36fg	37.88gh	39.71h
Cont*CSW	5.73a	18.13f	18.57h	18.74h	18.95h	20.56i	22.09h	23.98i	24.46i
CD*CSW	5.45a	23.67ef	42.72bc	49.04b	54.02c	57.13cd	59.86b	59.99cd	61.19de
CD*CSW	5.66a	30.19cde	35.13de	40.92cde	43.53e	44.40fg	49.19cd	55.14d	57.83def
VC*CSW	6.13a	25.46def	31.44ef	36.22def	35.80f	38.71gh	44.91de	48.13ef	54.78efg
TC*CSW	5.97a	24.24def	29.83ef	35.98ef	34.15f	37.41h	42.45e	45.62f	51.55fg
BI*CSW	6.26a	22.02f	26.97fg	32.69f	30.45fg	34.66h	38.84ef	42.52fg	48.25g
RHB*CSW	6.01a	20.93f	22.60gh	25.05g	26.78g	26.27i	28.37gh	34.04h	36.70h
CV(%)	9.55	8.73	5.12	4.73	5.50	4.76	4.28	4.17	4.36
LSD $_{(0.05)}$	1.73	7.39	5.46	5.27	7.18	6.56	6.32	6.67	7.48

Con = control, CDS= cowdung slurry, RHB = rice husk biochar, CD = cow dung,VC = vermicompost, TC =trico-compost and BI= bacteria inoculant, FC= Field Capacity and CSW= Continuous Standing Water.

The interaction effects of organic materials and irrigation management practice on ammonium nitrogen content of industrial polluted soil at different days after incubation were presented in Table 156. The best combination for increasing the availability of ammonium nitrogen release by mineralization was observed in CDSxCSW treated soil (60.61 mg/kg) followed by CDxCSW (57.82 mg/kg) and VCxCSW (53.40 mg/kg) at 120 DAI. The lowest combination for mineralized nitrate nitrogen content was observed in controlxFC (24.24 mg/kg) condition.

Table 156. Interaction effect of different organic materials (OM) and irrigation management (IM) practice on ammonium nitrogen content of industrial polluted soil at different days after incubation (DAI)

OM*IM	NH_4-N (mg kg^{-1})								
	0 DAI	3 DAI	7 DAI	15 DAI	21 DAI	30 DAI	60 DAI	90DAI	120 DAI
Cont*FC	5.68abcd	15.37h	18.31h	21.67i	21.67j	22.41h	23.86i	23.90i	24.24j
CD*FC	5.83abcd	20.58de	32.31de	33.69de	36.85d	37.81e	39.17e	41.13d	42.83ef
CDS*FC	5.54cd	24.49b	33.68cd	34.65de	37.47d	38.62de	40.43de	45.57c	46.14de
VC*FC	5.90abcd	19.34ef	30.55e	32.09ef	33.51ef	36.89e	37.91ef	38.94de	41.36f
TC*FC	5.36cd	18.45f	29.41e	29.55fg	31.02fg	33.07f	35.59fg	37.03ef	39.53fg
BI*FC	6.58a	17.50fg	25.71f	29.56fg	30.35fg	32.28f	33.65g	35.79fg	37.44gh
RHB*FC	6.08abc	15.42h	20.65gh	26.65gh	26.82hi	26.53g	27.68h	29.86h	30.19i
Cont*CSW	5.57bcd	16.40gh	23.16fg	23.47hi	24.52ij	24.87gh	26.00hi	29.58h	30.36i
CD*CSW	6.53ab	27.10a	43.06b	47.02a	49.34ab	50.16a	52.85a	55.43a	57.82a
CDS*CSW	5.61bcd	26.54a	46.63a	48.89a	52.21a	51.04a	54.14a	57.31a	60.61a
VC*CSW	5.77abcd	22.70bc	36.07c	42.57b	46.56bc	47.51ab	49.29b	50.88b	53.40b
TC*CSW	5.06d	23.45bc	35.88c	38.37c	43.70c	45.20bc	46.63bc	49.14b	49.90c
BI*CSW	5.58a	22.50cd	34.38cd	35.72cd	36.73de	41.73cd	43.65cd	45.98c	48.43cd
RHB*CSW	6.08abc	18.64f	24.31f	27.66g	27.84gh	30.56f	32.69g	33.89g	34.52h
CV(%)	9.79	5.54	5.71	5.89	5.40	5.76	5.06	4.40	4.69
LSD $_{(0.05)}$	0.96	1.91	2.97	3.33	3.22	3.58	3.29	2.78	3.35

Con = control, CDS= cowdung slurry, RHB = rice husk biochar, CD = cow dung,VC = vermicompost, TC =trico-compost and BI= bacteria inoculant, FC= Field Capacity and CSW= Continuous Standing Water.

The interaction effects of organic materials and irrigation management practice on organic carbon mineralization of industrial polluted soil at different days after incubation were presented in Table 157. The best combination for increasing the availability of organic carbon mineralization was observed in CDSxFC treated soil (1.72 %) at 120 DAI. The lowest organic carbon mineralization rate was observed in controlxFC condition.

Table 157. Interaction effect of different organic materials (OM) and irrigation management (IM) practice on organic carbon mineralization of industrial polluted soil at different days after incubation (DAI)

OM*IM	% Organic Carbon mineralization								
	0 DAI	3 DAI	7 DAI	15 DAI	21 DAI	30 DAI	60 DAI	90DAI	120 DAI
Cont*FC	0.69bcd	0.87d	0.90e	0.87e	0.89c	0.89d	0.89e	0.90d	0.90c
CD*FC	0.68bcd	1.27ab	1.43abc	1.48abc	1.49a	1.61ab	1.74a	1.65ab	1.69a
CDS*FC	0.63d	1.27ab	1.48a	1.50abc	1.51a	1.63ab	1.65abc	1.68ab	1.72a
VC*FC	0.71abc	1.24ab	1.41abc	1.48abc	1.47a	1.59ab	1.61bc	1.63ab	1.65a
TC*FC	0.63d	1.23b	1.40abc	1.46bc	1.45a	1.58ab	1.59bc	1.60ab	1.62a
BI*FC	0.65cd	1.23b	1.38c	1.41c	1.43a	1.54b	1.56c	1.57b	1.60a
RHB*FC	0.71abc	1.06c	1.09d	1.13d	1.15b	1.16c	1.16d	1.17c	1.17b
Cont*CSW	0.76a	0.92d	0.89e	0.87e	0.87c	0.92d	0.93e	0.93d	0.94c

CD*CSW	0.69bcd	1.29ab	1.46abc	1.54ab	1.50a	1.66a	1.68abc	1.70a	1.71a
CD*CSW	0.65cd	1.33a	1.47ab	1.56a	1.51a	1.66a	1.70ab	1.72a	1.73a
VC*CSW	0.72ab	1.25ab	1.42abc	1.49abc	1.49a	1.61ab	1.64abc	1.67ab	1.69a
TC*CSW	0.65cd	1.25ab	1.41abc	1.47abc	1.47a	1.59ab	1.61bc	1.64ab	1.65a
BI*CSW	0.66bcd	1.24ab	1.39bc	1.42c	1.45a	1.55b	1.58bc	1.60ab	1.62a
RHB*CSW	0.72ab	1.09c	1.11d	1.16d	1.15b	1.17c	1.17d	1.18c	1.19b
CV(%)	5.64	5.18	3.99	4.18	3.85	4.13	5.04	4.81	5.33
LSD $_{(0.05)}$	0.065	0.103	0.087	0.094	0.087	0.099	0.124	0.119	0.134

Con = control, CDS= cowdung slurry, RHB = rice husk biochar, CD = cow dung,VC = vermicompost, TC =trico-compost and BI= bacteria inoculant, FC= Field Capacity and CSW= Continuous Standing Water.

The interaction effects of organic materials and irrigation management practice on biomass carbon content of industrial polluted soil at different days after incubation were presented in Table 158. Biomass carbon content increased up to 7 DAI and afterwards a declining trend was observed in all of the interactions. The best combination for increasing the availability of biomass carbon content by mineralization was observed in RHB*CSW treated soil (256.35 mg/kg) followed by RHB*FC, CDS*CSW and CDS*FC at 7 DAI. The lowest combination for biomass carbon content was observed in controlxFC (48.58 mg/kg) condition at 7 DAI.

The interaction effects of organic materials and irrigation management practice on biomass nitrogen content of industrial polluted soil at different days after incubation were presented in Table 159. Biomass nitrogen content increased up to 7 DAI and afterwards a declining trend was observed in all of the interactions. The best combination for increasing the availability of biomass nitrogen content by mineralization was observed in CD*CSW treated soil (41.63 mg/kg) followed by CD*FC and CDS*CSW at 7 DAI. The lowest combination for biomass carbon content was observed in controlxFC (10.14 mg/kg) condition at 7 DAI.

Table 158. Interaction effect of different organic materials (OM) and irrigation management (IM) practice on biomass carbon content of industrial polluted soil at different days after incubation

OM*IM	**Biomass Carbon C (mg Kg^{-1})**								
	0 DAI	**3 DAI**	**7 DAI**	**15 DAI**	**21 DAI**	**30 DAI**	**60 DAI**	**90DAI**	**120 DAI**
Cont*FC	46.65a	48.11f	48.58e	46.58f	42.95e	38.10e	35.00e	31.99g	29.42g
CD*FC	46.72a	50.65f	69.00d	60.70e	55.32d	51.54d	46.52de	41.76ef	40.43ef
CDS*FC	46.71a	153.18c	249.93a	241.84a	233.26a	226.30a	217.25a	207.98a	197.92a
VC*FC	47.06a	130.34d	225.52b	191.96bc	181.79b	172.88b	165.21b	157.07bc	149.11bc
TC*FC	46.81a	120.97e	197.92c	182.50bcd	173.13bc	164.35bc	156.08bc	148.32cd	139.27cd
BI*FC	46.30a	117.86e	194.95c	179.56d	170.26c	161.73c	152.30c	144.58d	135.96d
RHB*FC	46.73a	161.63ab	254.12a	246.41a	238.06a	231.97a	222.01a	212.18a	196.94a
Cont*CSW	46.87a	48.91f	49.01e	46.40f	42.64e	38.20e	35.79de	32.36fg	30.10fg
CD*CSW	46.42a	52.97f	72.07d	62.75e	57.43d	53.54d	48.37d	43.84e	42.37e
CDS*CSW	46.95a	154.68bc	251.05a	243.95a	234.31a	229.55a	218.15a	209.66a	201.77a
VC*CSW	46.95a	131.64d	227.85b	192.81b	183.25b	173.97b	166.41b	158.41b	150.68b
TC*CSW	46.91a	123.69de	201.66c	184.13bcd	173.59bc	165.18bc	159.30bc	148.63cd	141.76bcd
BI*CSW	46.52a	120.48e	198.75c	180.76cd	169.84c	160.80c	156.00bc	145.62d	138.68cd
RHB*CSW	46.81a	163.98a	256.35a	247.48a	239.75a	233.75a	223.82a	214.26a	198.67a
CV(%)	3.24	4.40	4.79	4.34	4.07	4.36	5.31	4.16	4.96
SE(±)	1.24	4.05	6.98	5.85	5.21	5.34	6.20	4.60	5.19
LSD $_{(0.05)}$	2.54	8.33	14.35	12.02	10.71	10.98	12.76	9.45	10.67

Table 159. Interaction effect of different organic materials (OM) and irrigation management (IM) practice on biomass nitrogen content of industrial polluted soil at different days after incubation (DAI)

OM*IM	**Biomass Nitrogen (mg Kg^{-1})**								
	0 DAI	**3 DAI**	**7 DAI**	**15 DAI**	**21 DAI**	**30 DAI**	**60 DAI**	**90DAI**	**120 DAI**
Cont*FC	8.68a	9.23h	10.14f	8.32i	8.01i	7.74f	7.15g	6.46g	6.07h
CD*FC	8.67a	27.69a	41.28a	37.70a	34.17ab	32.18ab	29.96ab	27.29a	22.38bc
CDS*FC	8.63a	25.87b	38.78b	34.83b	32.46bc	30.86b	28.31bc	26.61ab	24.01a
VC*FC	8.68a	20.87c	33.84c	30.93cd	28.34ef	26.17c	24.11d	23.20c	21.61c

TC*FC	8.68a	17.21de	29.42d	26.96f	25.24g	23.25d	21.76e	19.95e	18.18e
BI*FC	8.69a	14.40f	29.11d	28.28ef	26.89fg	26.50c	22.51de	18.93e	14.06f
RHB*FC	8.68a	9.98gh	15.99e	12.86h	12.18h	11.89e	11.42f	10.92f	10.06g
Cont*CSW	8.55a	9.65h	11.24f	8.99i	8.50i	8.01f	7.54g	7.02g	6.09h
CD*CSW	8.55a	25.27b	41.63a	34.72b	35.55a	33.87a	31.41a	28.09a	24.21a
CD*CSW	8.52a	26.90ab	40.69ab	37.07a	33.74ab	31.88ab	29.18b	27.78a	23.21ab
VC*CSW	8.52a	21.71c	35.31c	32.31c	30.68cd	28.19c	26.67c	25.22b	23.04ab
TC*CSW	8.49a	18.58d	30.92d	28.75ef	25.93g	24.03d	22.72de	21.96cd	20.06d
BI*CSW	8.55a	16.71e	30.01d	29.84de	29.16de	27.48c	23.82d	20.60de	17.78e
RHB*CSW	8.59a	11.61g	16.55e	15.21g	13.52h	12.31e	12.52f	11.88f	11.32g
CV (%)	3.49	5.46	4.11	4.70	4.78	5.46	5.34	5.29	4.86
SE(±)	0.24	0.81	0.97	1.01	0.96	1.03	0.93	0.85	0.68
LSD $_{(0.05)}$	0.50	1.67	1.99	2.07	1.97	2.12	1.91	1.75	1.41

6.5 Effect of organic materials on soil pH under FC and CSW

Different organic amendment had significant effects ($p < 0.05$) on soil pH at different incubation period (Figure 153a). The result shows that addition of different organic matter progressively increase the soil pH up to 120 DAI. Among the treatments the highest pH change was observed in RHB (4.95 to 5.90) and the lowest pH change was found in control treatment (4.85 to 5.10). The initial pH of different organic amendment indicate the inherent capacity of soil and nature of organic matters. Different organic amendment had significant effects ($p < 0.05$) on soil pH in heavy metal polluted soil at different incubation period at field capacity (FC) and continuous standing water (CSW) moisture regime (Figure 153b). The result shows that the higher soil pH was recorded in CSW condition as compare to FC condition throughout the whole incubation period. Soil pH increased significantly after adding of organic amendments in both FC and CSW moisture regime.

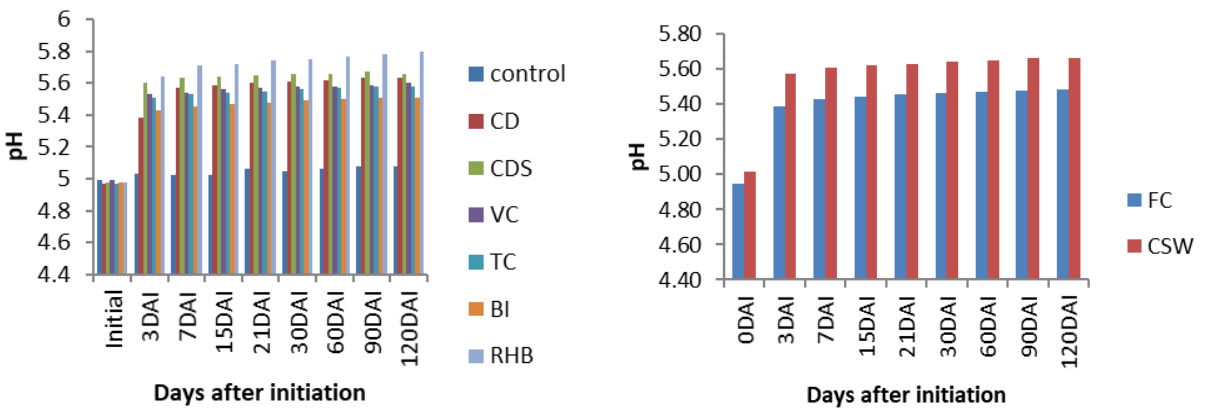


Figure 153. Effect of (a) different organic materials (OM) and (b) irrigation management (IM) practices on pH change at different incubation period of industrial polluted soil

Different organic materials, moisture regimes and their interactions showed significant effects on pH change of industrial polluted soil in different incubation periods (Figure 146 A-B, Table 160). The initial pH value (at 0 days) of organic amended industrial polluted soil was the contributions of soil inherent capacity. Addition of organic amendments improved soil pH in industrial polluted soil.

The interaction effects of organic materials and irrigation management practice on soil pH of heavy metal polluted soil at different days after incubation were presented in Table 160. The best combination for increasing soil pH was observed in RHBxCSW (5.99) followed by RHBxFC (5.88) at 120 DAI. The lowest soil pH at 120 DAI was observed in controlxFC treatment.

Table 160. Interaction effect of different organic materials (OM) and irrigation management (IM) practice on soil pH of industrial polluted soil at different days after incubation (DAI)

OM*IM	Soil pH								
	0 DAI	3 DAI	7 DAI	15 DAI	21 DAI	30 DAI	60 DAI	90DAI	120 DAI
Cont*FC	4.97bc	5.02i	4.99k	5.02j	5.04j	5.03k	5.03j	5.06i	5.06h
CD*FC	4.94cd	5.24h	5.43h	5.45h	5.47h	5.48h	5.49g	5.50g	5.49f
CDS*FC	4.95cd	5.46f	5.51g	5.51g	5.52g	5.53g	5.54f	5.54f	5.54f
VC*FC	4.96cd	5.44f	5.45h	5.46h	5.48h	5.49h	5.49g	5.50fg	5.51f
TC*FC	4.94cd	5.43f	5.45h	5.45h	5.46h	5.48h	5.49g	5.49g	5.50f
BI*FC	4.93cd	5.32g	5.35i	5.36i	5.37i	5.38i	5.39h	5.40h	5.40g
RHB*FC	4.93d	5.81b	5.83b	5.84b	5.84b	5.85b	5.86b	5.87b	5.88b
Cont*CSW	5.01a	5.05i	5.05j	5.03j	5.08j	5.08j	5.08i	5.10i	5.10h
CD*CSW	4.99ab	5.53e	5.71d	5.73d	5.74d	5.74d	5.75c	5.76c	5.76c
CDS*CSW	5.01a	5.74c	5.75c	5.77c	5.78c	5.78c	5.79c	5.80c	5.79c
VC*CSW	5.02a	5.62d	5.64e	5.65e	5.66e	5.67e	5.67d	5.69d	5.69d
TC*CSW	5.01a	5.60d	5.61e	5.63e	5.64e	5.65e	5.66d	5.67d	5.66de
BI*CSW	5.03a	5.54e	5.56f	5.57f	5.59f	5.60f	5.61e	5.62e	5.61e
RHB*CSW	5.03a	5.93a	5.94a	5.95a	5.96a	5.96a	5.97a	5.97a	5.99a
CV (%)	0.40	0.41	0.42	0.41	0.40	0.42	0.44	0.47	0.54
SE(±)	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
LSD $_{(0.05)}$	0.03	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.05

Con = control, CDS= cowdung slurry, RHB = rice husk biochar, CD = cow dung,VC = vermicompost, TC =trico-compost and BI= bacteria inoculant, FC= Field Capacity and CSW= Continuous Standing Water.

6.6 Effect of organic materials on Soil CEC under FC and CSW

Addition of different organic matter significantly increased the soil CEC as compared with initial soil (Figure 154a). Among all the treatments, the highest CEC (14.25 meq/100g soil) was observed in RHB added soil while lowest value (12.12 meq/100g soil) was found in BI treated soil. The CEC of polluted soil significantly increased in both FC and CSW moisture regimes at 120 DAI (Figure 154b). The highest CEC was recorded in CSW (12.78 meq/100g soil) as compare to FC (12.58 meq/100g soil).

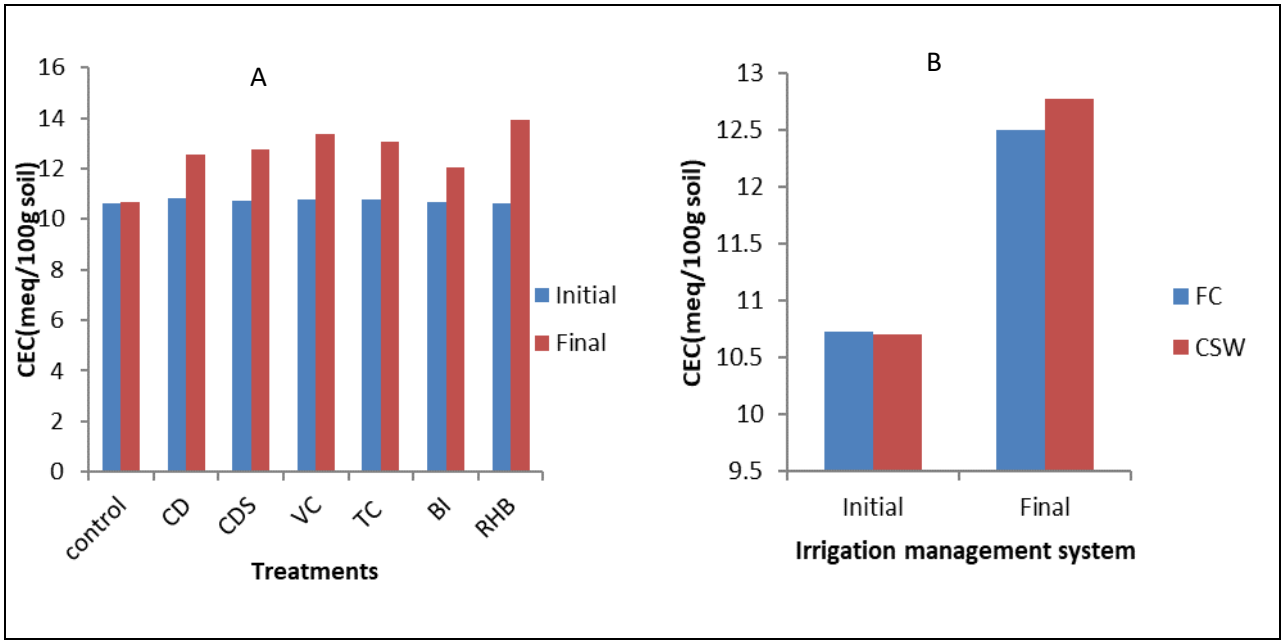


Figure 154. Eeffect of different A. organic materials (OM) and B. Irrigation management (IM) practice on CEC content of industrial polluted soil.

7 **Expt. VI.** Field study on nitrogen and carbon mineralization dynamics using different organic materials in climate vulnerable soils of heavy metal polluted area of Bhaluka (PhD student's study under objective III)

7.2 Study location

The field experiment was conducted in heavy metal polluted area of Bhaluka (Figure 155).

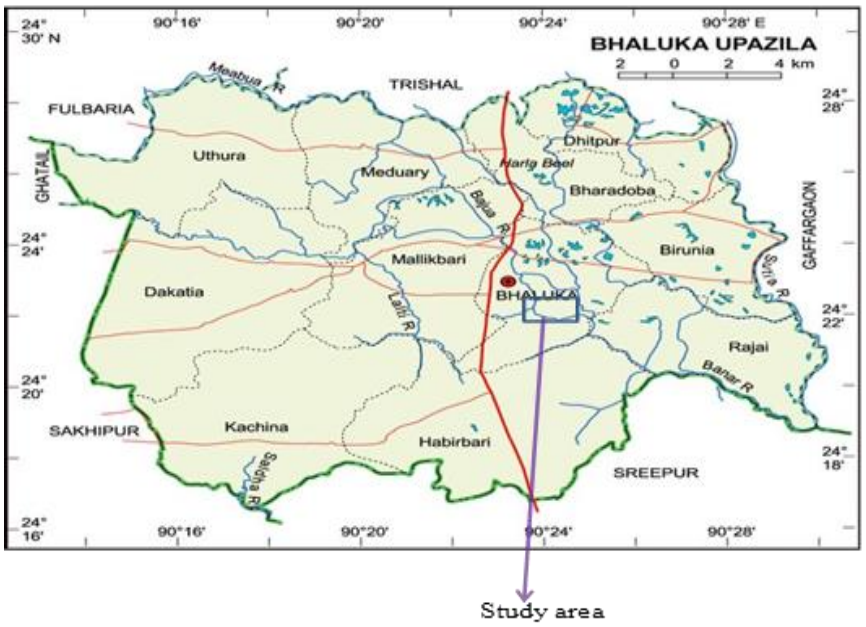


Figure 155. Map of study area (24.22 N and 90.24 E)

7.3 Experimental details

The study was conducted in T. aman season (September to December) of 2020. Seven treatments viz. T_1=control, T_2= cowdung, T_3= cowdung slurry, T_4= rice husk biochar, T_5= Vermicompost, T_6= Tricocompost and T_7= Bacteria inoculant were used. Application rate of the all-organic materials were calculated as 2 tons C ha^{-1}. For bacterial inoculant, 4ml of *Agrococcus jejuensis* broth culture was added per plot (4m x 2.5m). The experiment was laid out in Randomized Complete Block Design (RCBD) with 4 replications. Thirty days older seedlings of BU dhan1 were transplanted on 10 August, 2020 maintaining 20cm × 20cm spacing. Urea, triple super phosphate (TSP), muriate of potash (MoP), gypsum and zinc sulphate fertilizers were applied to supply N, P, K, S and Zn nutrient respectively. Fertilizer rate was calculated (N-P-K-S-Zn @ 60-11-43-9-0.8 kg ha^{-1}) on the basis of soil test by following BARC model (FRG, 2018). The whole amount of all fertilizers was applied during final land preparation and the urea was applied in three equal splits (15 days after transplanting, at maximum vegetative stage and panicle initiation stage). Intercultural operations were performed as and when required by following the standard method. After 95 days of transplanting, crop was harvested on 15 November 2020.

7.4 Biochar and other organic materials preparation

Rice husk biochar was prepared in a modified biochar preparation stove developed by the Department of Soil Science, Bangabandhu Sheikh Mujibur Rahman Agricultural University

(BSMRAU), Bangladesh through pyrolysis process (oxygen deficit condition) at 350-450^{0}C temperature. After cooling, biochar was sieved through 60-mesh sieve. Trico-compost was collected from HRC, BARI, Gazipur. Cowdung, Vermicompost and Cowdung slurry were collected from Farmers Dairy Farm, Joydebpur, Gazipur. Bacteria inoculant was prepared in Microbiology Laboratory of Soil Science Department, BSMRAU. All the organic materials were applied except control plot before final land preparation and rice seedlings were transplanted after one week of organic materials application.

7.5 Soil sampling and analysis

Soil samples were collected from each plot at 0-15 cm depth with 15 days' interval (0, 15, 30, 45, 60, 75 and 90 days). Physico-chemical properties of initial and post-harvest soils were analyzed by following standard methods (Table 153).

Figure 156. Initial soil sample collection for physical and chemical analysis

7.6 Results

7.6.1 Organic materials mineralization

Different organic materials showed significant effects ($p < 0.05$) on the nitrogen, ammonium nitrogen (NH_4^+-N), nitrate nitrogen (NO_3^--N), organic carbon, biomass carbon and biomass nitrogen availability in soils at different days after transplanting of rice (Figure 33A-F). Total N, NH_4^+-N and NO_3^-N concentration significantly increased up to 45 DAT and after that up to 75 DAT declining trend were observed. Afterwards the mineralization rate of total N, NH_4^+-N and NO_3^-N were almost stable. At 45 DAT the highest mineralization rate was observed in CDS and lowest was found in control. Among the organic matters the lowest value was observed in RHB. On an average in the whole incubation period different organic matter shows the following trends: CDS>CD>VC>TC>BI>RHB>Control.

The organic carbon (OC) content increased significantly by addition of different organic materials in polluted soils at different DAT. The highest OC content was observed at 30 DAT in all treatments. Afterwards the OC content declined in all the organic amended soils up to 75 DAT and steady condition was observed up to 90 DAT. Among the organic matters the highest value was observed in RHB. On an average in the whole incubation period different organic matter shows the following trends: RHB>CDS>VC>TC>BI>CD>Control. Biomass C and N contents in soils were increased with the advancement of rice growing periods (Figure 33A-F). The biomass C enriched in soils in the order of RHB > CDS.> VC > TC > BI > CD > control. The maximum biomass C (204.62 mg kg^{-1}) was found in the rice husk biochar applied plot at harvest, while the lowest (121.56 mg kg^{-1}) was found in the control treatment. At harvest, the maximum biomass N was also found in the cowdung slurry applied plot (24.67 mg kg^{-1}) while the lowest was found in the control treatment (15.20 mg kg^{-1}). The biomass N enriched in soils in the order of CDS > CD > VC > TC > BI > RHB > control (Figure 157A-F).

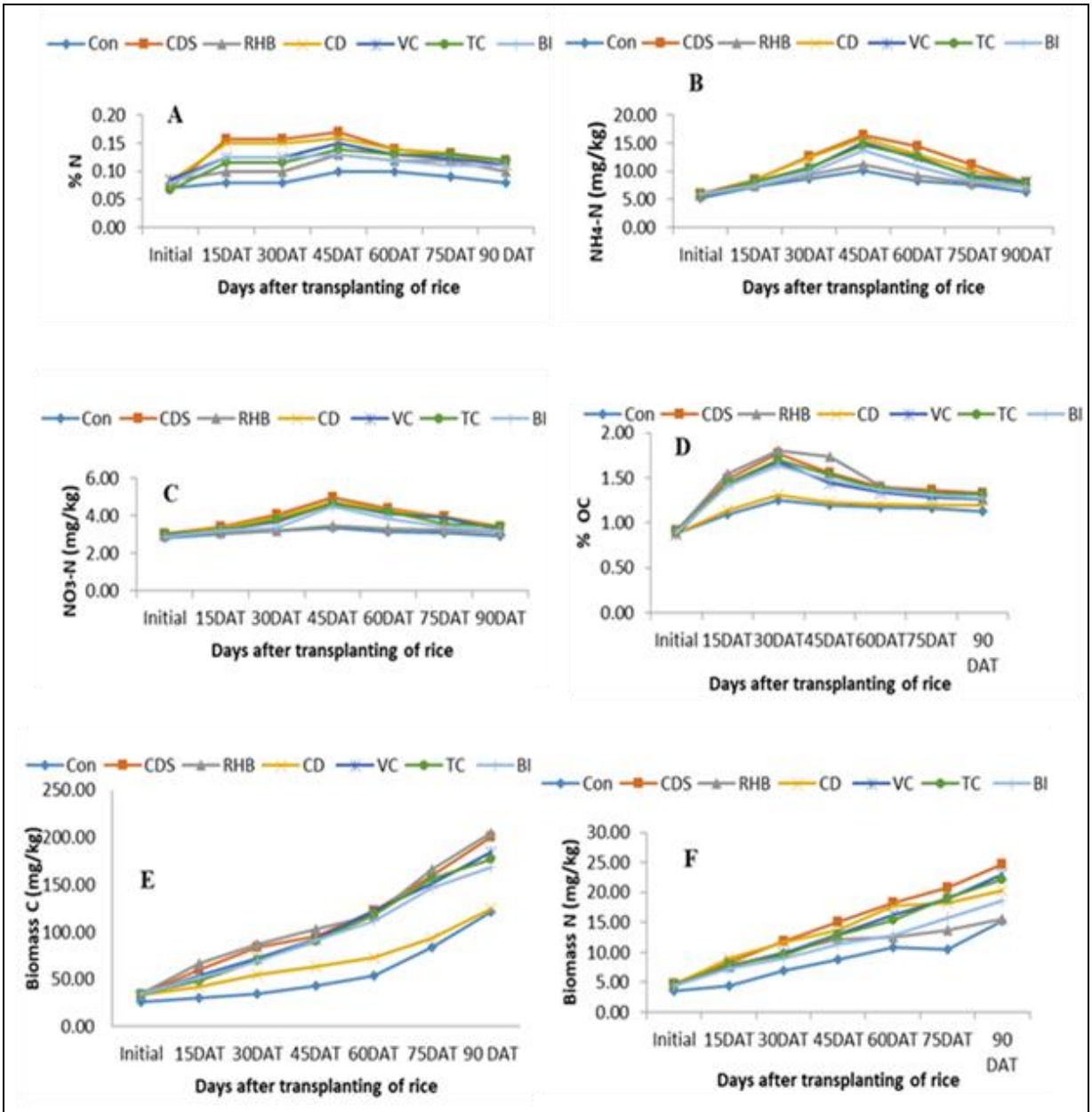


Figure 157. Effect of organic materials on release of A. nitrogen, B. ammonium nitrogen, C. nitrate nitrogen, D. Organic carbon, E. Microbial biomass carbon and F. microbial biomass nitrogen in soils at different days after transplanting of rice in industrial polluted soil. (Con = control, CDS= cowdung slurry, RHB = rice husk biochar, CD = cow dung,VC = vermicompost, TC =trico-compost and BI= bacteria inoculant).

7.6.2 Effect of organic materials on Soil *pH*

Addition of organic materials significantly increased pH at different DAT of rice in industrial polluted soil (Figure 158). The highest pH value was found in rice husk biochar (5.84) at 90 DAT of rice followed by cowdung slurry (5.77) and cow dung (5.74), while the lowest was found in control (5.28) plots.

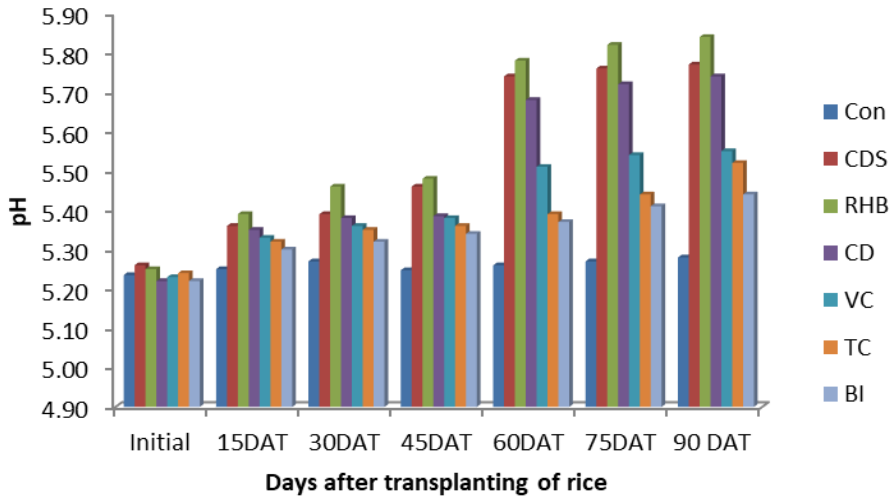


Figure 158. pH level of soil samples under different organic materials applied plots in industrial polluted soil (Con = control, CDS= cowdung slurry, RHB = rice husk biochar, CD = cow dung, VC = vermicompost, TC =trico-compost and BI= bacteria inoculant). Error bars show the standard error of the mean ($p < 0.05$).

7.6.3 Nutrient status of post-harvest soil

The nutrient status of post-harvest soil was presented in Table 161. After the final crop harvest different organic amendment significantly increased the available phosphorus (P), exchangeable (K), available (S) and available (Zn) in polluted soil. The highest available P (14.67ppm) was found in CD treated plot and lowest (5.03) was observed in control treatment. Among the treatments, TC showed significantly highest soil exchangeable K (0.22 meq/100 g soil) which was statistically similar to CD, VC and RHB. The lowest exchangeable K (0.09 meq/100 g soil) was observed in control plot. The available S content in soil was significantly higher in CDS treated plot (20.86 mg kg^{-1}) followed by CD (20.41 mg kg^{-1}) and VC (19.29 mg kg^{-1}). The lowest S was found in control plot (9.10 mg kg^{-1}). The significantly highest amount of Zn was observed in CDS treated soil having the value 1.13 mg kg^{-1} while the lowest value was found in the control treatment having the value 0.63 mg kg^{-1}.

Table 161. Effect of organic materials on nutrient status of post-harvest soil of T. aman rice 2020

Treatments	Available P (ppm)	Exchangeable K (meq/100g soil)	Available S (ppm)	Available Zn (ppm)
Con	5.19f	0.09d	9.10e	0.63d
CDS	12.73d	0.17bc	20.86a	1.13a
RHB	11.53e	0.21a	17.38c	0.90c
CD	14.64a	0.20ab	20.41ab	1.07ab
VC	12.87d	0.19ab	19.29ab	0.98bc
TC	13.26c	0.23a	18.87bc	0.95c
BI	14.39b	0.15c	12.69d	0.92c
CV (%)	3.02	13.43	6.38	7.39
SE (±)	0.10	0.017	0.764	0.049
$LSD_{(0.05)}$	0.22	0.035	1.606	0.103

Con = control, CDS= cowdung slurry, RHB = rice husk biochar, CD = cow dung, VC = vermicompost, TC =trico-compost and BI= bacteria inoculant

8.1 Expt. VII. Impact of different organic materials on crop productivity in Rice-Rice cropping pattern in the climate vulnerable arsenic contaminated area of Faridpur sadar, saline areas of Batiaghata and heavy metal polluted areas of Bhaluka using different organic amendments (Under objective III).

Figure 159. Field experiment of Boro rice 2019 in as contaminated area of Faridpur Sadar

The effects of different organic amendment treatments on straw yield of Boro (t/ha) rice during 2019 and 2020 in arsenic contaminated soil are presented in Figure 36. In Boro season, the straw yield remarkably influenced by different treatments. During 2019 the straw yields of Boro rice ranged from 4.87 to 7.52 t/ha. The maximum straw yield was 7.52 t/ha in the T_4 treatment which was statistically similar to all other treatments except T_1. While the lowest yield (4.87 t/ha) was recorded in T_1 treatment. Meanwhile, during 2020 the straw yields of Boro rice ranged from 4.76 to 7.51 t/ha. The maximum straw yield was 7.51 t/ha in the T_4 treatment which was statistically similar to all other treatments except T_1. While the lowest yield (4.76 t/ha) was recorded in T_1 treatment. After two years the straw yields in T_4 treatment of Boro season were increased by 37% over control treatment. The results revealed the positive influence of organic manure addition along with recommended fertilizer application on rice yields.

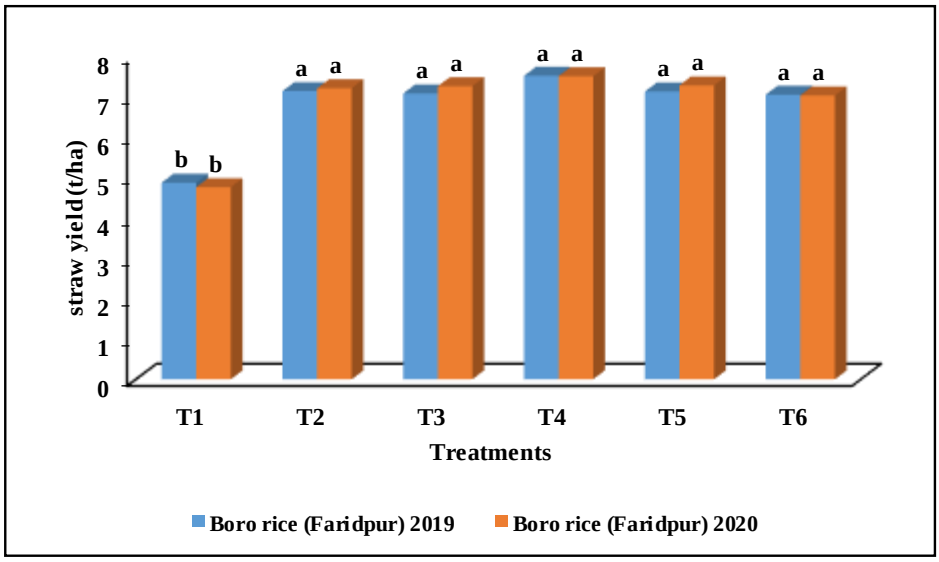


Figure 160. Effects of organic and inorganic fertilizers on straw yields of Boro (t/ha) rice during 2019 and 2020 in Faridpur research field. T_1 = Control, T_2 = Recommended Fertilizer, T_3 = Biochar + Recommended Fertilizer, T_4 = Poultry Manure + Chemical Fertilizer, T_5 = Vermicompost + Chemical Fertilizer, T_6 = Standard Organic Fertilizer + Chemical Fertilizer

The effects of different treatments on grain yield of Boro rice during 2019 and 2020 in arsenic contaminated soil are presented in Figure 37. In both of the seasons, the grain yield remarkably increased by different treatments. The grain yield of Boro rice was ranged from 4.01 to 6.35 t/ha and 3.93 to 6.35 t/ha during the year 2019 and 2020 respectively. The maximum grain yield was found in the T_4 treatment representing the data 6.31 t/ha in 2019 and 6.35 t/ha in 2020. While the lowest yield was recorded in T_1 treatment maintaining a data of 4.01 t/ha and 3.93 t/ha in the year 2019 and 2020 respectively. The average grain yield in T_4 treatment in the both seasons were increased by 38% over control treatment. The results revealed the positive influence of organic manure addition on rice yields.

The effects of different treatments on straw yield of T. aman rice during 2019 and 2020 in arsenic contaminated soil are presented in Figure 38. In both of the seasons, the straw yield remarkably increased by different treatments. The straw yield of T. aman rice was ranged from 4.25 to 6.52 t/ha and 4.24 to 6.48 t/ha during the year 2019 and 2020 respectively. The maximum straw yield was found in the T_4 treatment representing the data 6.52 t/ha in 2019 and 6.48 t/ha in 2020. While the lowest yield was recorded in T_1 treatment maintaining a data of 4.25 t/ha and 4.24 t/ha in the year 2019 and 2020 respectively. The average straw yield in T_4 treatment in the both seasons were increased by 35% over control treatment. The results revealed the positive influence of organic manure addition on rice straw yields.

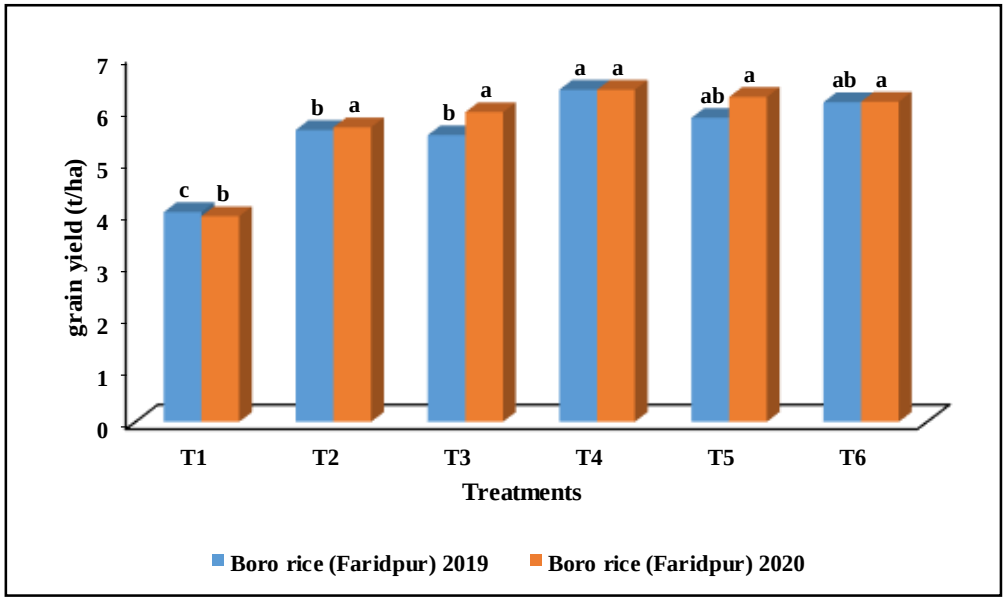


Figure 161. Effects of organic and inorganic fertilizers on grain yields of Boro (t/ha) rice during 2019 and 2020 in Faridpur research field. T_1 = Control, T_2 = Recommended Fertilizer, T_3 = Biochar + Recommended Fertilizer, T_4 = Poultry Manure + Chemical Fertilizer, T_5 = Vermicompost + Chemical Fertilizer, T_6 = Standard Organic Fertilizer + Chemical Fertilizer

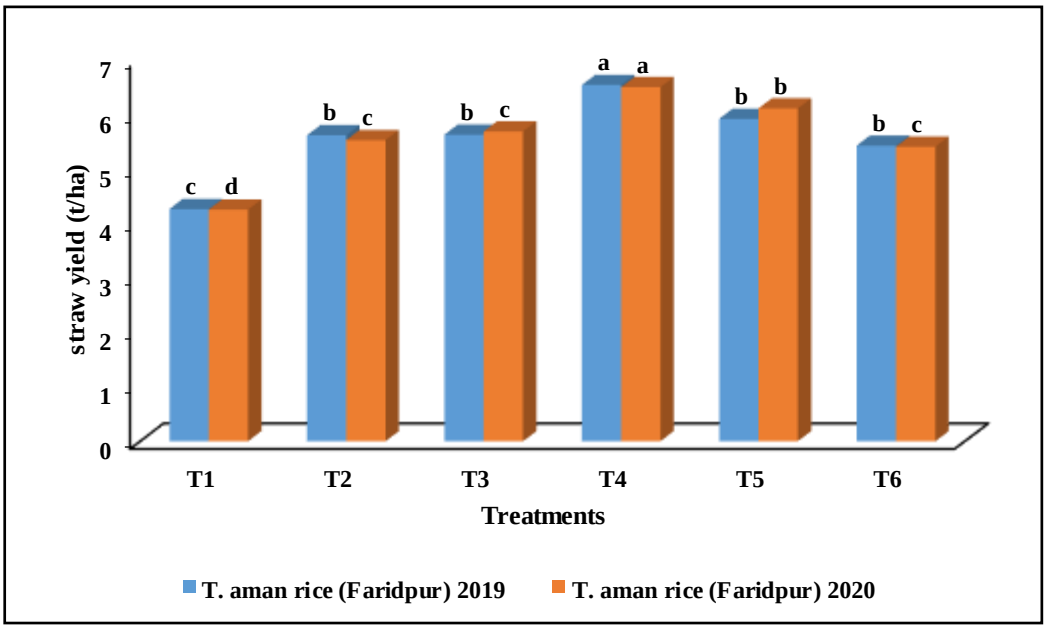


Figure 162. Effects of organic and inorganic fertilizers on straw yields (t/ha) of T. aman during 2019 and 2020 in Faridpur research field. T_1 = Control, T_2 = Recommended Fertilizer, T_3 = Biochar + Recommended Fertilizer, T_4 = Poultry Manure + Chemical Fertilizer, T_5 = Vermicompost + Chemical Fertilizer, T_6 = Standard Organic Fertilizer + Chemical Fertilizer

Figure 39 represent the effects of different treatments on grain yield of T. aman rice during 2019 and 2020 in arsenic contaminated soil. Addition of different organic amendment had a significant positive change in grain yield in both of the seasons. The grain yield of T. aman rice was ranged from 3.27 to 5.06 t/ha and 3.56 to 5.31 t/ha during the year 2019 and 2020 respectively. The maximum grain yield was found in the T_4 treatment representing the data 5.06 t/ha in 2019 and 5.31 t/ha in 2020. While the lowest yield was recorded in T_1 treatment maintaining a data of 3.27 t/ha and 3.56 t/ha in the year 2019 and 2020 respectively. The average grain yield in T_4 treatment in the both seasons were increased by 33% over control treatment. The results revealed the positive influence of organic manure addition on rice yields.

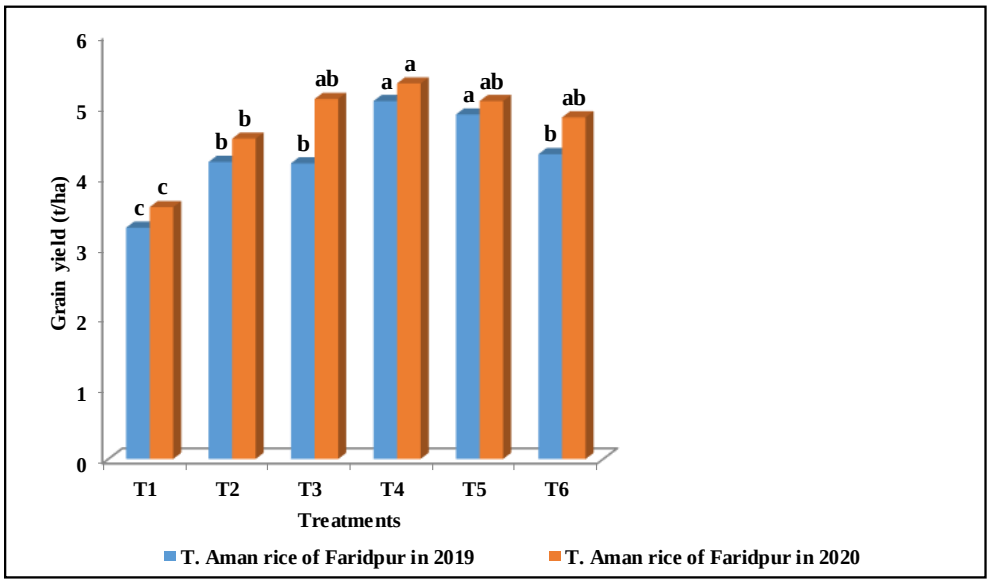


Figure 163. Effects of organic and inorganic fertilizers on grain yields (t/ha) of T. aman rice during 2019 and 2020 in Faridpur research field. T_1 = Control, T_2 = Recommended Fertilizer, T_3 = Biochar + Recommended Fertilizer, T_4 = Poultry Manure + Chemical Fertilizer, T_5 = Vermicompost + Chemical Fertilizer, T_6 = Standard Organic Fertilizer + Chemical Fertilizer

Figure 164. Field experiment of T. aman rice 2019 in saline area of Batiaghata, Khulna

Straw yield of T. aman rice in arsenic contaminated soil during 2019 and 2020 remarkably increased by different treatments (Figure 165). The straw yield of T. aman rice was ranged from 4.22 to 6.49 t/ha and 4.32 to 6.51 t/ha during the year 2019 and 2020 respectively. The maximum straw yield was found in the T_4 treatment representing the data 6.49 t/ha in 2019 and 6.51 t/ha in 2020. While the lowest yield was recorded in T_1 treatment maintaining a data of 4.22 t/ha and 4.32 t/ha in the year 2019 and 2020 respectively. The average straw yield in T_4 treatment in the both seasons were increased by 34% over control treatment. The results revealed the positive influence of organic manure addition on rice straw yields.

Figure 42 represent the effects of different treatments on grain yield of T. aman rice during 2019 and 2020 in salt-affected soil. Addition of different organic amendment had a significant positive change in grain yield in both of the seasons. The grain yield of T. aman rice was ranged from 3.37 to 5.39 t/ha and 3.35 to 5.41 t/ha during the year 2019 and 2020 respectively. The maximum grain yield was found in the T_4 treatment representing the data 5.39 t/ha in 2019 and 5.41 t/ha in 2020. While the lowest yield was recorded in T_1 treatment maintaining a data of 3.37 t/ha and 3.35 t/ha in the year 2019 and 2020 respectively. The average grain yield in T_4 treatment in the both seasons were increased by 38% over control treatment. The results revealed the positive influence of organic manure addition on rice yields.

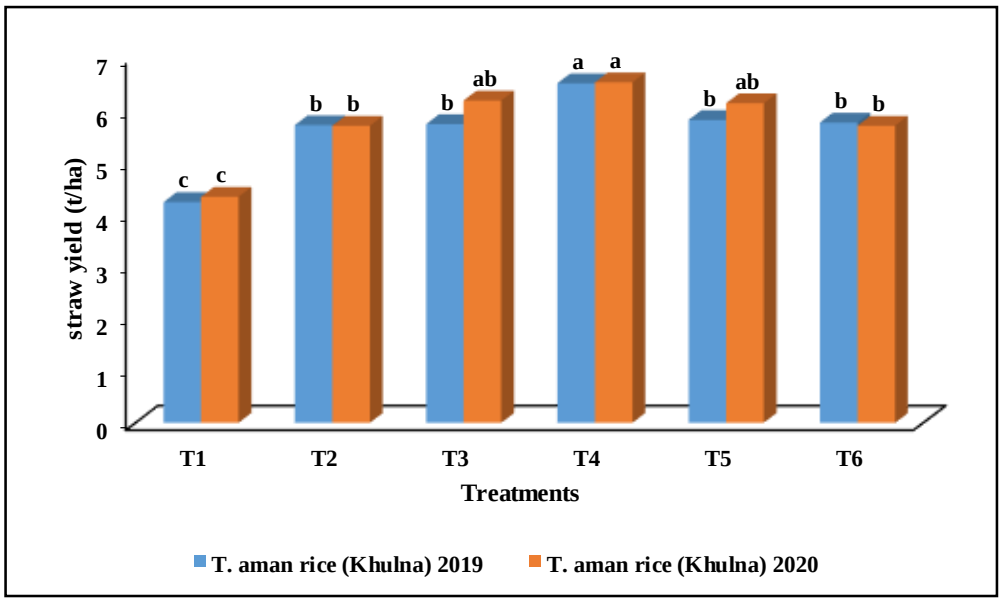


Figure 165. Effects of organic and inorganic fertilizers on straw yield of T. aman (t/ha) rice during 2019 and 2020 in Khulna research field. T_1 = Control, T_2 = Recommended Fertilizer, T_3 = Biochar + Recommended Fertilizer, T_4 = Poultry Manure + Chemical Fertilizer, T_5 = Vermicompost + Chemical Fertilizer, T_6 = Standard Organic Fertilizer + Chemical Fertilizer

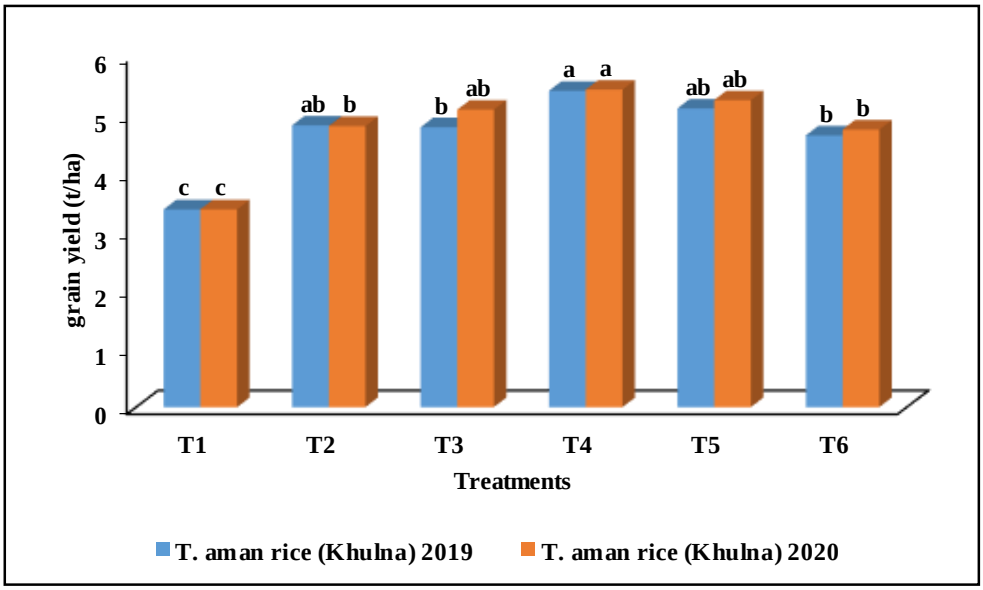


Figure 166. Effects of organic and inorganic fertilizers on grain yields of T. aman (t/ha) rice during 2019 and 2020 in Khulna research field. T_1 = Control, T_2 = Recommended Fertilizer, T_3 = Biochar + Recommended Fertilizer, T_4 = Poultry Manure + Chemical Fertilizer, T_5 = Vermicompost + Chemical Fertilizer, T_6 = Standard Organic Fertilizer + Chemical Fertilizer

Figure 167. Field experiment of T. aman in Heavy metal polluted area of Bhaluka

Straw yield of Boro rice in heavy metal polluted soil during 2019 remarkably increased by different treatments (Figure 168). The straw yield of Boro rice was ranged from 4.53 to 7.35 t/ha during the year 2019. The maximum straw yield was found in the T_4 treatment representing the data 7.35 t/ha in 2019. While the lowest yield was recorded in T_1 treatment maintaining a data of 4.53 t/ha in the year 2019. On the other hand, the Boro rice during 2020 the straw yields were missing due to COVID-19.

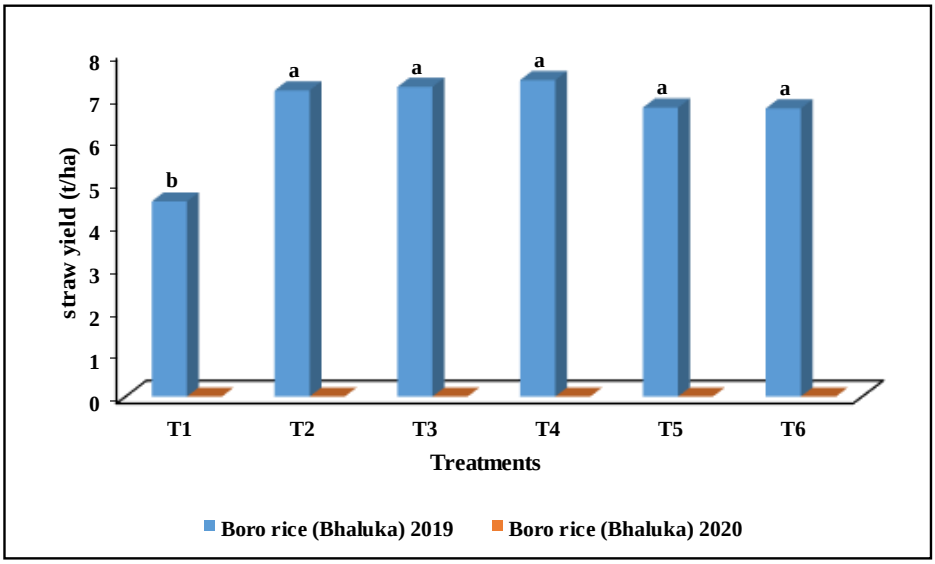


Figure 168. Effects of organic and inorganic fertilizers on straw yields of Boro (t/ha) rice during 2019 and 2020 in Bhaluka research field. T_1 = Control, T_2 = Recommended Fertilizer, T_3 = Biochar + Recommended Fertilizer, T_4 = Poultry Manure + Chemical Fertilizer, T_5 = Vermicompost + Chemical Fertilizer, T_6 = Standard Organic Fertilizer + Chemical Fertilizer

Grain yield of Boro rice in heavy metal polluted soil during 2019 remarkably increased by different treatments (Figure 169). The grain yield of Boro rice was ranged from 3.59 to 6.25 t/ha during the year 2019. The maximum grain yield was found in the T_4 treatment representing the data 6.25 t/ha in 2019. While the lowest yield was recorded in T_1 treatment maintaining a data of 3.59 t/ha in the year 2019. But, the Boro rice during 2020 the grain yields were missing due to COVID-19.

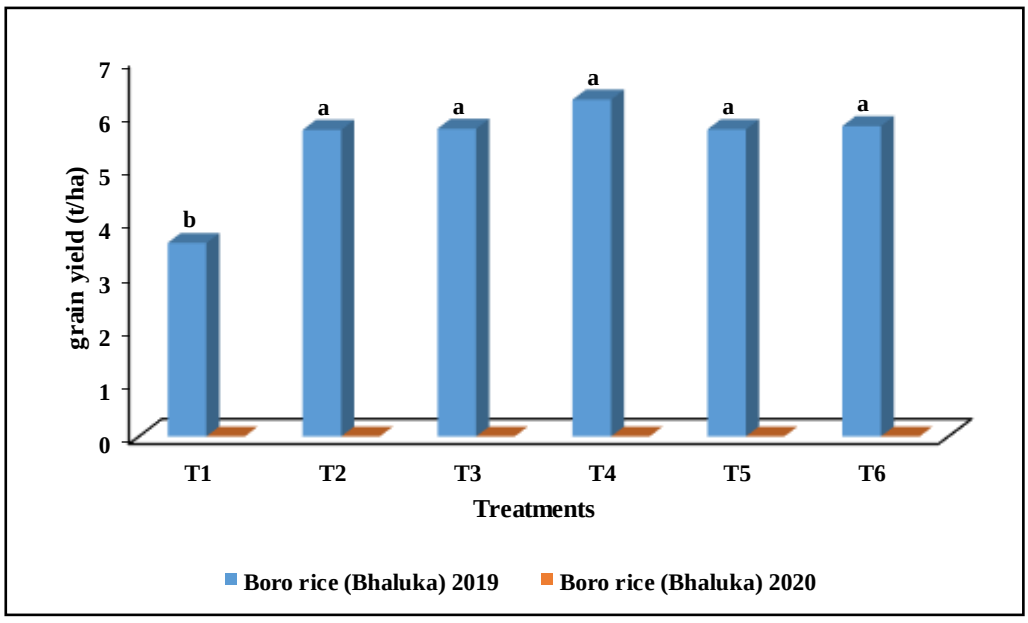


Figure 169. Effects of organic and inorganic fertilizers on grain yields of Boro (t/ha) rice during 2019 and 2020 in Bhaluka research field. T_1 = Control, T_2 = Recommended Fertilizer, T_3 = Biochar + Recommended Fertilizer, T_4 = Poultry Manure + Chemical Fertilizer, T_5 = Vermicompost + Chemical Fertilizer, T_6 = Standard Organic Fertilizer + Chemical Fertilizer

Straw yield of T. aman rice in heavy metal polluted soil during 2019 and 2020 remarkably increased by different treatments (Figure 170). The straw yield of T. aman rice was ranged from 4.16 to 6.50 t/ha and 3.90 to 6.52 t/ha during the year 2019 and 2020 respectively. The maximum straw yield was found in the T_4 treatment representing the data 6.50 t/ha in 2019 and 6.52 t/ha in 2020. While the lowest yield was recorded in T_1 treatment maintaining a data of 4.16 t/ha and 3.90 t/ha in the year 2019 and 2020 respectively. The average straw yield in T_4 treatment in the both seasons were increased by 40% over control treatment.

Figure 171 represent the effects of different treatments on grain yield of T. aman rice during 2019 and 2020 in heavy metal polluted soil. Addition of different organic amendment had a significant positive change in grain yield in both of the seasons. The grain yield of T. aman rice was ranged from 3.52 to 5.46 t/ha and 3.56 to 5.43 t/ha during the year 2019 and 2020 respectively. The maximum grain yield was found in the T_4 treatment representing the data 5.46 t/ha in 2019 and 5.43 t/ha in 2020. While the lowest yield was recorded in T_1 treatment maintaining a data of 3.52 t/ha and 3.56 t/ha in the year 2019 and 2020 respectively. The average grain yield in T_4 treatment in the both seasons were increased by 34% over control treatment.

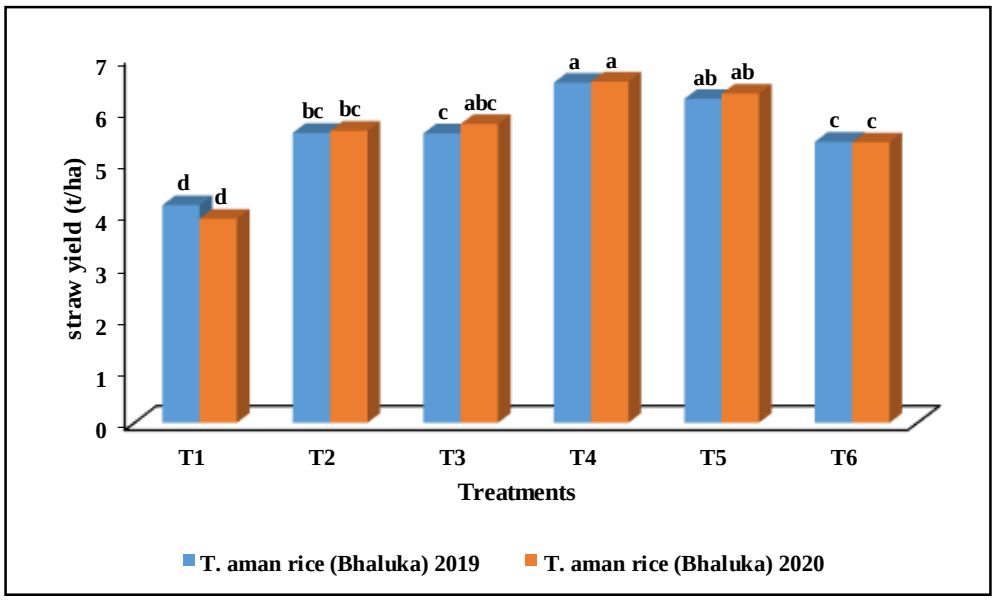


Figure 170. Effects of organic and inorganic fertilizers on straw yields of T. aman (t/ha) rice during 2019 and 2020 in Bhaluka research field. T_1 = Control, T_2 = Recommended Fertilizer, T_3 = Biochar + Recommended Fertilizer, T_4 = Poultry Manure + Chemical Fertilizer, T_5 = Vermicompost + Chemical Fertilizer, T_6 = Standard Organic Fertilizer + Chemical Fertilizer

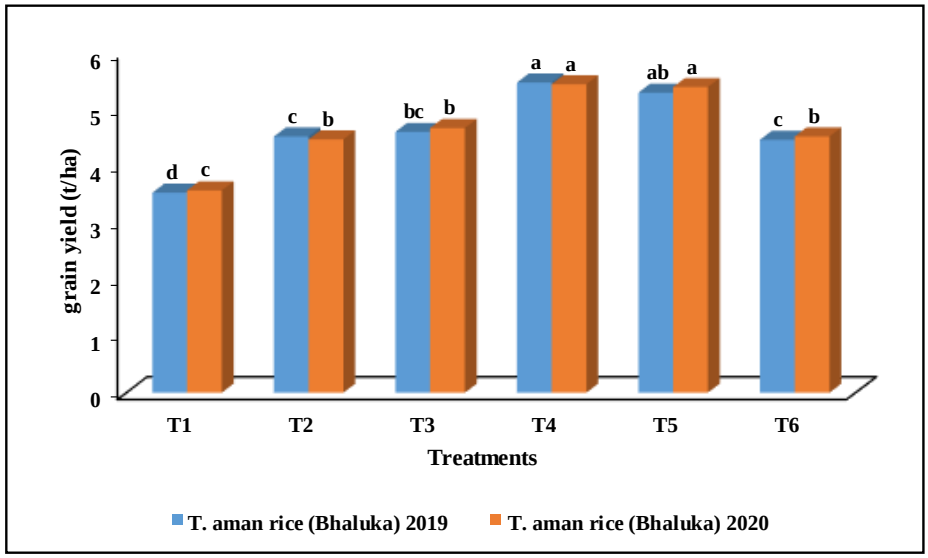


Figure 171. Effects of organic and inorganic fertilizers on grain yields of and T. aman (t/ha) during 2019 and 2020 in Bhaluka research field. T_1 = Control, T_2 = Recommended Fertilizer, T_3 = Biochar + Recommended Fertilizer, T_4 = Poultry Manure + Chemical Fertilizer, T_5 = Vermicompost + Chemical Fertilizer, T_6 = Standard Organic Fertilizer + Chemical Fertilizer

Figure 172. Field experiment of Boro rice 2019 in Bhaluka

Expt. VIII. Soil aggregate stability, storage of organic carbon and caon sequestration in different climate vulnerable soils using different organic materials at Dekar haor areas of Sunamganj, arsenic area of Faridpur sadar, saline areas of Batiaghata and heavy metal polluted areas of Bhaluka (Under objective III).

Dekar haor areas of Sunamganj

8.2 Aggregate stability

For aggregate stability, soil was divided into four different sized viz. 2.0, 1.0, 0.50 and 0.25 mm. Water stables soil aggregates were determined by wet sieving method (Castellanos-Navarette *et al.*, 2013).

8.3 Soil aggregate stability

Soil aggregates of different sized particles indicated that smaller the size more the number stable soil aggregates and such trend is applicable in case of locations (Figure 173) and depths (Figure 174). Particle size of 0.25 mm gave the highest soil aggregates stability in case of location and depth. With the increase of the particle size (i.e. 0.5 mm, 1 mm and 2 mm) the percentage of soil aggregates stability decreased in both the cases of locations and depths. In case of location overall soil aggregate stability was higher in basin soil but in case of depth there were no significant differences. In case of locations, 2 mm sized soil contributed to aggregates stability of 11.86, 12.41 and 14.15% in ridge, middle and basin soils, respectively. On the other hand, 0.25 mm sized soil attributed to soil aggregates stability of 22.63, 25.75 and 31.44% in ridge, middle and basin soils, respectively. Similar results of aggregates stability also appeared in case of soil depths. The results indicated that 0.25 mm sized soil particles are stronger in building soil aggregates and have the potential more than the double of 2 mm sized soils.

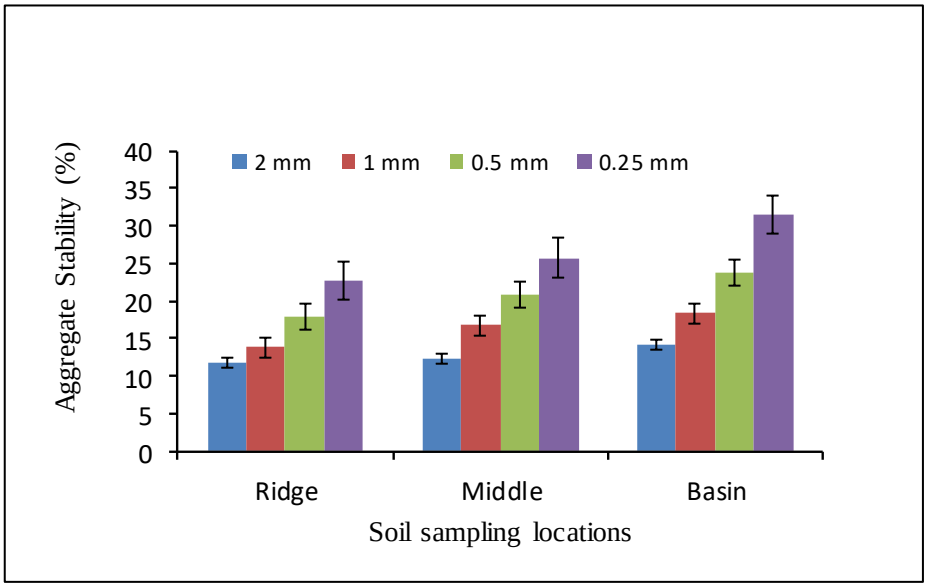


Figure 173. Soil aggregate stability in various locations of Dekar haor

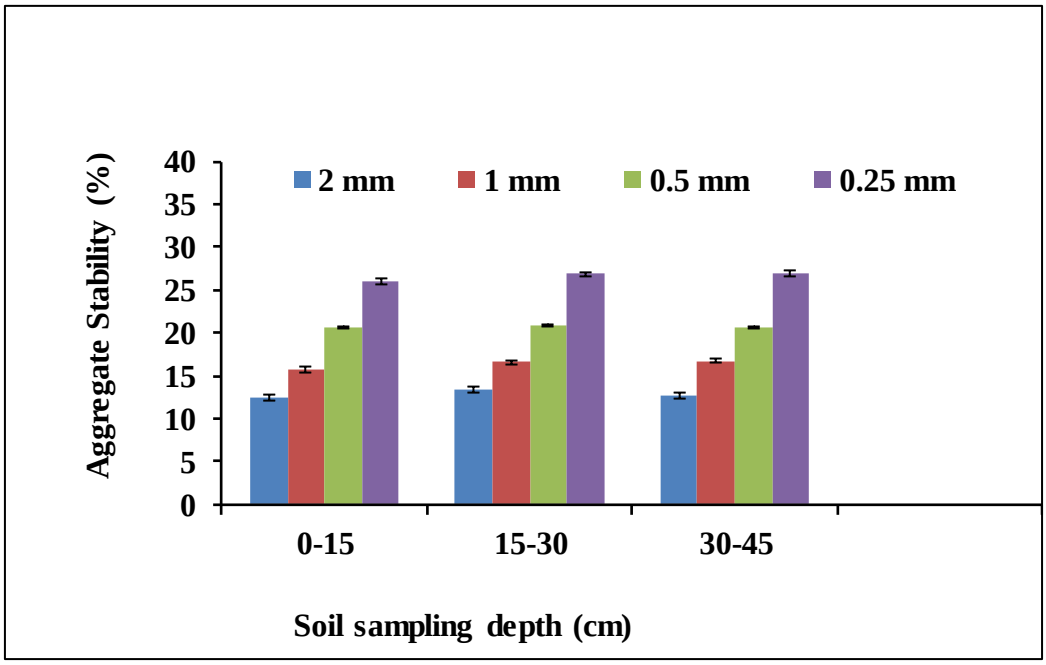


Figure 174. Soil aggregate stability in various depths of Dekar haor

Soil aggregates are vital factor for sustaining soil health and crop productivity. When a group of soil particles adhere more strongly it increases soil aggregates and thereby improves stability of aggregates, which is beneficial for plant growth and development (Roy *et al*., 2019). Such stability in soil aggregates depends not only on OC but also on phosphorus, clay contents and different basic cations present in soils (Rahman and Yakupitiyage, 2006). The soil of Dekar haor contained less OC and P, while high amount of Ca. So, there should be an adjustment of formation of soil aggregates among OC, P and Ca. Soil OC in agricultural soils has the greatest potential to improve soil aggregates and thus soil health. Clay and OM act as glues to form soil aggregates and exhibit stronger soil aggregation. The OC content in soils of Bangladesh is low because of quicker microbial decomposition of OM influenced by high temperature and moisture and also as a consequence of application of high doses of inorganic fertilizer application (FRG, 2018; Rahman, 2013).

Carbon stock: Carbon stock was calculated by using following formula (Rahman *et al*., 2016)

Carbon stock (t ha^{-1}) = Carbon concentration (%) × bulk density (g cc^{-1}) × depth (cm)

Carbon stock

Carbon stock was found higher in basin soil which was 17.56 t ha^{-1} (Fig. 50). In ridge and middle soil C stocks were 12.56 and 17 t ha^{-1}, respectively. In case of depth, C stocks were higher in 0-15 cm depth (17.23 t ha^{-1}), followed by 15-30 cm (14.81 t ha^{-1}) and 30-45 cm (14.08 t ha^{-1}) (Figure. 51). The haor soils under the present study contained lower amount of soil C, which attributed to lower C stocks.

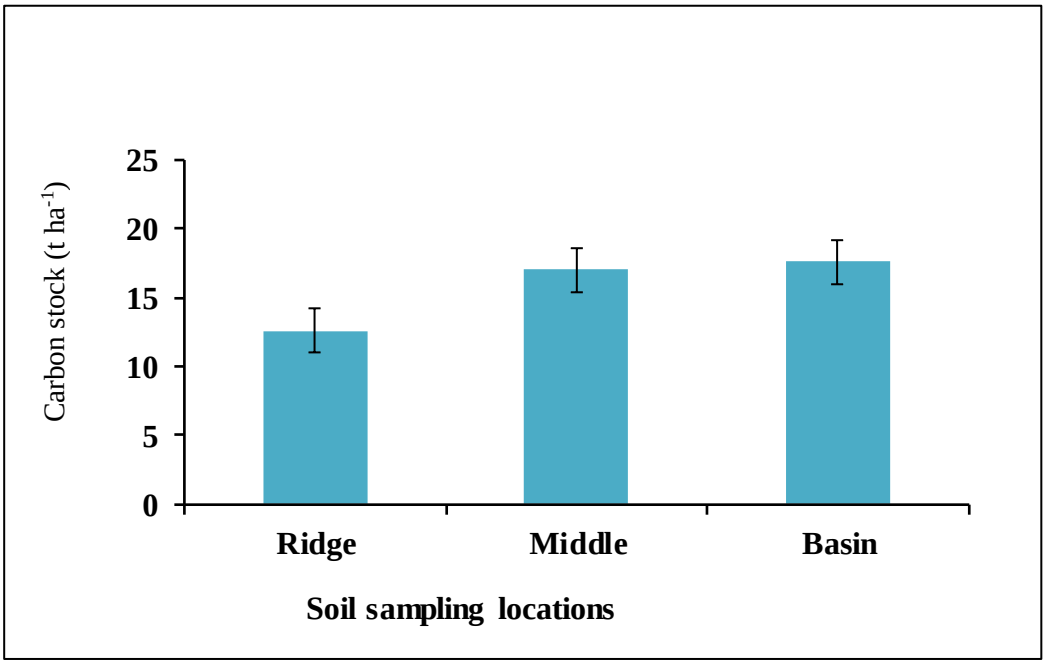


Figure 175. Carbon stock in various locations of Dekar haor

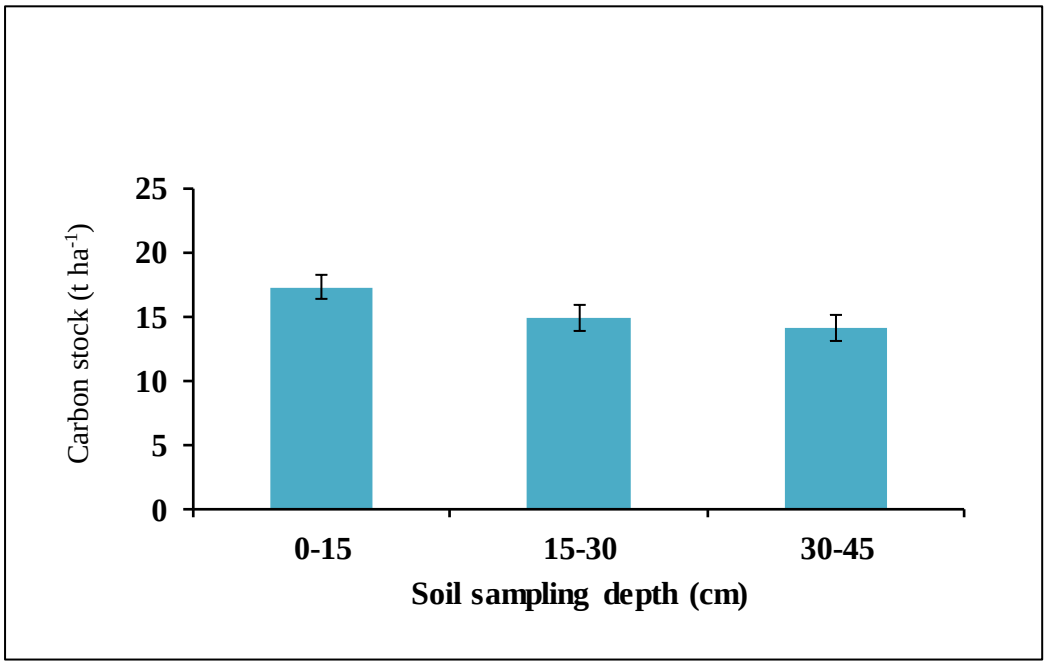


Figure 176. Carbon stock in various depths of Dekar haor

It was mentioned earlier that a good soil should contain at least 1.16% OC. Thus, a soil having OC content of 1.16%, bulk density 1.36 g c.c.$^{-1}$ (bulk density of ridge soil) and a depth of 15 cm (top soil) should contribute to a C stock of 23.67 t ha^{-1}. This indicated that the existing carbon stock in soils of Dekar haor is almost half of marginally good soil for agriculture. It is not easy to increase C contents and maintain a handsome C stock in soils under tropical and sub-tropical climatic conditions, where mineralization of soil OM is faster. However, attempts need to be taken for a continuous supply of organic materials to crop fields using the locally available resources to replenish OM level in soils.

Arsenic area of Faridpur sadar

Soil aggregates of different sized particles indicated that smaller the size more the number stable soil aggregates (Figure. 177). Particle size of 0.25 mm gave the highest soil aggregates stability in arsenic contaminated soil. With the increase of the particle size (i.e., 0.5 mm, 1 mm and 2 mm) the percentage of soil aggregates stability decreased. Addition of different organic materials had a significant positive effect on all aggregate fractionations (i.e.,0.25mm, 0.5 mm, 1 mm and 2 mm) of soil. Among the amending substances, biochar treated soil gave the maximum aggregate stability (19.75%, 23.61%, 24.07% and 31.40% in 2mm, 1mm, 0.5mm and 0.25mm) and the lowest in control treatment (14.89%, 15.19%, 17.22% and 20.76% in 2mm, 1mm, 0.5mm and 0.25mm).

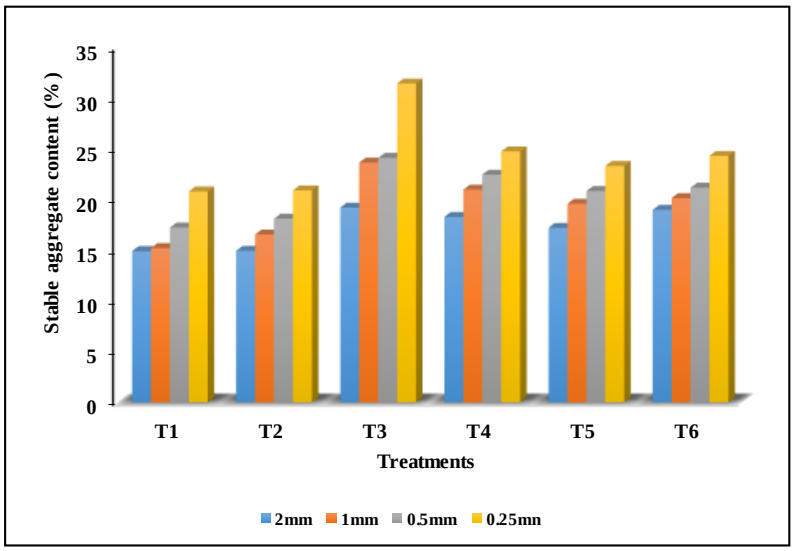


Figure 177. Effect of different organic matters on Soil Stable aggregate content (%) of the Faridpur experimental site. T_1 = Control, T_2 = Recommended Fertilizer, T_3 = Biochar + Recommended Fertilizer, T_4 = Poultry Manure + Chemical Fertilizer, T_5 = Vermicompost + Chemical Fertilizer, T_6 = Standard Organic Fertilizer + Chemical Fertilizer

8.4 Post-harvest soil Carbon sequestration

After three years continuous application of different organic fertilizers a significant positive change of soil carbon sequestration was observed in arsenic contaminated soil (Table 162). The soil carbon sequestration was ranged from 10.08 to 12.56 (t/ha). The significantly highest soil carbon sequestration (12.56t/ha) was found in the T_3 treatment. The lowest soil carbon sequestration (10.08t/ha) was noted in T_1 treatment.

Table 162. Effect of different organic matters on post-harvest soil Carbon sequestration (t/ha) of the arsenic contaminated soil Faridpur

Treatments	Carbon sequestration (t/ha)
T_1	10.08c
T_2	10.44bc
T_3	12.56a
T_4	11.94ab
T_5	11.53abc
T_6	11.39abc
CV (%)	9.62
SE (±)	0.77

T_1 = Control, T_2 = Recommended Fertilizer, T_3 = Biochar + Recommended Fertilizer, T_4 = Poultry Manure + Chemical Fertilizer, T_5 = Vermicompost + Chemical Fertilizer, T_6 = Standard Organic Fertilizer + Chemical Fertilizer

Saline areas of Batiaghata

8.5 Post-harvest soil stable aggregate content (%)

Soil aggregates of different sized particles indicated that smaller the size more the number stable soil aggregates (Figure. 178). Particle size of 0.25 mm gave the highest soil aggregates stability in arsenic contaminated soil. With the increase of the particle size (i.e., 0.5 mm, 1 mm and 2 mm) the percentage of soil aggregates stability decreased. Addition of different organic materials had a significant positive effect on all aggregate fractionations (i.e.,0.25mm, 0.5 mm, 1 mm and 2 mm) of soil. Among the amending substances, biochar treated soil gave the maximum aggregate stability (19.74%, 22.62%, 24.47% and 31.28% in 2mm, 1mm, 0.5mm and 0.25mm) and the lowest in control treatment (14.04%, 16.25%, 18.67% and 21.82% in 2mm, 1mm, 0.5mm and 0.25mm).

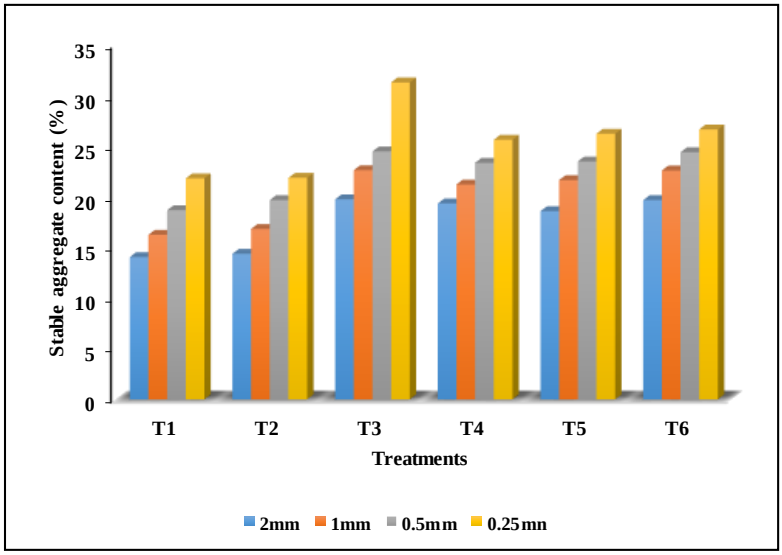


Figure 178. Effect of different organic matters on Soil Stable aggregate content (%) of the Khulna experimental site. T_1 = Control, T_2 = Recommended Fertilizer, T_3 = Biochar + Recommended Fertilizer, T_4 = Poultry Manure + Chemical Fertilizer, T_5 = Vermicompost + Chemical Fertilizer, T_6 = Standard Organic Fertilizer + Chemical Fertilizer

8.6 Post-harvest soil Carbon sequestration

After three years continuous application of different organic fertilizers a significant positive change of soil carbon sequestration was observed in saline affected soil (Table 163). The soil carbon sequestration was ranged from 6.81 to 8.76 (t/ha). The significantly highest soil carbon sequestration (8.76t/ha) was found in the T_3 treatment. The lowest soil carbon sequestration (6.81t/ha) was noted in T_1 treatment.

Table 163. Effect of different organic matters on post-harvest soil Carbon sequestration (t/ha) of the selected experimental site of Khulna

Treatments	Carbon sequestration (t/ha)
T_1	6.81c
T_2	7.77b
T_3	8.76a
T_4	8.39ab
T_5	8.02ab
T_6	7.93b
CV (%)	6.56
SE (±)	0.36

T_1 = Control, T_2 = Recommended Fertilizer, T_3 = Biochar + Recommended Fertilizer, T_4 = Poultry Manure + Chemical Fertilizer, T_5 = Vermicompost + Chemical Fertilizer, T_6 = Standard Organic Fertilizer + Chemical Fertilizer

Heavy metal polluted areas of Bhaluka

8.7 Effect of organic materials on aggregate stability in different soil particle

Soil aggregates of different sized particles indicated that smaller the size more the number stable soil aggregates (Figure 179). Particle size of 0.25 mm gave the highest soil aggregates stability in arsenic contaminated soil. With the increase of the particle size (i.e. 0.5 mm, 1 mm and 2 mm) the percentage of soil aggregates stability decreased. Addition of different organic materials had a significant positive effects on all aggregate fractionations (i.e.0.25mm, 0.5 mm, 1 mm and 2 mm) of soil. Among the amending substances, biochar treated soil gave the maximum aggregate stability (18.74%, 21.62%, 23.47% and 33.23% in 2mm, 1mm, 0.5mm and 0.25mm) and the lowest in control treatment (14.04%, 17.25%, 18.67% and 20.82% in 2mm, 1mm, 0.5mm and 0.25mm).

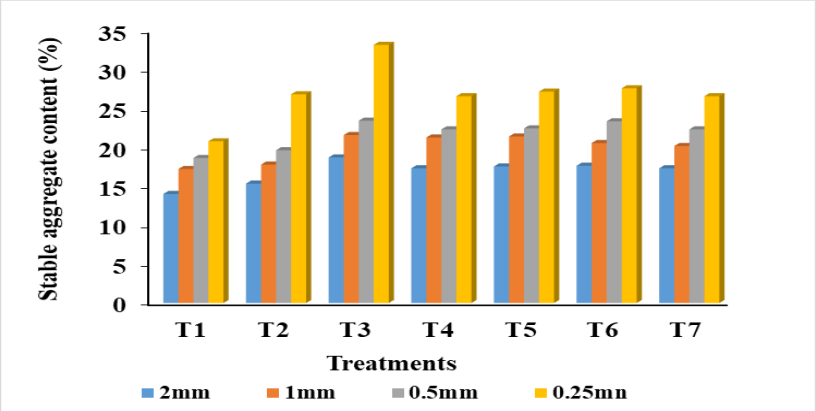


Figure 179. Aggregate stability of harvest soil samples under different organic materials applied plots in industrial polluted soil. Con = control, CDS= cowdung slurry, RHB = rice husk biochar, CD = cow dung, VC = vermicompost, TC =trico-compost and BI= bacteria inoculant.

Carbon stock and C sequestration will be calculated using the following equation 1 and 2, respectively (Rahman et al., 2016).

Carbon stock (t ha^{-1}) = Carbon concentration (%) x bulk density (g cm^{-3}) x depth (cm) ….. (1)

Carbon sequestration (t ha^{-1}) = Final C stock (t ha^{-1}) – Initial C stock (t ha^{-1}) …….. (2)

8.8 Effect of organic materials on bulk density, carbon stock and carbon sequestration

Effect of different organic materials on soil organic carbon, bulk density, carbon stock and carbon sequestration at post-harvest T. aman rice are presented in Table 164. Different organic fertilizers had a significant positive effect on carbon sequestration in heavy metal polluted soil. The soil carbon sequestration was ranged from 0.38 to 4.05 (t/ha).

Table 164. Effect of organic materials and chemical fertilizers on soil bulk density, carbon stock and carbon sequestration after T. aman rice

Treatment	Initial Soil			Final Soil			C sequestration (t ha^{-1})
	OC (%)	BD (g c.c^{-1})	CS (t ha^{-1})	OC (%)	BD (g c.c^{-1})	CS (t ha^{-1})	
Control	0.93	1.38	19.25	0.95d	1.39a	19.63d	0.38d
CDS	0.93	1.38	19.25	1.09b	1.32bc	21.57b	2.32b
RHB	0.93	1.38	19.25	1.19a	1.31c	23.30a	4.05a
CD	0.93	1.38	19.25	1.02c	1.30c	20.00cd	0.75cd
VC	0.93	1.38	19.25	1.04c	1.35abc	21.11b	1.86b
TC	0.93	1.38	19.25	1.04c	1.33abc	20.71bc	1.45bc
BI	0.93	1.38	19.25	0.97d	1.38ab	20.05cd	0.80cd
CV (%)	--	--	--	2.73	3.22	3.21	7.56
SE (±)	--	--	--	0.02	0.03	0.47	0.47
LSD $_{(0.05)}$	--	--	--	0.04	0.06	0.99	0.99

CDS= cowdung slurry, RHB= rice husk biochar, CD= cowdung, VC= vermicompost, TC= Trico-compost, BI = bacteria inoculant, BD= bulk density, CS= carbon stock, C sequestration = carbon sequestration

The significantly highest soil carbon sequestration (4.05 t/ha) was found in the RHB treated soil. The lowest soil carbon sequestration (0.38t/ha) was noted in control treatment. Carbon sequestration among the different treatments followed in the order of RHB (4.05 t/ha)>CDS (2.32 t/ha)>VC (1.86 t/ha)>TC (1.45 t/ha)> BI (0.80 t/ha)>CD (0.75 t/ha)>Control (0.38 t/ha).

SAU component

Activity 1: Base line survey to characterize biological, physical and chemical properties of soil in the selected study areas.

- Base line survey was conducted in saline soils of KalaparaUpazila under Patuakhali district.
- Base line soil samples were collected in the month of September 2018.
- All soil samples were analyzed for biological, physical and chemical properties.
- Site for the experiment was selected on the basis of salinity data of base line survey.
- Initial soil was collected from the experimental plots from 3 soil depth (0-15, 15-30 and 30-45 cm) for physical, chemical and biological analysis.

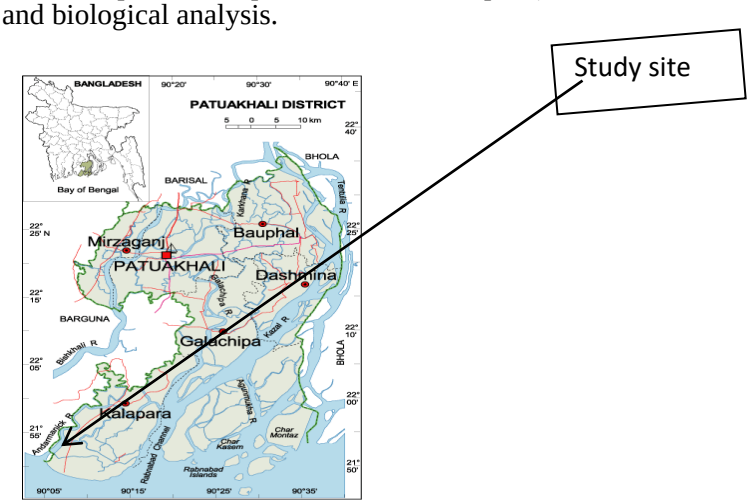


Fig. 180. Map of Kalapara Upazila

Table 165. Chemical properties of collected soil samples of base line survey

Sample number	pH	EC (dS/m)	Total nitrogen (%)	Available P (ppm)	Ex. Na (meq/100g)	Ex. K (meq/100g)	Avail.S (ppm)	OC (%)
1*	**6.25**	**5.12**	**0.09**	**20.12**	**16.47**	**0.16**	**20.21**	**1.10**
2	6.93	3.30	0.11	22.21	11.74	0.21	25.45	1.15
3	7.12	3.79	0.10	20.33	13.96	0.18	24.31	1.11
4	6.69	3.65	0.12	25.12	11.74	0.20	28.12	1.21
5	6.66	3.25	0.11	21.32	10.65	0.22	26.33	1.16
6	5.21	3.99	0.09	20.22	14.20	0.19	29.34	1.11
7	6.46	3.13	0.11	22.11	9.22	0.23	32.35	1.13
8	6.56	3.69	0.12	29.12	11.78	0.21	30.92	1.22
9	6.91	3.47	0.10	26.15	10.35	0.25	31.12	1.11
10	6.18	3.77	0.11	28.31	13.43	0.20	20.55	1.14
11	6.34	3.96	0.11	26.12	14.00	0.18	21.22	1.11
12	5.64	3.94	0.12	30.11	13.96	0.19	21.26	1.17
13	6.54	3.10	0.11	24.44	9.83	0.26	30.12	1.12
14	6.92	4.56	0.10	21.11	14.28	0.22	33.08	1.10
15	6.17	3.85	0.12	29.16	13.09	0.18	23.21	1.21
16**	**6.52**	**3.82**	**0.11**	**23.91**	**13.65**	**0.19**	**27.52**	**1.15**
17	6.94	3.84	0.12	28.41	12.96	0.18	29.13	1.23
18	6.78	3.95	0.11	30.11	14.28	0.17	33.11	1.16
19	6.81	3.92	0.12	32.10	14.15	0.18	32.10	1.20
20	6.54	4.20	0.13	33.09	14.42	0.16	33.21	1.21
21	6.36	3.26	0.12	30.13	11.09	0.21	31.55	1.19
22	5.35	3.77	0.11	24.31	12.96	0.18	29.33	1.18
23	5.55	3.32	0.11	23.98	11.49	0.22	30.12	1.14
24	5.93	3.49	0.11	22.90	12.35	0.21	28.45	1.15
25	6.54	3.36	0.12	29.40	11.78	0.18	30.33	1.19
26**	**6.04**	**4.82**	**0.11**	**22.32**	**14.49**	**0.18**	**24.82**	**1.13**
27	5.80	3.25	0.11	23.10	10.52	0.27	27.13	1.17
28	5.06	3.38	0.12	30.40	11.78	0.25	32.44	1.24
29	5.32	3.53	0.11	28.12	11.96	0.22	30.33	1.20
30	6.12	3.64	0.10	23.45	12.83	0.23	27.12	1.12
Range	5.06-7.12	3.10-5.12	0.09-0.13	20.12-33.09	9.22-16.47	0.16-0.27	20.21-33.21	1.10-1.24

*Experimental field-1 (Nilgonj union)** Experimental field-2 (Latachapli union)
Sample no. 1-15 from Nilgonj union and 16-30 from Latachapli union.

Fig. 181. Analysis of soil samples

Table 166. Physical properties of collected soils for base line survey

Sample number	Textural class	Bulk density (g/cm^3)	Particle density (g/cm^3)	Porosity (%)
1*	**Silty clay**	**1.47**	**2.49**	**40.96**
2	Silty clay	1.31	2.39	45.19
3	Silty clay	1.32	2.38	44.54
4	Silty clay	1.40	2.45	42.86
5	Silty clay	1.35	2.41	43.98
6	Silty clay	1.32	2.41	45.23
7	Silty clay	1.41	2.42	41.74
8	Silty clay	1.35	2.39	43.51
9	Silty clay	1.33	2.38	44.12
10	Silty clay	1.32	2.37	44.30
11	Silty clay	1.42	2.43	41.56
12	Silty clay	1.30	2.31	43.72
13	Silty clay	1.33	2.39	44.35
14	Silty clay	1.38	2.41	42.74
15	Silty clay	1.34	2.40	44.17
16**	**Silty clay**	**1.30**	**2.41**	**46.06**
17	Silty clay	1.35	2.42	44.21
18	Silty clay	1.31	2.40	45.42
19	Silty clay	1.32	2.41	45.23
20	Silty clay	1.31	2.35	44.26
21	Silty clay	1.32	2.41	45.23
22	Silty clay	1.36	2.43	44.03
23	Silty clay	1.31	2.40	45.42
24	Silty clay	1.33	2.42	45.04
25	Silty clay	1.30	2.39	45.61
26**	**Silty clay**	**1.32**	**2.40**	**45.00**
27	Silty clay	1.30	2.40	45.83

Sample number	Textural class	Bulk density (g/cm^3)	Particle density (g/cm^3)	Porosity (%)
28	Silty clay	1.30	2.39	45.61
29	Silty clay	1.35	2.41	43.98
30	Silty clay	1.31	2.40	40.96
Range		1.30-1.47	2.31-2.49	40.96-46.06

Table 167. Biological properties of collected soils for base line survey

Sample number	Rhizobium**(CFU/g)**	Azotobacter**(CFU/g)**	Phosphate Solubilizing Bacteria **(CFU/g)**
1*	**2.17×10^9**	**1.66×10^9**	**1.22×10^8**
2	1.90×10^7	1.37×10^7	7.80×10^6
3	1.72×10^9	2.42×10^9	1.55×10^8
4	1.56×10^9	1.22×10^9	2.62×10^7
5	2.45×10^9	2.10×10^8	2.50×10^6
6	1.43×10^7	1.38×10^7	1.02×10^7
7	1.06×10^9	1.92×10^9	7.80×10^7
8	2.38×10^9	2.1×10^9	8.50×10^7
9	2.28×10^8	1.18×10^9	1.67×10^8
10	1.83×10^9	1.55×10^7	1.72×10^7
11	2.90×10^8	1.64×10^7	6.80×10^6
12	1.68×10^9	3.33×10^7	1.55×10^8
13	1.93×10^9	2.02×10^8	5.55×10^6
14	1.77×10^9	1.92×10^8	1.04×10^9
15	1.98×10^9	3.10×10^7	2.50×10^8
16**	**2.08×10^8**	**2.18×10^9**	**1.38×10^8**
17	1.67×10^8	1.88×10^7	2.02×10^6
18	1.89×10^7	1.42×10^7	7.80×10^6
19	1.32×10^9	1.42×10^9	1.85×10^8
20	1.36×10^9	1.92×10^8	1.8×10^8
21	2.88×10^9	3.10×10^8	6.50×10^7
22	1.44×10^9	1.18×10^9	1.08×10^9
23	1.86×10^9	1.22×10^9	1.80×10^9
24	1.93×10^7	1.58×10^7	1.02×10^7
25	2.10×10^9	1.07×10^8	4.80×10^6
26**	**2.32×10^9**	**1.67×10^9**	**1.26×10^8**
27	1.43×10^8	1.28×10^8	1.12×10^7
28	1.75×10^9	1.08×10^8	1.88×10^7
29	2.06×10^9	1.77×10^9	6.90×10^7
30	2.18×10^8	1.10×10^9	2.50×10^7
Range	1.43×10^7- 2.88×10^9	1.37×10^7 - 2.10×10^9	2.02×10^6 - 1.80×10^9

Colony forming unit (cfu); cfu/g = (no. of colonies x dilution factor) / volume of culture plat

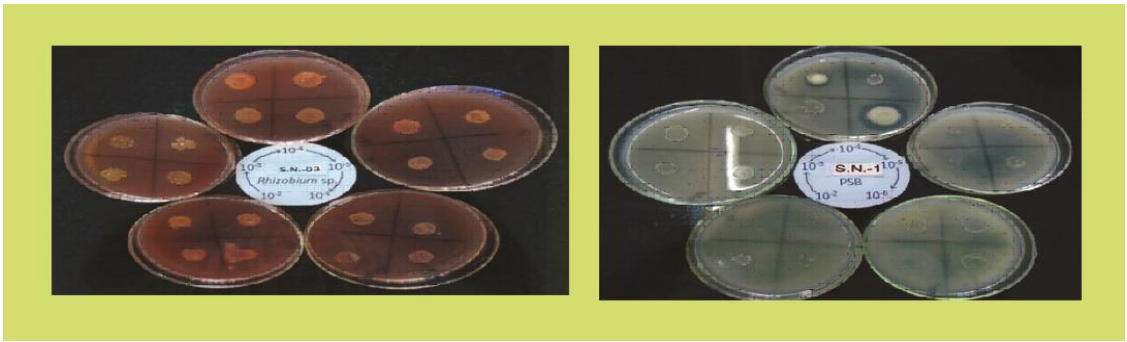


Fig. 182. Estimation of bacterial population

Activity 2: Study on the mineralization rate of commonly used organic materials in Bangladesh under field capacity and CSW conditions (Laboratory study)

✓ 4 types of organic materials were analysed for the laboratory study:

1. Rice husk biochar
2. Poultry manure
3. Vermicompost and
4. Standard organic fertilizer

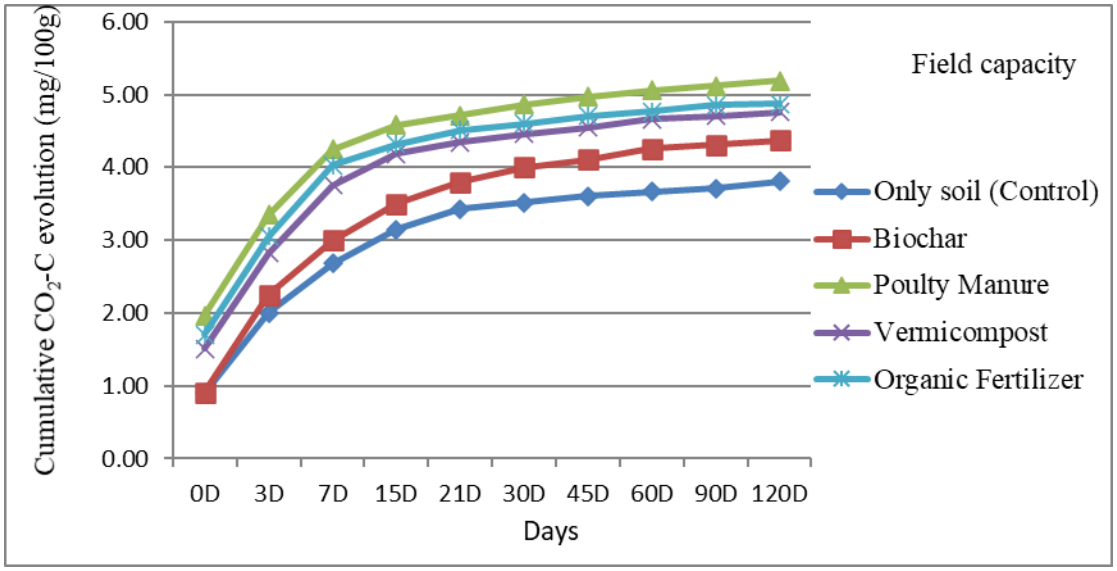


Fig. 183. Effect of different organic amendments on cumulative CO_2-C mineralization under field capacity in the saline soils of Kalapara, Patuakhali

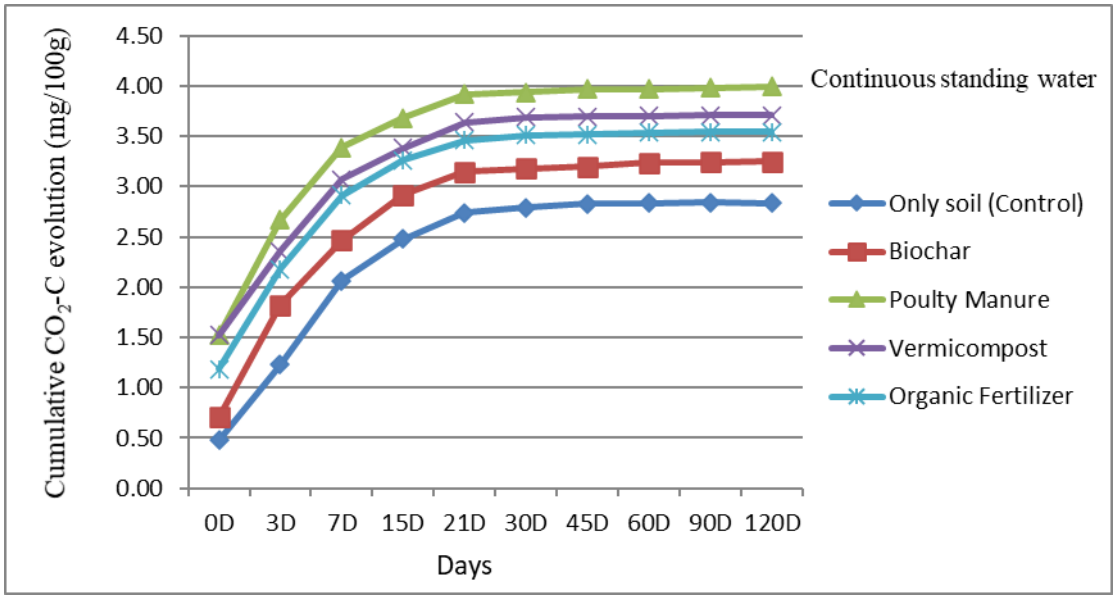


Fig. 184. Effect of different organic amendments on cumulative CO_2-C mineralization under continuous standing water in the saline soils of Kalapara, Patuakhali

The effect of C mineralization is presented in fig.183-184. From the above figure, it is observed that the highest C mineralization was found in poultry manure and the lowest was found in rice husk biochar in both moisture regimes (field capacity and continuous standing water) among all the organic amendments. In case of field capacity condition, the C mineralization followed the order as poultry manure > organic fertilizer> vermicompost> biochar. On the other hand, in continuous standing water the C mineralization followed the order as poultry manure > vermicompost > organic fertilizer> biochar. In both cases, the highest CO_2-C mineralization was found in poultry manure whichwas similar to the results of Contreras *et al.* (2005).

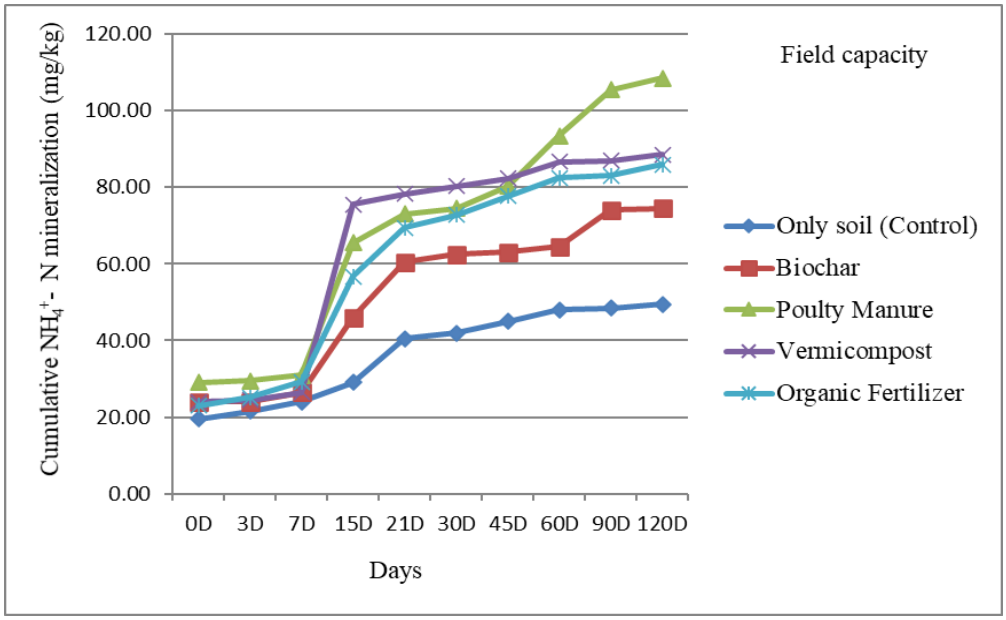


Fig. 185. Effect of different organic amendments on cumulative NH_4^+- N mineralization under field capacity in the saline soils of Kalapara, Patuakhali

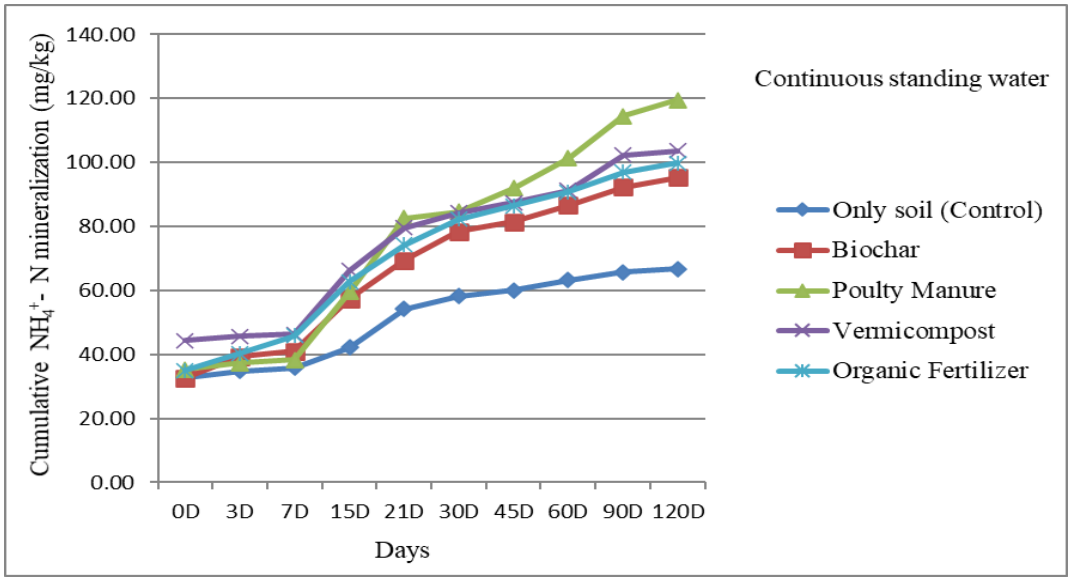


Fig. 186. Effect of different organic amendments on cumulative NH_4^+- N mineralization under continuous standing water in the saline soils of Kalapara, Patuakhali

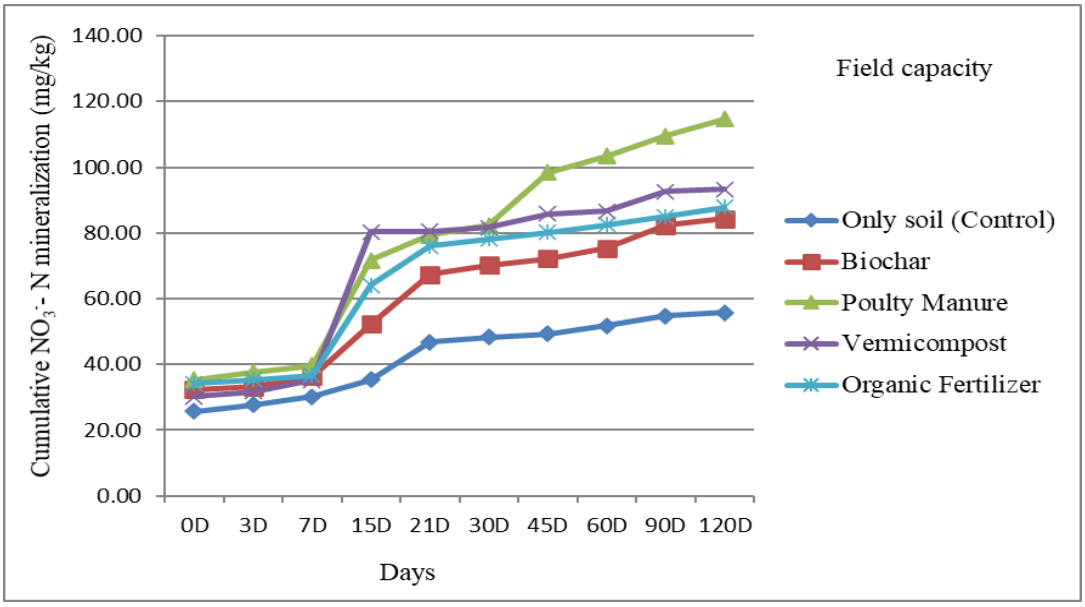


Fig. 187. Effect of different organic amendments on cumulative NO_3^-- N mineralization under field capacity in the saline soils of Kalapara, Patuakhali

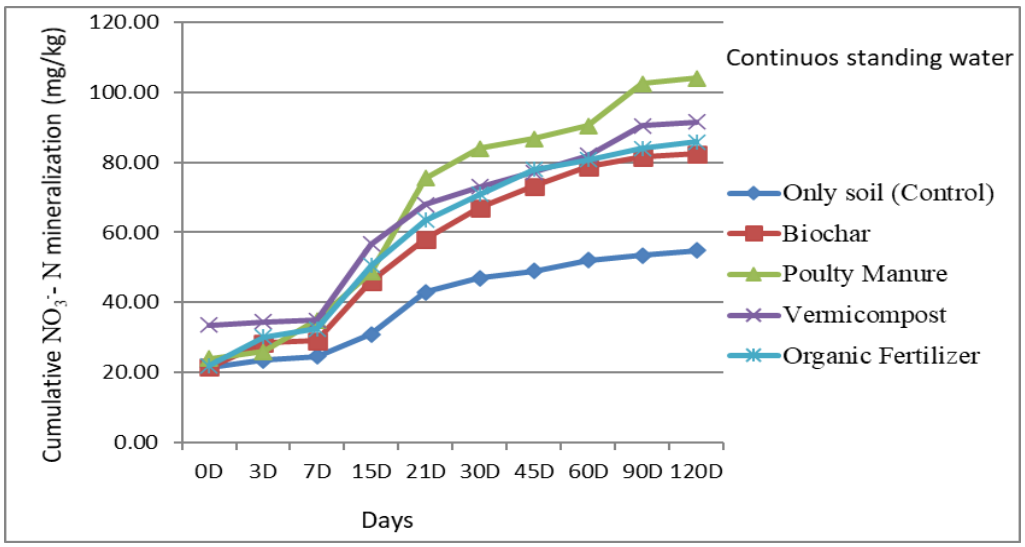


Fig. 188. Effect of different organic amendments on cumulative NO_3^-- N mineralization under continuous standing water in the saline soils of Kalapara, Patuakhali

The effect of N (NH_4^+- N and NO_3^-- N**)** mineralization is presented in fig.185-188. From the above figure, it is observed that the highest NH_4^+- N and NO_3^-- N mineralization was found in poultry manure and the lowest was found in rice husk biochar in both moisture regimes (field capacity and continuous standing water) among all the organic amendments. In both moisture regimes (field capacity and continuous standing water) the NH_4^+- N and NO_3^-- N mineralization followed the order as poultry manure > vermicompost > organic fertilizer> biochar. The results showed that that the lowest N mineralization was found in biochar amended soil which was similar to the results obtained by Luo*et al.*(2016).

Activity3: Improvement of soil health in unfavorable eco-systems (saline soil) with organic amendments for sustainable crop production

Objective: To evaluate the effect of organic amendments on maize (var. Don 111) for sustaining yield and improve soil health in saline soil.

Table 168. Nutrient status of the organic materials used under study

Organic materials	pH	EC (dS/m)	Total nitrogen (%)	Organic carbon (%)	Ca (%)	Mg (%)	K (%)	P (%)	S (%)
Biochar	6.6	0.23	2.20	4.70	0.98	0.53	1.02	0.88	0.42
Poultry manure	7.2	2.86	1.43	36.35	1.69	0.77	0.56	2.05	0.57
Vermicompost	7.2	0.41	1.78	7.12	3.52	1.64	0.80	1.99	0.79
Standard organic fertilizer	6.8	0.42	3.68	6.51	1.80	1.38	0.88	1.55	0.89

Design: RCBD Replication:3, Crop: Maize (var. Don 111)
Treatments: 6(six)
T_1= Control,
T_2 = 100% RDCF (Recommended Dose of Chemical Fertilizer)
T_3 = 100% RDCF + Biochar (2 t/ha)
T_4 = Poultry manure 3 t/ha + rest of the nutrients from chemical fertilizers
T_5 = Vermicompost 3 t/ha + rest of the nutrients from chemical fertilizers
T_6 = Organic fertilizer 3 t/ha + rest of the nutrients from chemical fertilizers
Location: Kalapara (AEZ- 13)
Factors: Two (Mulch and non-mulch)

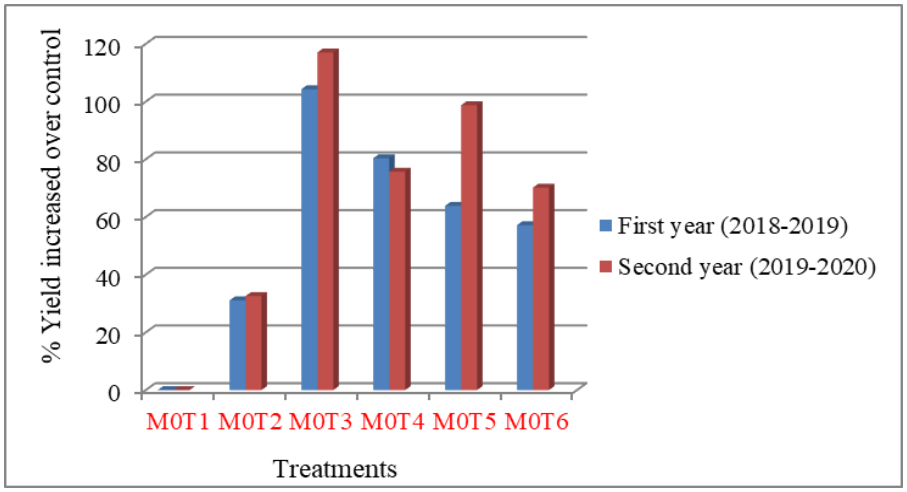
3.1 Effect of Organic Amendments on Maize (var DON 111)

The effect of organic amendments with mulch and no mulch condition on yield was presented in table 169--172. The effect of organic and inorganic amendments on yield was statistically significant in both (no mulch and mulch) condition. The results showed that both the grain and straw yield was higher in mulch condition than no mulch condition in both the years and locations because of mulching can reduce soil salinity by conserving soil moisture. Similar result was reported by Kumar *et.al* (2018).

In No Mulch Condition

In first year, the highest grain yield (8.54 t ha^{-1} in Nilgonj and 6.30 t ha^{-1} in Latachapli) was found in M_0T_3 treatment and the lowest grain yield (4.18 t ha^{-1} in Nilgonj and 3.05 t ha^{-1} in Latachapli) was found in M_0T_1 (control) treatment. The highest stover yield (9.02 t ha^{-1} in Nilgonj and 6.70 t ha^{-1} in Latachapli) was found in M_0T_3 treatment and the lowest stover yield (4.75 t ha^{-1} in Nilgonj and 3.62 t ha^{-1}in Latachapli) was found in M_0T_1 (control) treatment (Table 169).In second year, the highest grain yield (8.66t ha^{-1} in Nilgonj and 6.56 t ha^{-1} in Latachapli) was found in M_0T_3 treatment and the lowest grain yield (3.99t ha^{-1} in Nilgonj and 2.96 t ha^{-1} in Latachapli) was found in M_0T_1 (control) treatment. The highest stover yield (9.24 t ha^{-1} in Nilgonj and 6.77 t ha^{-1} in Latachapli) was found in M_0T_3 treatment and the lowest stover yield (4.44 t ha^{-1}in Nilgonj and 2.59 t ha^{-1} in Latachapli) was found in M_0T_1 (control) treatment (Table 169). It revealed that the highest grain and stover yield of maize was found in biochar treated plot among all the treatments because biochar has the capacity to reduce the soil salinity to the lowest limit. The similar result was found by Ali *et al*. (2017).

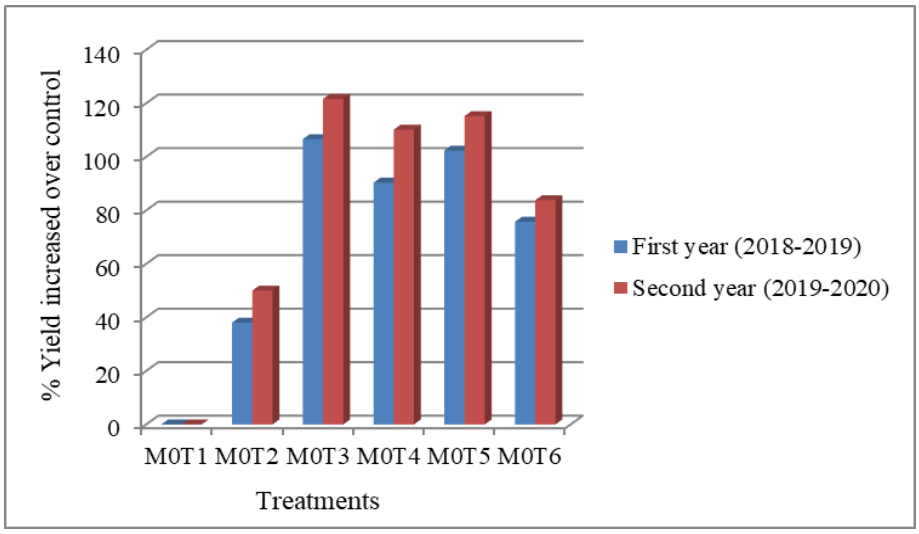
In Nilgonj union, the M_0T_2, M_0T_3, M_0T_4, M_0T_5 and M_0T_6 increased the maize yield by 31.10, 104.31, 80.38, 63.88 and 57.18%, respectively over control treatment in first year (2018-2019) whereas32.58, 117.04, 75.69, 98.75 and 70.18%, respectively in second year (2019-2020) (Fig. 189).



Note: M_0= Non mulch, T_1= Control, T_2 = 100% Recommended Fertilizer, T_3 = 100% Recommended Fertilizer + Biochar (2 t ha^{-1}), T_4 = 3 tons/ha Poultry Manure + Chemical Fertilizer with IPNS basis, T_5 = 3 tons/ha Vermicompost + Chemical Fertilizer with IPNS basis, T_6 = 3 tons/ha Organic Fertilizers + Chemical Fertilizer with IPNS basis.

Fig. 189. Maize yield increased by different organic amendments over control treatment in Nilgonj union of Kalapara Upazila.

In Latachapli union, the M_0T_2, M_0T_3, M_0T_4, M_0T_5 and M_0T_6 increased the maize yield by 38.03, 106.58, 90.36, 102.30 and 75.74%, respectively over control treatment in first year (2018-2019) whereas50.0, 121.62, 110.14, 115.20 and 83.78%, respectively in second year (2019-2020) (Fig. 190)



Note: M_0= Non mulch, T_1= Control, T_2 = 100% Recommended Fertilizer, T_3 = 100% Recommended Fertilizer + Biochar (2 t ha^{-1}), T_4 = 3 tons/ha Poultry Manure + Chemical Fertilizer with IPNS basis, T_5 = 3 tons/ha Vermicompost + Chemical Fertilizer with IPNS basis, T_6 = 3 tons/ha Organic Fertilizers + Chemical Fertilizer with IPNS basis.

Fig. 190. Maize yield increased by different organic amendments over control treatment in Latachapli union of KalaparaUpazila.

In first year, the highest pH value (6.65in Nilgonj and 6.74 in Latachapli) in post- harvest soil was found in M_0T_4treatment and the lowest pH value (6.13 in Nilgonj and 6.20 in Latachapli) was found in M_0T_2 treatment. The highest EC value (6.82 dS/m in Nilgonj and 8.18 dS/m in Latachapli) was found in M_0T_1 (control) treatment and the lowest EC value (5.33 dS/m in Nilgonj and 6.07dS/m in Latachapli) was found in M_0T_3 treatment. The

highest organic carbon (1.22% in Nilgonj and 1.19% in Latachapli) was found in M_0T_3 treatment and the lowest organic carbon (1.07% in Nilgonj and 1.0% in Latachapli) was found in M_0T_1 treatment. The highest sodium content (20.24 meq/100gin Nilgonj and 22.42 meq/100gin Latachapli) was found in M_0T_1 treatment and the lowest sodium content (14.0 meq/100gin Nilgonj and 18.98 meq/100g in Latachapli) was found in M_0T_3 treatment (Table 170).

In second year, the highest pH value (6.61in Nilgonj and 6.70in Latachapli) in post- harvest soil was found in M_0T_4treatment and the lowest pH value (6.10 in Nilgonj and 6.18 in Latachapli) was found in M_0T_2 treatment. The highest EC value (6.63dS/m in Nilgonj and 8.75dS/m in Latachapli) was found in M_0T_1 (control) treatment and the lowest EC value (3.29dS/m in Nilgonj and 5.14 dS/m in Latachapli) was found in M_0T_3 treatment. The highest organic carbon (1.33% in Nilgonj and 1.30% in Latachapli) was found in M_0T_3 treatment and the lowest organic carbon (1.00% in Nilgonj and 0.99 % in Latachapli) was found in M_0T_1 treatment. The highest sodium content (21.43meq/100gin Nilgonj and 22.67meq/100gin Latachapli) was found in M_0T_1 treatment and the lowest sodium content (13.62meq/100gin Nilgonj and 16.84meq/100g in Latachapli) was found in M_0T_3 treatment (Table 6). The similar results were found by Haefele*et al*. (2011).

Table 169. Effect of different organic amendments with no mulch on the yield of Maize (var. DON 111) in two sites of Kalaparaupazila inconsecutive two years

Treatment	Nilgonj Union				Latachapli Union			
	2018-2019		2019-2020		2018-2019		2019-2020	
	Grain yield (t ha^{-1})	Stover yield (t ha^{-1})	Grain yield (t ha^{-1})	Stover yield (t ha^{-1})	Grain yield (t ha^{-1})	Stover yield (t ha^{-1})	Grain yield (t ha^{-1})	Stover yield (t ha^{-1})
M_0T_1	4.18e	4.75b	3.99f	4.44f	3.05c	3.62b	2.96f	2.59e
M_0T_2	5.48d	7.24ab	5.29e	6.81e	4.21bc	5.45a	4.44e	5.48d
M_0T_3	8.54a	9.02a	8.66a	9.24a	6.30a	6.70a	6.56a	6.77b
M_0T_4	7.32b	7.39a	7.01c	7.73c	6.05a	6.36a	6.22c	6.48c
M_0T_5	6.85c	7.58a	7.93b	7.92b	6.17a	6.39a	6.37b	6.95a
M_0T_6	6.57c	7.73a	6.79d	7.54d	5.36ab	5.93a	5.44d	6.39c
CV (%)	2.78	5.68	3.01	3.14	9.32	6.57	2.48	3.59
Level of significance	***	**	***	***	***	**	***	***

Means with the same letter in a column are not significantly different at 5% level by DMRT. * Significant at 5% level, ** Significant at 1% level, *** Significant at 0.1% level, CV = Coefficient of variation, M_0= Non mulch.

[T_1= Control, T_2 = 100% Recommended Fertilizer, T_3 = 100% Recommended Fertilizer + Biochar (2 t ha^{-1}), T_4 = 3 tons/ha Poultry Manure + Chemical Fertilizer with IPNS basis, T_5 = 3 tons/ha Vermicompost + Chemical Fertilizer with IPNS basis, T_6 = 3 tons/ha Organic Fertilizers + Chemical Fertilizer with IPNS basis].

Table 170. Effect of different organic amendments with no mulch on the post-harvest soil parameters of Maize (var. DON 111) in two sites of KalaparaUpazila in consecutive two years

Treatment	Nilgonj union								Latachapli union							
	2018-2019				2019-2020				2018-2019				2019-2020			
	pH	EC (dS/m)	OC (%)	Na (meq/100g)	pH	EC (dS/m)	OC (%)	Na (meq/100g)	pH	EC (dS/m)	OC (%)	Na (meq/100g)	pH	EC (dS/m)	OC (%)	Na (meq/100g)
M_0T_1	6.20	6.82a	1.07	20.24a	6.11c	6.63a	1.00	21.43a	6.24	8.18a	1.00b	22.42a	6.21c	8.75a	0.99	22.67a
M_0T_2	6.13	6.14a	1.08	18.45ab	6.10c	6.44b	1.05	20.47b	6.20	8.03a	1.02b	21.53ab	6.18c	8.28b	0.98	21.02ab
M_0T_3	6.22	5.33b	1.22	14.00c	6.16c	3.29f	1.33	13.62d	6.34	6.07b	1.19a	18.98c	6.27c	5.14f	1.30	16.84d
M_0T_4	6.65	6.41a	1.14	15.17c	6.61a	4.94d	1.18	14.55c	6.74	7.70a	1.14ab	20.47abc	6.70a	7.38d	1.12	20.00bc
M_0T_5	6.40	6.54a	1.19	14.32c	6.36b	4.85e	1.19	14.01d	6.59	7.91a	1.06b	20.00bc	6.58b	7.14e	1.09	19.09c
M_0T_6	6.42	6.36a	1.09	16.11bc	6.41b	5.02c	1.14	15.01c	6.58	7.61a	1.05b	20.67abc	6.57b	7.49c	1.10	20.12bc
CV (%)	3.92	8.89	5.31	6.93	2.38	4.31	9.11	4.35	4.27	10.42	8.01	3.38	3.44	3.60	10.1	3.25
Level of significance	NS	***	NS	***	***	***	NS	***	NS	**	**	***	***	***	NS	***

Means with the same letter in a column are not significantly different at 5% level by DMRT.

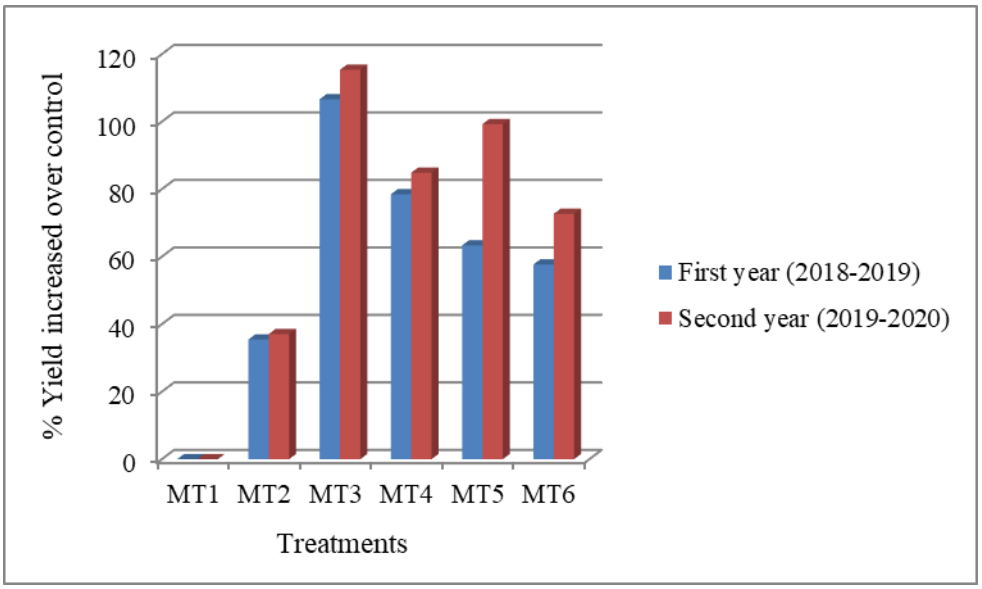
** Significant at 1% level, *** Significant at 0.1% level, OC= Organic carbon, NS= Not significant, CV = Coefficient of variation, M_0= Non mulch.

[T_1= Control, T_2 = 100% Recommended Fertilizer, T_3 = 100% Recommended Fertilizer + Biochar (2 t ha^{-1}), T_4 = 3 tons/ha Poultry Manure + Chemical Fertilizer with IPNS basis, T_5 = 3 tons/ha Vermicompost + Chemical Fertilizer with IPNS basis, T_6 = 3 tons/ha Organic Fertilizers + Chemical Fertilizer with IPNS basis].

In Mulch Condition

In first year, the highest grain yield (8.74 t ha^{-1} in Nilgonj and 6.52 t ha^{-1} in Latachapli) was found in MT_3 treatment and the lowest grain yield (4.23t ha^{-1} in Nilgonj and 3.15 t ha^{-1} in Latachapli) was found in MT_1 (control) treatment. The highest stover yield (9.57 t ha^{-1} in Nilgonj and 6.67 t ha^{-1} in Latachapli) was found in MT_3 treatment and the lowest stover yield (5.46 t ha^{-1} in Nilgonj and 3.98 t ha^{-1} in Latachapli) was found in MT_1 (control) treatment (Table 171). In second year, the highest grain yield (8.83t ha^{-1} in Nilgonj and 6.83 t ha^{-1} in Latachapli) was found in MT_3 treatment and the lowest grain yield (4.10t ha^{-1} in Nilgonj and 3.04 t ha^{-1} in Latachapli) was found in MT_1 (control) treatment. The highest stover yield (9.78 t ha^{-1} inNilgonj and 6.79 t ha^{-1} in Latachapli) was found in MT_3 treatment and the lowest stover yield (5.06 t ha^{-1} in Nilgonj and 2.88 t ha^{-1} in Latachapli) was found in MT_1 (control) treatment (Table 171). The revealed that the highest grain and stover yield of maize was found in biochar treated plot among all the treatments because biochar have the capacity to reduce the soil salinity to the lowest limit. The similar result was found by Ali *et al*. (2017).

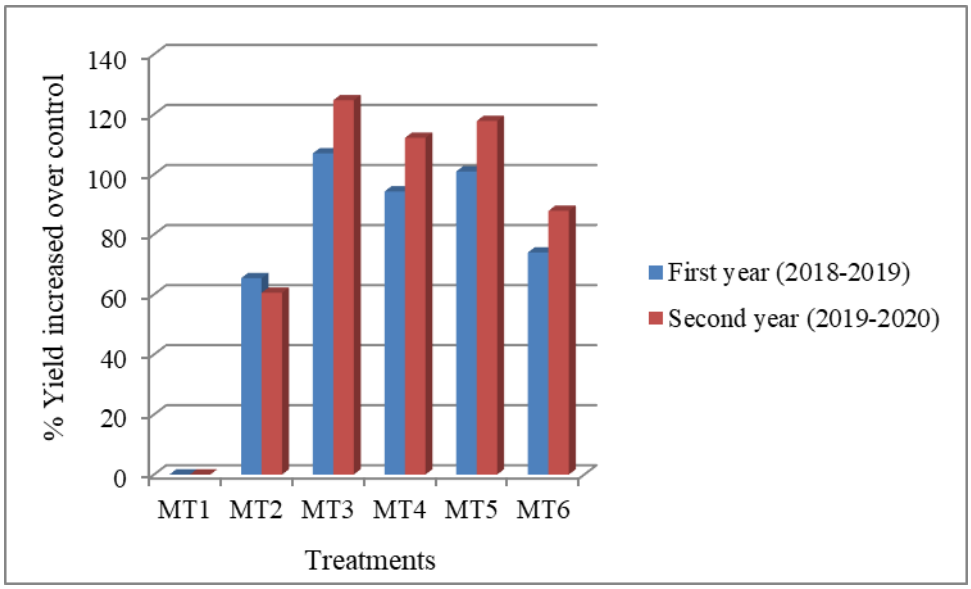
In Nilgonj union, the MT_2, MT_3, MT_4, MT_5 and MT_6 increased the maize yield by 35.46, 106.62, 78.49, 63.35 and 57.68%, respectivelyover control treatment in first year (2018-2019) whereas37.07, 115.37, 84.88, 99.27 and 72.68%, respectively in second year (2019-2020) (Fig. 191).



Note: M= Mulch, T_1= Control, T_2 = 100% Recommended Fertilizer, T_3 = 100% Recommended Fertilizer + Biochar (2 t ha^{-1}), T_4 = 3 tons/ha Poultry Manure + Chemical Fertilizer with IPNS basis, T_5 = 3 tons/ha Vermicompost + Chemical Fertilizer with IPNS basis, T_6 = 3 tons/ha Organic Fertilizers + Chemical Fertilizer with IPNS basis.

Fig. 191. Maize yield increased by different organic amendments over control treatment in Nilgonj union of Kalapara Upazila.

In Latachapli union, the MT_2, MT_3, MT_4, MT_5 and MT_6 increased the maize yield by 65.40, 106.98, 94.29, 100.95 and 73.97%, respectivelyover control treatment in first year (2018-2019) whereas 60.53, 124.67, 112,17, 117.76 and 87.83%, respectively in second year (2019-2020) (Fig. 192)



Note: M= Mulch, T_1= Control, T_2 = 100% Recommended Fertilizer, T_3 = 100% Recommended Fertilizer + Biochar (2 t ha^{-1}), T_4 = 3 tons/ha Poultry Manure + Chemical Fertilizer with IPNS basis, T_5 = 3 tons/ha Vermicompost + Chemical Fertilizer with IPNS basis, T_6 = 3 tons/ha Organic Fertilizers + Chemical Fertilizer with IPNS basis.

Fig. 192. Maize yield increased by different organic amendments over control treatment in Latachapli union of Kalapara Upazila.

In first year, the highest pH value (6.34in Nilgonj and 6.78in Latachapli) in post- harvest soil was found in MT_4treatment and the lowest pH value (6.12 in Nilgonj and 6.17 in Latachapli) was found in MT_2 treatment. The highest EC value (6.77dS/m in Nilgonj and 8.17dS/m in Latachapli) was found in MT_1 (control) treatment and the lowest EC value (5.11dS/m in Nilgonj and 6.03 dS/m in Latachapli) was found in MT_3 treatment. The highest organic carbon (1.37% in Nilgonj and 1.31% in Latachapli) was found in MT_3 treatment and the lowest organic carbon (1.04% in Nilgonj and 1.04% in Latachapli) was found in MT_2 treatment. The highest sodium content (18.81meq/100gin Nilgonj and 21.27meq/100gin Latachapli) was found in MT_1 treatment and the lowest sodium content (13.13meq/100gin Nilgonj and 17.95meq/100g in Latachapli) was found in MT_3 treatment (Table 8).

In second year, the highest pH value (6.36 in Nilgonj) was found in MT_6 treatment and (6.69in Latachapli) in post- harvest soil was found in MT_4treatment and the lowest pH value (6.03 in Nilgonj and 6.23 in Latachapli) was found in MT_2 treatment. The highest EC value (6.21dS/m in Nilgonj and 8.16dS/m in Latachapli) was found in MT_1 (control) treatment and the lowest EC value (3.12dS/m in Nilgonj and 4.70 dS/m in Latachapli) was found in MT_3 treatment. The highest organic carbon (1.40% in Nilgonj and 1.38% in Latachapli) was found in MT_3 treatment and the lowest organic carbon (1.04% in Nilgonj and 1.0% in Latachapli) was found in MT_1 treatment. The highest sodium content (19.06meq/100gin Nilgonj and 21.45meq/100gin Latachapli) was found in MT_1 treatment and the lowest sodium content (12.60meq/100gin Nilgonj and 15.75meq/100g in Latachapli) was found in MT_3 treatment (Table 172). The similar results were found by Haefele*et al*. (2011).

Table 171. Effect of different organic amendments with mulch on the yield of Maize (var. DON 111) in two sites of Kalapara Upazila in two years

Treatment	Nilgonj Union				Latachapli Union			
	2018-2019		2019-2020		2018-2019		2019-2020	
	Grain yield (t ha^{-1})	Stover yield (t ha^{-1})	Grain yield (t ha^{-1})	Stover yield (t ha^{-1})	Grain yield (t ha^{-1})	Stover yield (t ha^{-1})	Grain yield (t ha^{-1})	Stover yield (t ha^{-1})
MT_1	4.23 e	5.46b	4.10f	5.06e	3.15b	3.98b	3.04e	2.88d
MT_2	5.73 d	8.14a	5.62e	7.20d	5.21a	4.15ab	4.88d	5.64c
MT_3	8.74 a	9.57a	8.83a	9.78a	6.52a	6.67a	6.83a	6.79a
MT_4	7.55 b	8.85a	7.58c	8.83bc	6.12a	6.42a	6.45b	6.63b
MT_5	6.91 c	9.13a	8.17b	8.92b	6.33a	6.48a	6.62ab	6.88a
MT_6	6.67 c	9.37a	7.08d	8.74c	5.48a	6.19a	5.71c	6.54b
CV (%)	3.97	7.98	5.23	2.12	9.05	6.04	2.30	4.55
Level of significance	***	***	***	***	**	**	***	***

Means with the same letter in a column are not significantly different at 5% level by DMRT, * Significant at 5% level, ** Significant at 1% level, *** Significant at 0.1% level, NS= not significant, CV = Coefficient of variation, M= Mulch.

[T_1= Control, T_2 = 100% Recommended Fertilizer, T_3 = 100% Recommended Fertilizer + Biochar (2 t ha^{-1}), T_4 = 3 tons/ha Poultry Manure + Chemical Fertilizer with IPNS basis, T_5 = 3 tons/ha Vermicompost + Chemical Fertilizer with IPNS basis, T_6 = 3 tons/ha Organic Fertilizers + Chemical Fertilizer with IPNS basis].

Table 172. Effect of different organic amendments with mulch on the post-harvest soil parameters of Maize (var. DON 111) in two sites of Kalapara Upazila in two years

Treatment	Nilgonj union								Latachapli union							
	2018-2019				2019-2020				2018-2019				2019-2020			
	pH	EC (dS/m)	OC (%)	Na (meq/100 g)	pH	EC (dS/m)	OC (%)	Na (meq/100g)	pH	EC (dS/m)	OC (%)	Na (meq/100g)	pH	EC (dS/m)	OC (%)	Na (meq/100 g)
MT_1	6.17	6.77a	1.08	18.81a	6.07b	6.21a	1.04	19.06a	6.24	8.17a	1.04	21.27a	6.25c	8.16a	1.00	21.45a
MT_2	6.12	6.13a	1.04	17.45b	6.03bc	6.15b	1.06	18.97a	6.17	7.96a	1.04	19.69b	6.23c	7.77b	1.03	19.50b
MT_3	6.21	5.11b	1.37	13.13e	6.12b	3.12f	1.40	12.60e	6.27	6.03b	1.31	17.95c	6.26c	4.70e	1.38	15.75d
MT_4	6.34	6.11a	1.20	14.31cd	6.31a	4.32d	1.25	13.90c	6.78	7.69a	1.18	19.72b	6.69a	6.96cd	1.20	18.74bc
MT_5	6.27	6.36a	1.12	13.86de	6.29a	4.26e	1.27	12.87d	6.48	7.56a	1.08	19.20b	6.47b	6.88d	1.21	18.12c
MT_6	6.38	6.31a	1.08	15.23c	6.36a	4.45c	1.17	14.88b	6.73	7.34a	1.06	19.86b	6.48b	7.04c	1.15	18.75bc
CV (%)	3.79	11.58	8.23	3.01	4.11	3.07	8.83	3.6	5.30	10.26	4.42	2.07	9.6	5.1	8.73	2.13
Level of significance	NS	*	NS	***	***	***	NS	***	NS	**	NS	***	***	***	NS	***

Means with the same letter in a column are not significantly different at 5% level by DMRT.

* Significant at 5% level, ** Significant at 1% level, *** Significant at 0.1% level, OC= Organic carbon, NS= Not significant, CV = Coefficient of variation, M= Mulch.

[T_1= Control, T_2 = 100% Recommended Fertilizer, T_3 = 100% Recommended Fertilizer + Biochar (2 t ha^{-1}), T_4 = 3 tons/ha Poultry Manure + Chemical Fertilizer with IPNS basis, T_5 = 3 tons/ha Vermicompost + Chemical Fertilizer with IPNS basis, T_6 = 3 tons/ha

Fig. 193. Pictorial view of first field experiment (Maize; var. DON 111).

3.2 Effect of Organic Amendments on T. aman (var BRRI dhan52)

The collected initial soil samples from the experimental field during the month of July, 2019 and 2020 were analyzed for pH and EC value. The pH and EC value of initial soil was significantly influenced with different treatments in both unions of KalaparaUpazila because collected initial soils from different plots of T. aman field was treated with different organic amendments during cultivation of previous crop (Maize). In Nilgonj union, the highest pH (6.34 in 2019 and 6.35 in 2020) of initial soil in the T. aman field was recorded in T_4treatment and the lowest pH (6.10 in 2019 and 6.08 in 2020) was recorded in T_2treatment. Similarly, the highest EC (3.53 dS/m in 2019 and 3.65 dS/m in 2020) of initial soil in the T. aman field was recorded in T_1 treatment and the lowest EC (2.64 dS/m in 2019 and 2.39

dS/m in 2020) wasrecorded in T_3 treatment. The T_1, T_3, T_5 and T_6 treatments showed the statistically similar pH in both 2019 and 2020. TheT_2, T_4, T_5 and T_6 treatments showed the statistically similar EC value of initial soils in 2019. In Latachapli union, the highest pH (6.44 in 2019 and 6.35 in 2020) of initial soil in the T. aman field was recorded in T_4treatment and the lowest pH (6.19 in 2019 and 6.08 in 2020) was recorded in T_2treatment. Similarly, the highest EC (3.81 dS/m in 2019 and 4.00 dS/m in 2020) of initial soil in the T. aman field was recorded in T_1 treatment and the lowest EC (2.83 dS/m in 2019 and 2.78 dS/m in 2020) was recorded in T_3 treatment. The T_2, T_4, T_5 and T_6 treatments showed the statistically similar pH and EC value of initial soils (Table 173).

Table 173. pH and EC (dS/m) value of initial soils ofT. aman (var. BRRI dhan52) field in two sites of Kalapara Upazila

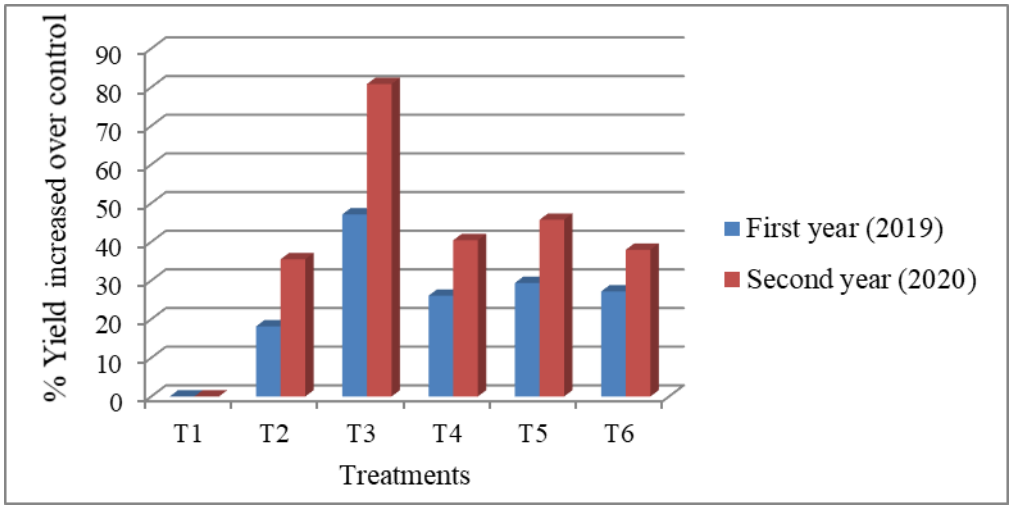
Treatment	Nilgonj union				Latachapli union			
	2019		2020		2019		2020	
	pH	EC (dS/m)	pH	EC (dS/m)	pH	EC (dS/m)	pH	EC (dS/m)
T_1	6.23 b	3.53 a	6.20 b	3.65 a	6.30 bc	3.81 a	6.20bc	4.00 a
T_2	6.10 c	3.17 b	6.08c	3.23 a	6.19 c	3.29 b	6.08c	3.25 b
T_3	6.25 b	2.64 c	6.23 b	2.39 b	6.32 b	2.83 c	6.23 b	2.78 c
T_4	6.34 a	3.06 b	6.35a	3.00 ab	6.44 a	3.20 b	6.35 a	3.10 bc
T_5	6.26 b	3.10 b	6.25b	3.10 ab	6.37 ab	3.13 b	6.27ab	3.10 bc
T_6	6.23 b	3.14 b	6.21b	3.11 ab	6.41 ab	3.15 b	6.32ab	3.12 bc
CV (%)	3.60	2.08	1.89	8.40	2.89	2.46	1.72	4.93
Level of significance	***	***	*	**	***	***	*	***

Means with the same letter in a column are not significantly different at 5% level by DMRT.

* Significant at 5% level, ** Significant at 1% level, *** Significant at 0.1% level, CV = Coefficient of variation,

[T_1= Control, T_2 = 100% Recommended Fertilizer, T_3 = 100% Recommended Fertilizer + Biochar (2 t ha^{-1}), T_4 = 3 tons/ha Poultry Manure + Chemical Fertilizer with IPNS basis, T_5 = 3 tons/ha Vermicompost + Chemical Fertilizer with IPNS basis, T_6 = 3 tons/ha Organic Fertilizers + Chemical Fertilizer with IPNS basis].

The effect of organic amendments on T. aman (var. BRRI dhan52) yield in salt affected soils of two unions (Nilgonj and Latachapli union) at KalaparaUpazila was very much encouraging. In Nilgonj union, the highest grain yield (4.06 t ha^{-1}in 2019 and 4.43 t ha^{-1} in 2020) was recorded in T_3 treatment receiving 100% recommended fertilizer and 2 t ha^{-1}biochar which was statistically similar with T_5 treatment in first year (2019) and was statistically similar with T_4, T_5 and T_6 treatments in second year (2020).The lowest grain yield (2.76 t ha^{-1}in 2019 and 2.45 t ha^{-1}in 2020) was recorded in T_1 treatment (Table 10). The T_2, T_3, T_4, T_5 and T_6 increased the T. aman yield by 18.12, 47.10, 26.07, 29.35 and 27.17%, respectivelyover control treatmentin first yearwhereas35.51, 80.82, 40.41, 45.71 and 37.96%, respectively in second year(Fig. 194).The highest straw yield (5.18 t ha^{-1}in 2019 and 5.67 t ha^{-1}in 2020) was obtained from T_3 treatment which was statistically not similar with other treatments and the lowest straw yield (3.18 t ha^{-1}in 2019 and 2.92 t ha^{-1}in 2020) was recorded in control treatment (Table 174).

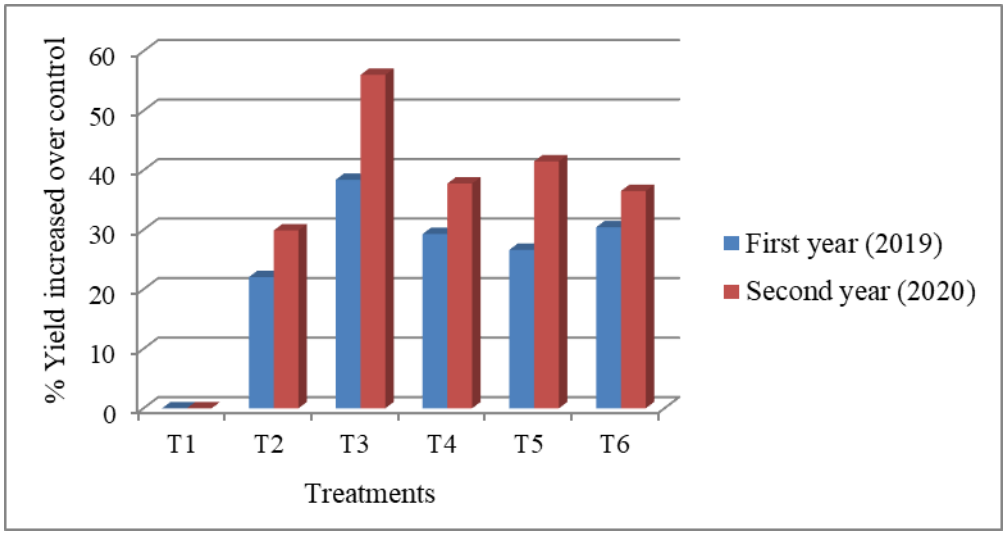


T_1= Control, T_2 = 100% Recommended Fertilizer, T_3 = 100% Recommended Fertilizer + Biochar (2 t ha^{-1}), T_4 = 3 tons/ha Poultry Manure + Chemical Fertilizer with IPNS basis, T_5 = 3 tons/ha Vermicompost + Chemical Fertilizer with IPNS basis, T_6 = 3 tons/ha Organic Fertilizers + Chemical Fertilizer with IPNS basis

Fig. 194. T. aman yield increased by different organic amendments over control in Nilgonj union of Kalapara Upazila

In Latachapli union, the highest grain yield (3.64 t ha^{-1}in 2019 and 3.76 t ha^{-1} in 2020) was recorded in T_3 treatment receiving 100% recommended fertilizer and 2 t ha^{-1}biochar which was statistically not similar with other treatments in first year (2019) but was statistically similar withT_2, T_4, T_5 and T_6 treatments in second year (2020). The lowest grain yield (2.63 t ha^{-1}in 2019 and 2.41 t ha^{-1}in 2020) was recorded in T_1 treatment (Table 10). It revealed that the highest grain and straw yield of T. aman was found in biochar treated plot among all the treatments because biochar has the capacity to reduce the soil salinity to the lowest limit. The similar result was found by Hafeez*et al*. (2019).

The T_2, T_3, T_4, T_5 and T_6 increased the T. aman yield by 22.05, 38.40, 29.28, 26.62 and 30.42%, respectivelyovercontroltreatmentin first year and 29.88, 56.02, 37.76, 41.49 and 36.51%, respectively in second year (Fig. 16). The highest straw yield (5.04 t ha^{-1}in 2019 and 4.98 t ha^{-1}in 2020) was obtained from T_3 treatment which was statistically not similar with other treatmentsand the lowest straw yield (3.19 t ha^{-1}in 2019 and 2.77 t ha^{-1}in 2020) was recorded in control treatment (Table 174).



T_1= Control, T_2 = 100% Recommended Fertilizer, T_3 = 100% Recommended Fertilizer + Biochar (2 t ha^{-1}), T_4 = 3 tons/ha Poultry Manure + Chemical Fertilizer with IPNS basis, T_5 = 3 tons/ha Vermicompost + Chemical Fertilizer with IPNS basis, T_6 = 3 tons/ha Organic Fertilizers + Chemical Fertilizer with IPNS basis

Fig. 195. T. aman yield increased by different organic amendments over control in Latachapli union of Kalapara Upazila

Table 174. Effect of different organic amendments on the yield of T. aman (var. BRRI dhan52) in two sites of Kalapara Upazila in two years

Treatment	Nilgonj Union				Latachapli Union			
	2019		2020		2019		2020	
	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})
T_1	2.76 c	3.18d	2.45c	2.92c	2.63 e	3.19 e	2.41b	2.77c
T_2	3.26b c	4.30c	3.32b	4.25b	3.21 cd	4.18 cd	3.13ab	3.73b
T_3	4.06 a	5.18a	4.43a	5.67a	3.64 a	5.04 a	3.76a	4.98a
T_4	3.48 b	4.83b	3.44ab	4.44b	3.40 b	4.33 c	3.32ab	4.18b
T_5	3.57 ab	4.80b	3.57ab	4.64ab	3.33c	4.11 d	3.41a	4.28ab
T_6	3.51 b	4.87b	3.38ab	4.32b	3.43 b	4.83 b	3.29ab	4.11b
CV (%)	6.91	0.95	10.72	8.60	1.44	1.44	10.97	6.64
Level of significance	***	***	**	***	***	***	*	***

Means with the same letter in a column are not significantly different at 5% level by DMRT. * Significant at 5% level,** Significant at 1% level, *** Significant at 0.1% level, CV = Coefficient of variation

[T_1= Control, T_2 = 100% Recommended Fertilizer, T_3 = 100% Recommended Fertilizer + Biochar (2 t ha^{-1}), T_4 = 3 tons/ha Poultry Manure + Chemical Fertilizer with IPNS basis, T_5 = 3 tons/ha Vermicompost + Chemical Fertilizer with IPNS basis, T_6 = 3 tons/ha Organic Fertilizers + Chemical Fertilizer with IPNS basis].

The post-harvest soils of T. aman were analyzed for pH, EC, sodium (Na) and potassium (K) content. The analyzed results of post-harvest soils were presented in Table 175. The soil pH was influenced significantly with different treatments in both the unions and years. In Nilgonj union, the highest soil pH (6.49 in 2019 and 6.61 in 2020)was recorded in T_4treatment and the lowest soil pH(6.20 in 2019 and 6.15 in 2020) was recorded in T_2treatment.In Latachapli union, the highest soil pH (6.64 in 2019 and 6.74 in 2020) was recorded in T_4treatment and the lowest soil pH (6.29 in 2019 and 6.14 in 2020) was recorded in T_2treatment.

Soil electrical conductivity (EC) was extremely influenced by the treatments in both the unions and years. In Nilgonj union, the highest soil EC (5.16dS/m in 2019 and 5.21dS/m in 2020) was recorded in T_1treatment and the lowest soil EC (4.22dS/m in 2019 and 3.34dS/m in 2020) was recorded in T_3treatment.In Latachapli union, the highest soil EC (5.44dS/m in 2019 and 5.46dS/m in 2020) was recorded in T_1treatment and the lowest soil EC (4.30dS/m in 2019 and 3.60dS/m in 2020) was recorded in T_3treatment. The results thus clearly evidenced that T_3 (100% recommended fertilizer and 2 t ha^{-1}biochar) treatment is highly capable to maintain soil EC value in a lower limit than other treatments in both the sites and years. The organic carbon of soil was extremely influenced by the treatments in both the unions.

In Nilgonj union, the highest soil organic carbon (1.36% in 2019 and 1.40% in 2020) was recorded in T_3treatment and the lowest soil organic carbon (1.23% in 2019 and 1.20% in 2020) was recorded in T_1treatment.InLatachapli union, the highest soil organic carbon (1.42% in 2019 and 1.45% in 2020) was recorded in T_3treatment and the lowest soil organic carbon (1.26% in 2019 and 1.23% in 2020) was recorded in T_1treatment.

The soil sodium (Na) was influenced significantly with different treatments in both the unions and years. In Nilgonj union, the highest soil Na (12.09 meq/100g in 2019 and 12.49 meq/100g in 2020) was recorded in T_1treatment and the lowest soil Na (6.39 meq/100g in 2019 and 6.44 meq/100g in 2020) was recorded in T_3treatment.InLatachapli union, the highest soil Na (14.09 meq/100g in 2019 and 14.74 meq/100g in 2020) was recorded in T_1treatment and the lowest soil Na (8.98 meq/100g in 2019 and 8.16 meq/100g in 2020) was recorded in T_3treatment. The lowest soil Na in T_3 (100% recommended fertilizer and 2 t ha^{-1}biochar) treatment means that the application of biochar in combination with 100% recommended fertilizer was highly capable to maintain soil Na to a lower limit among the other treatments. The similar results were found by Haefele*et al.* (2011).

Table 175. Effect of different organic amendments on the post-harvest soil parameters of T. aman (var. BRRI dhan52) in two sites of Kalapara Upazila

Treatment	Nilgonj union								Latachapli union							
	2019				2020				2019				2020			
	pH	EC (dS/m)	OC (%)	Na (meq/100g)	pH	EC (dS/m)	OC (%)	Na (meq/100g)	pH	EC (dS/m)	OC (%)	Na (meq/100g)	pH	EC (dS/m)	OC (%)	Na (meq/100g)
T_1	6.31 b	5.16 a	1.23c	12.09a	6.32ab	5.21a	1.20c	12.49a	6.49ab	5.44a	1.26c	14.09a	6.48ab	5.46a	1.23c	14.74a
T_2	6.20 c	4.80 b	1.30bc	9.34b	6.15b	4.72a	1.26c	10.15ab	6.29b	4.97b	1.28bc	11.53b	6.14b	5.01ab	1.25c	12.61b
T_3	6.32 b	4.22 c	1.36a	6.39c	6.42ab	3.34b	1.40a	6.44c	6.52a	4.30c	1.42a	8.98c	6.49ab	3.60c	1.45a	8.16d
T_4	6.49 a	4.71 b	1.33b	7.45bc	6.61a	4.66a	1.37b	8.06bc	6.64a	4.88b	1.33b	10.00bc	6.74a	4.74b	1.35b	10.40c
T_5	6.41ab	4.71 b	1.30bc	7.73bc	6.44ab	4.61a	1.34b	8.03bc	6.57a	4.77b	1.28bc	10.47bc	6.62a	4.70b	1.32b	10.07c
T_6	6.44 a	4.67 b	1.33b	8.22bc	6.45ab	4.69a	1.36b	8.12bc	6.59a	4.75b	1.33b	11.00b	6.69a	4.82b	1.36b	10.72c
CV (%)	2.44	1.33	2.06	13.76	2.72	6.01	2.12	12.89	1.20	2.01	2.12	5.60	2.16	3.69	3.19	4.79
Level of significance	***	***	***	***	*	***	***	***	**	***	***	***	**	***	***	***

Means with the same letter in a column are not significantly different at 5% level by DMRT.
* Significant at 5% level ** Significant at 1% level, *** Significant at 0.1% level, CV = Coefficient of variation

[T_1= Control, T_2 = 100% Recommended Fertilizer, T_3 = 100% Recommended Fertilizer + Biochar (2 t ha^{-1}), T_4 = 3 tons/ha Poultry Manure + Chemical Fertilizer with IPNS basis, T_5 = 3 tons/ha Vermicompost + Chemical Fertilizer with IPNS basis, T_6 = 3 tons/ha Organic Fertilizers + Chemical Fertilizer with IPNS basis].

Fig. 196. Some pictorial view of field experiment (T. aman; var. BRRI dhan 52).

The initial and post-harvest soils from 0-15, 15-30 and 30-45cm depth was collected and analyzed for pH, EC, total nitrogen (TN), phosphorus (P), sodium (Na), potassium (K), sulphur (S) and organic carbon (OC) to determine the effect of biochar on soil chemical properties. From the above results, in all the soil samples (0-15, 15-30 and 30-45cm depth) the pH, TN, P, K, S and OC was found highest in post-harvest soils and lowest in initial soils whereas the EC and Na content was highest in initial soils and lowest in post-harvest soils (Table 176-177).

Table 176. Initial soil chemical properties

Sample	Location	Soil depth (cm)	pH	EC (dS/m)	TN (%)	P (ppm)	Na (meq/ 100g)	K (meq/ 100g)	S (ppm)	OC (%)
1	Nilgonj	0-15	6.04	4.82	0.11	22.32	14.49	0.18	24.82	1.13
2	Nilgonj	15-30	6.36	3.53	0.09	19.71	11.78	0.17	19.48	1.00
3	Nilgonj	30-45	6.82	2.97	0.08	14.81	9.39	0.15	15.15	0.87
4	Latacha pli	0-15	6.25	5.12	0.09	20.22	16.47	0.16	20.21	1.10
5	Latacha pli	15-30	6.67	4.55	0.07	18.68	13.75	0.14	16.00	0.98
6	Latacha pli	30-45	7.06	3.12	0.05	15.86	11.92	0.11	15.30	0.83

Table 177. Post harvest soil chemical properties

Sample	Location	Soil depth (cm)	pH	EC (dS/m)	TN (%)	P (ppm)	Na (meq/ 100g)	K (meq/ 100g)	S (ppm)	OC (%)
1	Nilgonj	0-15	6.35	3.34	0.14	24.33	10.44	0.30	25.23	1.17
2	Nilgonj	15-30	6.65	3.16	0.10	20.19	8.51	0.22	20.49	1.04
3	Nilgonj	30-45	6.75	2.71	0.08	16.85	7.74	0.19	15.26	0.87
4	Latachap li	0-15	6.64	3.60	0.10	22.93	12.16	0.27	21.90	1.12
5	Latachap li	15-30	6.73	3.91	0.07	19.52	10.51	0.20	16.74	1.00
6	Latachap li	30-45	6.81	2.94	0.06	16.44	9.58	0.13	15.76	0.85

The initial and post-harvest soils from 0-15, 15-30 and 30-45cm depth was collected and analyzed for textural class, moisture, bulk density, particle density and porosity to determine the effect of biochar on soil chemical properties. From the above results, in all the soil samples (0-15, 15-30 and 30-45cm depth) the moisture, particle density and porositywas found highest in post-harvest soils and lowest in initial soils whereas the bulk density was highest in initial soils and lowest in post-harvest soils (Table 178--179).

Table 178. Initial soil physical properties

Sample	Location	Soil depth (cm)	Textural class	Moisture (%)	Bulk density (g/cm^3)	Particle density (g/cm^3)	Porosity (%)
1	Nilgonj	0-15	Silty clay	16.22	1.32	2.40	45.00
2	Nilgonj	15-30	Silty clay	18.31	1.38	2.35	41.28
3	Nilgonj	30-45	Silty clay	20.20	1.42	2.30	38.26
4	Latachapli	0-15	Silty clay	15.32	1.47	2.49	40.96
5	Latachapli	15-30	Silty clay	17.22	1.50	2.41	37.76
6	Latachapli	30-45	Silty clay	19.10	1.55	2.39	35.15

Table 179. Post harvest soil physical properties

Sample	Location	Soil depth (cm)	Moisture (%)	Bulk density (g/cm^3)	Particle density (g/cm^3)	Porosity (%)
1	Nilgonj	0-15	24.17	1.28	2.46	47.97
2	Nilgonj	15-30	24.30	1.31	2.39	45.19
3	Nilgonj	30-45	24.90	1.39	2.38	41.60
4	Latachapli	0-15	23.80	1.40	2.50	44.00
5	Latachapli	15-30	23.97	1.44	2.43	40.74
6	Latachapli	30-45	24.30	1.49	2.40	37.92

The initial and post-harvest soils from 0-15, 15-30 and 30-45cm depth was collected and analyzed for biological properties like population density of *Rhizobium*, *Azotobacter* and Phosphate solubilizing bacteria to determine the effect of biochar on soil chemical properties. From the above results, in all the soil samples (0-15, 15-30 and 30-45cm depth) the *Rhizobium*, *Azotobacter* and Phosphate solubilizing bacteriawas found highest in post-harvest soils and lowest in initial soils (Table 180-181).

Table 180. Initial soil biological properties

Sample	Location	Soil depth (cm)	*Rhizobium* (CFU/g)	*Aztobacter* (CFU/g)	Phosphate Solubilizing Bacteria (CFU/g)
1	Nilgonj	0-15	2.17×10^9	1.66×10^9	1.22×10^8
2	Nilgonj	15-30	2.43×10^9	1.72×10^9	1.32×10^8
3	Nilgonj	30-45	2.29×10^9	1.49×10^9	1.09×10^8
7	Latachapli	0-15	2.32×10^9	1.57×10^9	1.16×10^8
8	Latachapli	15-30	2.35×10^9	1.97×10^9	1.08×10^8
9	Latachapli	30-45	2.57×10^9	1.92×10^9	1.19×10^8

Table 181. Post harvest soil biological properties

Sample	Location	Soil depth (cm)	*Rhizobium* (CFU/g)	*Aztobacter* (CFU/g)	Phosphate Solubilizing Bacteria (CFU/g)
1	Nilgonj	0-15	2.73×10^9	2.75×10^9	1.56×10^8
2	Nilgonj	15-30	2.53×10^9	2.55×10^9	1.38×10^8
3	Nilgonj	30-45	2.46×10^9	2.48×10^9	1.11×10^8
7	Latachapli	0-15	2.70×10^9	2.74×10^9	1.53×10^8
8	Latachapli	15-30	2.40×10^9	2.44×10^9	1.11×10^8
9	Latachapli	30-45	2.55×10^9	2.34×10^9	1.19×10^8

12. Research highlight (title, background, objectives, methodology, key findings, and key words):

BARI Component

<table>
<tr><td>1. Title of technology</td><td>:</td><td>Application of Biochar in acidic soils of Narsingdi region to alleviate soil acidity and increase productivity of Cauliflower-Ladies finger-Indian Spinach cropping pattern</td></tr>
<tr><td>Background</td><td>:</td><td>1. Biochar can be produced from crop residues (e.g., rice husk, straw, black gram, mustard, barley, groundnut etc.), poultry liter and use into the soil.
2. Lime or dolomite is commonly used for acidic soils amelioration. But those have to be applied at least 15 days prior to sowing/transplanting for complete chemical reaction in the soil. In addition, seeds or seedlings can be sown immediately after using biochar which can reduce soil acidity as well as enriches the soil with carbon and maintains the health of the soil.
3. Biochar can be used at any time of the year.
4. Use of biochar increases the use efficiency of inorganic fertilizers in the soil.</td></tr>
<tr><td>Objectives</td><td>:</td><td>1. To find out comparative advantage of biochar application over other organic and inorganic amendments in reducing soil acidity.
2. To find out performance of different amendments in increasing productivity of Cauliflower-Ladis finger-Indian Spinach cropping pattern.</td></tr>
<tr><td>Methodology of Technology</td><td>:</td><td>
<table>
<tr><th>Cropping pattern</th><th>Cauliflower</th><th>Ladies finger</th><th>Indian spinach</th></tr>
<tr><td>Variety</td><td>Snow White</td><td>Greenfinger</td><td>Bari Puishak-</td></tr>
<tr><td>Season</td><td>Rabi</td><td>Kharif-1</td><td>Kharif-2</td></tr>
<tr><td>Sowing Time / Planting</td><td>First week of November</td><td>First week of March</td><td>First week of June</td></tr>
<tr><td>Sowing / planting method

Row to row (cm)
Plant to plant (cm)</td><td>Transplanting-35 days old seedlings
50
50</td><td>Sowing-2 seeds

20
20</td><td>Transplanting-35 days old seedlings
20
15</td></tr>
<tr><td>Irrigation</td><td>as required</td><td>as required</td><td>as required</td></tr>
<tr><td>Weed control</td><td>as needed</td><td>as needed</td><td>as needed</td></tr>
<tr><td>Disease and insect control</td><td>as needed</td><td>as needed</td><td>as needed</td></tr>
<tr><td>Harvest time</td><td>From last week of January to second week of February</td><td>First week of April to last week of May</td><td>Last week of July to first week of October</td></tr>
</table>
Fertilizer rate:
<table>
<tr><th>Fertilizer</th><th>Cauliflower</th><th>Ladies finger</th><th>Indian spinach</th></tr>
<tr><td>Urea (kg / ha)</td><td>270</td><td>160</td><td>150</td></tr>
<tr><td>TSP (kg / ha)</td><td>140</td><td>70</td><td>50</td></tr>
<tr><td>MOP (kg / ha)</td><td>160</td><td>90</td><td>45</td></tr>
</table>
</td></tr>
</table>

Gypsum (kg / ha)	130	55	0
Zinc sulphate (monohydrate) (kg / ha)	5	3	0
Boric acid (kg / ha)	2	0	0
Poultry liter biochar (t /ha)	2	0	0

Biochar application:
At the time of final land preparation, 2 tons / ha of poultry liter biochar should be applied and mixed thoroughly with the soil.

Fertilizer application method

Cauliflower:
Full amount of TSP, MoP, gypsum, zinc sulphate (monohydrate), boric acid and biochar and 1/3 of urea should be applied as basal dose during the final land preparation. Rest of urea should be applied in two equal installments at 25-30 and 50-55 days after transplanting.

Ladies finger:
Full amount of TSP, MoP, gypsum, zinc sulphate (monohydrate) and 1/3 of urea should be applied as basal dose during the final land preparation. Rest of urea should be applied in two equal installments at 25-30 and 50-55 days after sowing.

Indian spinach:
Full amount of TSP, MoP and 1/3 urea should be applied as basal dose during the final land preparation. The remaining urea should be applied in two equal installments at 25-30 and 50-55 days after transplanting.

Yield	**Recommended fertilizer (t/ha)**	**Biochar with Recommended fertilizer(t/ ha)**
Cauliflower	27.74	35.75
Ladies finger	13.16	16.57
Indian spinach	20.14	24.17
Total System productivity (equivalent yield of cauliflower)	57.55	74.69

Key findings :

- Poultry liter biochar acts as a liming material. Applying 2 t of Poultry liter biochar per hectare decreases soil acidity of the acidic soil.
- Increases total system productivity of the cropping pattern. Application of 2 t/ha of poultry liter biochar, the total system productivity of the pattern is 74.69 t / ha (equivalent yield of cauliflower) which is 29.8% higher than the recommended fertilizer treated yield.

2. Title of technology	:	**Application of biochar in drought prone areas of Barind region to preserve soil moisture and increase productivity of Mustard-Boro-Aus cropping pattern**
Background	:	**1.** Biochar can be produced from crop residues (e.g. rice husk, straw, black gram, mustard, barley, groundnut etc.), poultry liter and use into the soil. **2.** Biochar sustains soil health and does not require extra time for seed sowing or seedlings transplanting. **3.** Use of biochar in soil increases soil microorganisms as the soil is rich in carbon as well as preserves soil moisture. **4.** Biochar in soil for crop production can be used at any time of the year. **5.** Biochar increases the use efficiency of the applied inorganic fertilizers in

soil.

Methodology of Technology :

Cropping pattern	**Mustard**	**Boro**	**Transplanted Aus**
Variety	BARI Shorisha-14	BRRI dhan28	BRRI dhan88
Season	Rabi	Kharif-1	Kharif-2
Sowing / planting time	First week of November	First week of February	Second week of May
Sowing / planting method	Seed sowing	35 days old seedlings	25 days old seedlings
Row to row distance(cm)	30	20	20
Seed / Seedling distance (cm)	5	20	15
Irrigation	3	4	4
Disease and insect control	As required	As required	As required
Weed control	As required	As required	As required
Harvest time	Last week of January	First week of May	Last week of July

Fertilizer rate:

Fertilizer	**Mustard**	**Boro Rice**	**T. Aus rice**
Urea (kg / ha)	200	160	100
TSP (kg / ha)	120	80	35
MOP (kg / ha)	140	80	35
Gypsum (kg / ha)	80	30	20
Zinc sulphate (monohydrate) (kg / ha)	9	4	4
Boric acid (kg / ha)	5.5	0	0
Rice husk biochar (t / ha)	2	0	0

Biochar application:
At the time of final land preparation, 2 t / ha of rice husk biochar should be applied and mixed thoroughly with the soil.

Fertilizer application method
Mustard:
For mustard cultivation, except urea all other fertilizers should be applied during the final land preparation and mixed with the soil. Urea should be applied in three equal installments at 10, 20 and 40 days after sowing.

Boro Rice:
Except urea, all other fertilizers should be applied at the time of final land preparation. Urea should be applied in three equal installments at 6, 35 days (tillering stage) and 52 days (5-6 days before flowering) after transplanting.

Transplanted Aus:
Except urea, all other fertilizers should be applied at the time of final land preparation. Urea should be applied in three equal installments at 10, 30 (at

tillering stage) and 45 days (5-6 days before flowering) after transplanting.

Yield	Recommended fertilizer (t/ha)	Biochar with Recommended fertilizer (t/ha)
Mustard	1.13	1.45
Boro rice	5.33	6.35
T.Aus	3.82	4.32
Total System Productivity (Equivalent yield of boro rice)	13.67	17.47

Key findings :

- Application of 2 t/ha of rice husk biochar, the total system productivity of the pattern is 17.47 t / ha (equivalent yield of boro rice) which is 27.8% higher than the recommended fertilizer treated yield.
- Increases soil fertility.
- Increases soil water holding capacity by preserving soil moisture

Key words : Biochar, Drought, Moisture, Mustard, Boro, Aus

3. Title of technology : **Biochar application in saline soils of Khulna region to reduce soil salinity and increase productivity of Sweet gourd-fallow-Transplanted aman cropping pattern**

Background :

1. Biochar can be produced from crop residues (e.g., rice husk, straw, black gram, mustard, barley, groundnut, etc.), poultry liter and use in the soil.

2.Biochar increases the water holding capacity of the soil thus reducing salinity as well as enriching the soil with carbon and acting as a habitat for soil microorganisms. Seeds can be sown or transplanted immediately after the application of biochar in the soil.

3. Biochar can be used at any time of the year.

4. Biochar increases the use efficiency of applied inorganic fertilizers in the soil.

Methodology of Technology

Cropping pattern	Sweet gourd	T.Aman
Variety	Monica	BRRI dhan78
Season	Rabi	Kharif -2
Transplanting time	First week of December	First week of July
Transplanting of seedling	20-day old seedlings in pit Row to row - 3.0 m Pit to pit - 1.5 m	35 days old seedlings are transplanted Row to row - 20 cm Plant to plant- 20 cm
Irrigation	As required	As required
Disease and insect control	As required	As required
Harvest time	Second week of February to third week of March	Last week of November

Fertilizer rate:

Fertilizer	Sweet Gourd (2222 pit/ha)	Transplanted Aman
Urea (kg/ha)	200	120
TSP (kg/ha)	180	40
MOP (kg/ha)	160	40
Gypsum (kg/ha)	100	20
Zinc sulphate (monohydrate) (kg/ha)	10	4
Boric acid (kg / ha)	8	0
Rice husk biochar (t / ha)	2	0

Biochar application:
At the time of final land preparation, 2 t / ha of rice husk biochar should be applied and mixed thoroughly with the soil.

Fertilizer application method:

Sweet Gourd:
All TSP, MoP, gypsum, zinc sulphate (monohydrate), boric acid and biochar and 1/4 of urea should be applied as basal dose during the final land preparation. The remaining urea should be applied in three equal installments at 20-25, 40-45 and 60-65 days after transplanting.

Transplanted Aman:
Except urea all other fertilizers should be applied in soil at the time of final land preparation. Urea should be applied in soil in three equal installments at 7,35 (tillering stage) and 55 (5-6 days before flowering) days after transplanting.

Crops	Recommended fertilizer application (t / ha)	Biochar application with recommended fertilizer application (t /ha)
Sweet Gourd	15.34	19.21
T. Aman	3.18	3.60
Total system productivity (equivalent yield of transplanted aman)	9.32	11.28

Key findings :

- Application of 2 t/ha rice husk biochar, the total system productivity of the pattern is 11.28 t /ha which is 21% higher than the recommended fertilizer treated yield.
- The salinity of the saline soil can be reduced using biochar as it acts as mulch on the soil.
- Increases soil fertility.

Key words : Biochar, Salinity, Sweet gourd, T. Aman

BRRI Component

Improvement of soil health and crop productivity of major problem soils of Bangladesh through organic amendments. Soil is regarded as the primary recipient of toxic heavy metals and is mostly contaminated through different industrial activities. Objective of the study were i) to characterize the bio-physico-chemical properties of soil in heavy metal polluted areas of Sripur, Gazipur, ii) to determine mineralization rate of organic materials and evaluate the effect of organic materials for amelioration of heavy metal pollution in Sripur, Gazipur industrial areas and iii) to determine the effect of organic materials on crop yield and soil health. Study site were Sripur, Mirzapur and Pirujali. The main findings of the research were;

a) Rice soils of study area were acidic in nature, rich in OM and contaminated with Fe^{++}, Pb, Cd. The soil microbial populations and biomass carbon were very low compared to any healthy agricultural soil.

b) Incubation study result showed that irrespective of soils, higher amount of C, N and P accumulation was found in vermicompost (VC) applied treatment. Application of VC significantly increased C mineralization rate among the treatments and slightly higher (k =0.081) trend was found in the polluted soil. Applications of treatments were not able to reduce soil Cd and Pb concentration below the toxic limit.

c) Biochar, VC, poultry manure, organic fertilizer and bacteria inoculum were applied as organic source along with chemical fertilizer as IPNS basis to ameliorate the heavy metal toxicity and found that there was little or no significant positive effect found on grain yield of rice due to application of OM's and chemical fertilizer. There were abundant nutrients due to application of OM and chemical fertilizer but their impact on grain yield was suppressed by Fe toxicity and high concentrations of other heavy metals.

Key words: Rice, Heavy metal toxicity, biomass C, microbial populations, Nutrient uptake.

BINA Component

Experiment 1 :
Benchmark survey to characterize biophysico- chemical properties of soil in the selected study areas

- Soil organic carbon is medium level so; organic material is needed to improve soil quality.
- Microbial biomass carbon and total nitrogen contents are low in the soil.
- Potassium and phosphorus contents are high in the soil.

Experiment 2:
Study on the mineralization rate of commonly used organic materials in Bangladesh under field capacity and CSW conditions

- CSW increases 31.00 and 18.63% more NH_4-N and NO_3-N in soil over field capacity.
- Cowdung, biochar, organic fertilizer, and vermicompost increase 18.52, 29.63, 28.40, and 32.10% higher organic carbon over control means only soil.
- Maximum k value (0.0092 g d^{-1}) is observed in CSW × VC.
- 250μ size aggregate soil fraction contains the highest organic carbon content in the soil.

• Field capacity and organic fertilizer produce 59.95 and 27.15% higher cumulative CO2 than continuous standing water conditions and other organic amendments, respectively.

Experiment 3 :
Improvement of soil health in unfavorable eco-systems with organic amendments for sustainable crop production

- Integrated plant nutrition system (IPNS) + organic fertilizer (3 t ha-1) increase 9% rice yield over the recommended dose of chemical fertilizers in the T. aman season.
- Integrated plant nutrition system (IPNS) + organic fertilizer (3 t ha^{-1}) increase 44% mustard yield over the recommended dose of chemical fertilizers in rabi season
- Integrated plant nutrition system (IPNS) with 3.0 t ha-1 of poultry manure, vermicompost, and organic fertilizer increase 19, 21, and 18% organic carbon over the recommended dose of chemical fertilizer.

BAU Component

Title: Improvement of soil health and crop productivity in climate vulnerable and polluted areas through organic amendments

Background
Application of chemical fertilizers has been increasing in the world for enhancing cropping diversity and intensity for feeding the teeming population. However, sole application of chemical fertilizers not only increased economic loss but also caused several concerns for soil biological and physic-chemical degradation. Climate change, buildup of soil salinity and acidity, development of heavy metals including arsenic are major concerns which degrade soil health and hinder crop production in Bangladesh (Rahman et al., 2005; Akter et al. 2012; Rahman et al., 2016). Bangladesh is one of the most climate vulnerable countries in the world. The effects of climate change in agriculture can no longer be ignored and further climate risks to agriculture are expected to increase in coming decades (World Bank, 2012). Productivity of different crops in Bangladesh has been decreased because of degradation of soil health through adverse climatic events and pollution of different sources. Salinity is an environmental problem which is expected to aggravate because of climate change and sea level rise (IWM, 2014). Soil and water salinity is a burning issue which is increasing at an alarming rate in the coastal areas. Increasing soil acidity is also a major concern, especially in the Madhupur Tract. High concentration of different heavy metals in soils of industrial areas and arsenic in soils mainly in the Ganges Floodplains may cause reduction in crop yields as well as long term risks to ecosystems and humans health. The present rice production in the country is 34.86 MT (AIS, 2016), which needs to increase 44.5 MT in 2050 (Kabir et al., 2015). To ensure the food security in the south Asia it is estimated that annual rice and wheat production has to be increased by 1.1% and 1.7%, respectively in the next four decades (Ladha et al., 2003; Gathala et al., 2013). Moreover, the agricultural land is declining every year by 1% because of new human settlement, industrial expansion and road construction in many Asian countries including Bangladesh and India. Globally, it is estimated that feeding the world population will require 60% more yield in 2050 (FAO, 2014). Such an increase in agricultural production needs to be accomplished without jeopardizing soil and environment. Agriculture sector has some impact on climate change through greenhouse gas (GHG) emission, while the sector not only emits greenhouse gases, but also can sequester huge amount of carbon in soil if managed properly (Rahman, 2013; Rahman *et al.,* 2016). In Bangladesh, intensive cropping with modern crop varieties and use of less or no organic manures and crop residues results in decreased soil organic carbon and plant nutrients leading to severe land degradation. Applications of different organic materials transform into

stable forms of carbon with high adsorption sites which might help heavy metal adsorption and organo-mineral complexation and ultimately helps in environmental amelioration. It is hypothesized that resource conservation technologies comprising soil and crop management practices (minimum tillage, vermicompost, Tricho-compost, poultry manure, household wastes, organic fertilizers, crop residues, biochar etc.) can improve soil resilience and increase its productive capacity in the climate vulnerable and polluted areas and therefore studies are needed in these issues.

Objectives

- To characterize the biological and physico-chemical properties of problem soils of charland (Char Dadna, Islampur) and acidic soils (Madhupur);
- To prepare and characterise biochars from different organic sources for amending acid and char land soils;
- To investigate effect of biochars and other organic amendments on crop yields, soil health and carbon sequestration;
- To measure carbon and N mineralization rate and to evaluate the effect of organic materials for amending acid soils of Madhupur and Charland of Islampur.

Methodologies

The soils of the experimental sites were characterized along with identification of the existing cropping patterns. Initial soil characterization, evaluation of the nutrient content in organic materials for soil amendment and application to soils in the field was performed since April 2018. Biochar was produced using a biochar plant at BAU farm with pyrolysis of poultry manure and rice husk at 450°C for few hours. After completing the initial characterization of soils in acid and char land, two field experiments have been set. Different organic amendments were applied to the soils for improving crop production and soil health. Organic fertilizers mixing with acid and charland soils were placed in pots for incubation for 120 weeks at 25° C at control conditions to quantify mineralization rates of different nutrients. After each cropping pattern the system productivity was evaluated and after two consecutive years of cropping with the same organic amendments, changes in soil health parameters were evaluated.

All the samples will be analyzed for texture, moisture, bulk density, porosity, soil aggregate stability, pH, nutrients N, P, K, Ca. Mg, Na, S, B, Zn, CEC, water holding capacity, field capacity and microbial biomass C and N contents and microbial population following the standard laboratory protocols: soil organic carbon content has been analysed by wet oxidation method (Walkley and Black, 1934). Soil total N was determined using the Kjeldahl method (Bremmer and Mulvaney, 1982); Soil aggregate stability will be measured by wet sieving method (Patton et al., 2001); Water holding capacity by pressure plate method; Field capacity by gravimetric method; Soil bulk density (ρb) was determined by following the standard core method (McKenzie et al., 2004; Microbial Biomass C by chloroform fumigation extraction method (Wu *et al*., 1990; Vance et al., 1987) and Microbial Biomass N chloroform fumigation extraction method(Brookes et al., 1985). Soil basal respiration (BR) was measured by the *in-vitro* steady static incubation method (Cheng *et al.,* 2013) and soil microbial population was measured by plate count method. A glass electrode pH meter was used to measure the pH of the samples in a 1: 2.5 (soil: water ratio) (Jackson, 1973).

Key findings

In both acidic and char land sites, a three-crop pattern can be accommodated and system productivity can be increased. Organic treatments in both sites have improved soil health parameters like physico-chemical condition and microbial population. Soil organic carbon can be increased with organic amendments. In acidic soil site, poultry manure biochar and dolomite improved soil crop yields and soil quality. However, biochar was found to be the

best treatment to increase soil pH and organic carbon content. In char land site, poultry manure biochar and vermicompost were found to be better to improve soil quality, crop yields, and carbon sequestration capacity.

Keywords: soil health, cropping pattern, biochar, dolomite, vermicompost, poultry manure, acidic soil, char land soil

BSMRAU Component

Title: Improvement of soil health and crop productivity of major problem soils of Bangladesh through organic amendments.

Background: Climate change, buildup of soil salinity and acidity, development of heavy metals including arsenic are major concerns which degrade soil health and hinder crop production in Bangladesh (Rahman et al., 2005; Akter et al. 2012; Rahman et al., 2016). Bangladesh is one of the most climate vulnerable countries in the world. The effects of climate change in agriculture can no longer be ignored and further climate risks to agriculture are expected to increase in coming decades (World Bank, 2012). Productivity of different crops in Bangladesh has been decreased because of degradation of soil health through adverse climatic events and pollution of different sources. Salinity is an environmental problem which is expected to aggravate because of climate change and sea level rise (IWM, 2014). Soil and water salinity is a burning issue which is increasing at an alarming rate in the coastal areas. Increasing soil acidity is also a major concern, especially in the Madhupur Tract. High concentration of different heavy metals in soils of industrial areas and arsenic in soils mainly in the Ganges Floodplains may cause reduction in crop yields as well as long term risks to ecosystems and humans health. The present rice production in the country is 34.86 MT (AIS, 2016), which needs to increase 44.5 MT in 2050 (Kabir et al., 2015). To ensure the food security in the south Asia it is estimated that annual rice and wheat production has to be increased by 1.1% and 1.7%, respectively in the next four decades (Ladha et al., 2003; Gathala et al., 2013). Moreover, the agricultural land is declining every year by 1% because of new human settlement, industrial expansion and road construction in many Asian countries including Bangladesh and India. Globally, it is estimated that feeding the world population will require 60% more yield in 2050 (FAO, 2014). Such an increase in agricultural production needs to be accomplished without jeopardizing soil and environment. Agriculture sector has some impact on climate change through greenhouse gas (GHG) emission, while the sector not only emits greenhouse gases, but also can sequester huge amount of carbon in soil if managed properly (Rahman, 2013; Rahman et al., 2016). In Bangladesh, intensive cropping with modern crop varieties and use of less or no organic manures and crop residues results in decreased soil organic carbon and plant nutrients leading to severe land degradation. Applications of different organic materials transform into stable forms of carbon with high adsorption sites which might help heavy metal adsorption and organo-mineral complexation and ultimately helps in environmental amelioration. It is hypothesized that resource conservation technologies comprising soil and crop management practices (minimum tillage, vermi-compost, tricho-compost, poultry manure, household wastes, organic fertilizers, crop residues, biochar etc.) can improve soil resilience and increase its productive capacity in the climate vulnerable and polluted areas and therefore studies are needed in these issues.

Objectives:

Sub-project general objective (s):

i. Bio-physicochemical characterization of soil in the climate vulnerable and polluted areas,

ii. Examine potentiality of different organic materials for amending problem soils and improving crop yields in the study areas
iii. Quantify the effects of different organic materials on carbon sequestration
iv. Development of climate smart technology packages for major crops and cropping patterns in Bangladesh.

Sub-project specific objectives:

i. Characterize the bio-physicochemical properties of soil in the climate vulnerable Dekar haor areas of Sunamganj, arsenic area of Faridpur sadar, saline areas of Batiaghata and heavy metal polluted areas of Bhaluka using different organic amendments
ii. Evaluate the adsorption and desorption isotherms of heavy metals using organic materials including biochar for amending heavy metals in Bhaluka.
iii. Mineralization study of organic materials and their effects of climate vulnerable and arsenic and heavy metal polluted areas on soil properties and crop productivity and carbon sequestration in the selected areas.

Methodology:

Benchmark survey to characterize bio-physicochemical properties of soil in the selected study areas

Soil samples were collected from the selected study areas of the climate vulnerable Dekar haor areas of Sunamganj, arsenic area of Faridpur sadar, saline areas of Batiaghata and heavy metal polluted areas of Bhaluka. Soil samples were collected from each point from the selected study areas. All the samples were analyzed for Chemical properties like pH, N (%), OC (%), P (mg/kg), S (mg/kg), K (cmol/kg), Zn (mg/kg), CEC (cmol/kg), NH_4-N (mg/kg), NO_3-N (mg/kg), physical properties like bulk density (g/cm3), carbon sequestration (t/ha) and biological properties like biomass C (mg /kg), biomass N (mg/kg) were analyzed using standard methods and heavy metals Pb, Cd, Ni, As contents following standard protocols (Page et al., 1989). Carbon stock and C sequestration were calculated using the following equation 1 and 2, respectively (Rahman et al., 2016).

Carbon stock (t ha^{-1}) = Carbon concentration (%) x bulk density (g cm^{-3}) x depth (cm) …. (1)
Carbon sequestration (t ha^{-1}) = Final C stock (t ha^{-1}) – Initial C stock (t ha^{-1}) …….. (2)

Small Scale Production of biochar: Different crop residues were collected and air-dried at room temperature and ground to pass a 10-mesh sieve. The ground crop residues were then placed in biochar plant. The pyrolysis temperature was raised to 300-450 ^{O}C at a rate of approximately 20^{O}C per min and hold constant for 4 h, then biochar was allowed to cool at room temperature using modified method (Rahaman et al., 2020).

Study on the mineralization rate of commonly used organic materials in Bangladesh under field capacity and CSW conditions (Laboratory study)

Two factors: 4 types of organic materials (biochar, poultry manure, vermicompost and standard organic fertilizer) under 2 moisture regimes (Field capacity and continuous standing water) were studied. Organic materials (2.5 g C kg^{-1} soil) were mixed with soil and kept for 9 incubation periods (0, 3, 7, 15, 21, 30, 60, 90 and 120 days). Carbon mineralization rate (k) was calculated using the following kinetic model (Standford and Smith, 1972).

$C/C_0 = (1-e^{-kt})$ …… (3)
C, C_0, k and t indicate final C, initial C, degradation rate constant and time, respectively.

Adsorption and desorption study of heavy metals using different organic materials

Adsorption and desorption study was carried out with the following method (MS thesis, Md. Jahangir Alam, 2020).

$$R = \frac{Co - Ce}{Co} \times 100 \quad \text{---------- (1)}$$

Where,
C_0 (mg L^{-1}) represents the initial nitrate concentration in the solution,
Ce (mg L^{-1}) represents the nitrate concentration in the solution at equilibrium and
R represents the adsorption percentage of Cd, Pb and Ni.
The adsorption capacity of biochar at time t were determined by using the equation (2) while the adsorption equilibrium of Cd, Pb and Ni were calculated based on equation (3)

q_t (mg g^{-1}) = $[(C_o – C_t)V]/m$ ---------- (2)

q_e (mg g^{-1}) = $[(C_o – C_e)V]/m$ ---------- (3)

Where,
C_o represents the initial concentration of Cd, Pb and Ni solutions (mg L^{-1}),
q_t represents the concentration of Cd, Pb and Ni at time t (mg g^{-1}),
q_e represents the Cd, Pb and Ni uptake at equilibrium,
C_e represents the equilibrium concentration of Cd, Pb and Ni (mg L^{-1}) respectively,
V represents the volume of Cd, Pb and Ni stock solution (L) and
m indicates the weight of the biochar used (g).

Improvement of soil health in unfavorable eco-systems with organic amendments for sustainable crop production

A series of field experiments with rice-rice cropping pattern in consecutive two years were carried out in the three locations of arsenic area of Faridpur sadar, saline areas of Batiaghata and heavy metal polluted areas of Bhaluka with the following treatments.

Treatments:
T_1 = Control, T_2 = Recommended Fertilizer, T_3 = Biochar + Recommended Fertilizer, T_4 = Poultry Manure + Chemical Fertilizer, T_5 = Vermicompost + Chemical Fertilizer, T_6 = Standard Organic Fertilizer + Chemical Fertilizer

Key findings:

Three problem soils as industrial polluted areas (Bhaluka), saline soil (Batiagata, Khulna) and arsenic polluted areas (Faridpur sadar) were selected for the study on “Improvement of soil health and crop productivity of major problem soils of Bangladesh through organic amendments”. The activities and key outputs by the Department of Soil Science of BSMRAU is summarized below for the period of 2018-21 under the project.

- A series of field experiments with T. aman and boro rice were conducted in the selected three locations. The yield data of T. aman at industrial polluted area of Bhaluka, saline soil of Batiagata and arsenic polluted area of Faridpur sadar were significantly influenced with the different organic materials treatments.
- In average, the maximum grain yield 5.43 t/ha in the T4 (Poultry Manure + Chemical Fertilizer) treatment which was statistically similar to T5 (Vermicompost + Chemical Fertilizer) treatment (5.38 t/ha) followed by T3 (Biochar + Recommended Fertilizer) treatment (4.66 t/ha) as compared to the lowest yield (3.56 t/ha) of T1 (control) treatment.
- After consecutive two seasons the grain yield in T4 treatment of both T. aman and boro rice was increased by 33-40% over control treatment in all sites.
- Mineralization and nutrient dynamics of organic materials under the field capacity and

continuous standing water at laboratory and field conditions to investigate the impact of various organic materials for determining how fast organic matter mineralizes and releases nutrients into the soil. The soil was treated with six types of organic materials, *viz.* Cowdung (CD), cowdung slurry (CDS), rice husk biochar (RHB), Vermicompost (VC), Tricocompost (TC) and Bacterial inoculant (BI) under field capacity and continuous standing water condition with control treatment. At incubation periods with different organic materials have a significant impact on carbon, nitrogen, ammonium and nitrate nitrogen mineralization in soils at different days after incubation. The mineralization trends of carbon and nitrogen maintains the order of CDS>CD>VC>TC>BI>RHB>Control and CDS>CD>VC>TC>BI>RHB>Control respectively both in the laboratory and field conditions.

- The trend of heavy metals (Pb, Cd and Ni) adsorption and desorption capacities were found with the following orders of RHB>VC>CD>CDS>TC and TC>CDS>CD>VC>RHB, respectively.

Key words: bio-physicochemical, organic amendments, adsorption and desorption, biochar, Mineralization, carbon sequestration

SAU Component

Title: Improvement of soil health in unfavorable eco-systems (saline soil) with organic amendments for sustainable crop production

Climate changes, buildup of soil salinity in soils are major concerns which degrade soil health and hinder crop production in Bangladesh. Bangladesh is one of the most climate vulnerable countries in the world. The effects of climate change in agriculture can no longer be ignored and further climate risks to agriculture are expected to increase in coming decades. Productivity of different crops in Bangladesh has been decreased because of degradation of soil health through adverse climatic events and pollution of different sources. Salinity is an environmental problem which is expected to aggravate because of climate change and sea level rise. Soil and water salinity is a burning issue which is increasing at an alarming rate in the coastal areas. Applications of different organic materials transform into stable forms of carbon with high adsorption sites which might help heavy metal adsorption and organo-mineral complexation and ultimately helps in environmental amelioration. It is hypothesized that resource conservation technologies comprising soil and crop management practices (minimum tillage, vermicompost, Trichocompost, poultry manure, household wastes, organic fertilizers, crop residues, biochar etc.) can improve soil resilience and increase its productive capacity in the climate vulnerable and polluted areas and therefore studies are needed in these issues.

Objective: To evaluate the effect of organic amendments on maize (var. Don 111) and T. aman (BRRI dhan52) for sustaining yield and improve soil health in saline soil.

Methodology: Crop: Maize (var. Don 111)and T. aman (BRRI dhan52)

Design: RCBD, Replication :3,

Treatments: 6(six),
T_1= Control,
T_2 = 100% RDCF (Recommended Dose of Chemical Fertilizer)
T_3 = 100% RDCF + Biochar (2 t/ha)
T_4 = Poultry manure 3 t/ha + rest of the nutrients from chemical fertilizers
T_5 = Vermicompost 3 t/ha + rest of the nutrients from chemical fertilizers
T_6 = Organic fertilizer 3 t/ha + rest of the nutrients from chemical fertilizers

Factors: Two (Mulch and non-mulch only in case of Maize)
Location: Kalapara, Patuakhali (AEZ- 13)

Key Findings: The results found that among all the organic amendments biochar is more stable in soil. On the other hand, biochar reduce the soil EC and Na in a lower limit than other organic amendments as a result the highest crop yield was found in biochar treated plots. So, biochar is a new technology to reduce soil salinity and increase crop yield in saline soils.

Key words: Biochar, vermicompost

B. Implementation Status

1. Procurement:

Description of equipment and capital items	PP Target		Achievement		Remarks
	Physical (No.)	Financial (Tk.)	Physical (No.)	Financial (Tk.)	
BARC Component					
(a) Office equipment					
i) Desktop Computer	01	60000	01	59800	
ii) Laptop	01	60000	01	59900	
iii) UPS (Offline)	01	10000	01	9800	
iv) Portable HDD	02	17000	02	17000	
v) Digital Camera	01	25000	01	25000	
BARI Component					
(a) Office equipment					
1. Laptop	01	60000	01	60000	Good condition
(b) Lab & field equipment					
1. GPS machine	01	24500	01	24500	Good condition
2. Digital slide calipers	01	25000	01	25000	Good condition
3. Plant sampler grinder	01	298000	01	298000	Good condition
4. pH meter (portable)	01	90000	01	90000	Good condition
5. pH meter (bench top)	01	240000	01	240000	Good condition
6. EC meter (portable)	01	60000	01	60000	Good condition
7. Automatic pH titrator	01	482000	01	482000	Good condition
8. Micro pipette	01	30000	01	30000	Good condition
9. Biochar making device	02	200000	02	200000	Good condition
(c) Other capital items					
1. Bicycle	01	12000	01	12000	Good condition
BRRI Component					
(a) Office equipment:					
i) Desktop Computer	01	60000	01		
ii) CJPS (offline)	01	10000	01		
iii) Laptop	01	60000	01		
iv) Computer Table	01	5000	01		
v) Computer Chair	01	3500	01		
vi) Visitor chair	01	20000	01		

Description of equipment and capital items	PP Target		Achievement		Remarks
	Physical (No.)	Financial (Tk.)	Physical (No.)	Financial (Tk.)	
vii) File cabinet	01	20000	01		
viii) Executive chair	01	10000	01		
ix) Incubator	01	150000	01		
(b) Lab & field equipment:	Lump	Total: 394500 (Year 1) Total: 200000 (Year-2)	Lump	Total: 393000 (Year -1) Total: 198000 (Year-2)	100% (Price re-fixed as per BRRI procurement committee)
(c) Other capital items i) Autoclave	01	Total: 500000	01	499000	100% (Price re-fixed as per BRRI procurement committee)
BINA Component					
(a) Office equipment					
i) Laptop	01	60000	01	56000	
ii) Laser Printer	01	20000	01	25200	
iii) Freeze	01	45900	01	42500	
(b) Lab &field equipment					
i) Distillation unit	01	594000	01	385000	
ii) Digital balance	01	120000	01	107900	
iii) Sieve shaker and sieve	01 and 04	120000	01 and 04	197000	
iv) Magnetic stirrer	01	42000	01	26500	
v) Soil moisture/temp/EC meter	03	100000	03	50000	
(c) Other capital items					
BAU Component					
(1) **Office equipment**					
2) **Lab/Field Equipment**					
a) Digital Camera	1	25000	1	25000	
b) Desktop Computer	1	58400	1	58400	
c) UPS	1	6000	1	6000	
d) pH & EC meter	1	120000	1	120000	
e) Printer	1	20000	1	20000	
BSMRAU Component					
(a) Office equipment					
i) Laptop	1	85000.00	1	85000.00	

Description of equipment and capital items	PP Target		Achievement		Remarks
	Physical (No.)	Financial (Tk.)	Physical (No.)	Financial (Tk.)	
ii) Desktop Computer	1	60000.00	1	60000.00	
iii) Digital Camera	1	25000.00	1	25000.00	
(b) Lab & field equipment					
i) Hollow cathode lamps (As, Pb, Cd, Ni)	4	154000.00	4	154000.00	
ii) Auto dispenser (1 L)	2	148000.00	2	148000.00	
iii) Micro pipette	2	58000.00	2	58000.00	
iv) GPS	1	40000.00	1	40000.00	
v) 4 digit balance	1	105000.00	1	105000.00	
vi) Plant sample grinder	1	310000.00	1	310000.00	
(c) Other capital items					
i) Bicycle	1	12000.00	1	12000.00	
SAU Component					
(a) Office equipment	4	100000	4	100000	
(b) Lab & field equipment	1	100000	1	84000	
(c) Other capital items					

2. Establishment/renovation facilities: N/A

Description of facilities	Newly established		Upgraded/refurbished		Remarks
	PP Target	Achievement	PP Target	Achievement	
SAU Component					
i) PI room repair (one table fan, one stand fan, bulb, wire)			PI room repair	Completed	
ii) Repairing distillation plant of soil science department, SAU-			Repairing distillation plant	Completed	
iii) Irrigation pump repairing at Patuakhali-			Irrigation pump repairing	Completed	
iv. 5 Sitting chair purchase at PI room	Sitting chair purchase	Completed			

3. Training/study tour/ seminar/workshop/conference organized:

Description	Number of participants			Duration (Days/weeks/ months)	Remarks
	Male	Female	Total		
BARC Component					
(a) Training					
(b) Workshop					
i) Inception workshop	54	11	65	09-08-2018 (01day)	
ii) 1st Annual review workshop	43	07	50	26-06-2019 (01day)	
iii) 2nd Annual review workshop	51	09	60	29-09-2020 (01day)	
(c) Others (if any)					

C. Financial and physical progress (Combined & Component wise)

Fig in Tk

Items of expenditure/activities	Total approved budget	Fund received	Actual expenditure	Balance/ unspent	Physical progress (%)	Reasons for deviation
Combined (All Component)						
a. Contractual staff salary	12337596	12352975	12352975	0	100%	
b. Field research/lab expenses and supplies	12734901	12689795	12689795	0	100%	
c. Operating expenses	2626921	2515347	2515347	0	100%	
d. Vehicle hire and fuel, oil & maintenance	1939000	1884720	1884720	0	100%	
e. Training/workshop/ seminar etc.	739900	646420	646420	0	100%	
f. Publications and printing	550000	480100	480100	0	100%	
g. Miscellaneous	849145	783217	783217	0	100%	
h. Capital expenses	4830600	4830000	4830000	0	100%	
Total	**36608063**	**36182574**	**36182574**	**0**	**100%**	
BARC Component						
a. Contractual staff salary	4834539	4834539	4834539	0	100%	
b. Field research/lab expenses and supplies	0	0	0	0	100%	
c. Operating expenses	321538	296728	296728	0	100%	
d. Vehicle hire and fuel, oil & maintenance	77200	17200	17200	0	100%	
e. Training/workshop/ seminar etc.	739900	646420	646420	0	100%	
f. Publications and printing	400000	395100	395100	0	100%	
g. Miscellaneous	109680	79960	79960	0	100%	
h. Capital expenses	171500	171500	171500	0	100%	
Total	**6654357**	**6441447**	**6441447**	**0**	**100%**	
BARI Component						
a. Contractual Staff Salary	1700453	1700453	1700453	0	100%	
b. Field Research / Lab expenses and supplies	2545290	2545290	2545290	0	100%	
c. Operating Expenses	464707	464707	464707	0	100%	
d. Vehicle Hire and Fuel, Oil & Maintenance	264700	264700	264700	0	100%	
e. Training/ Workshop/ Seminar etc.	0	0	0	0	100%	
f. Publications and printing	25000	25000	25000	0	100%	
g. Miscellaneous	102000	102000	102000	0	100%	
h. Capital Expenses	1521500	1521500	1521500	0	100%	
Total	**6623650**	**6623650**	**6623650**	**0**	**100%**	
BRRI Component						
a. Contractual staff salary	1204589	1204589	1204589	0	100%	

Items of expenditure/activities	Total approved budget	Fund received	Actual expenditure	Balance/ unspent	Physical progress (%)	Reasons for deviation
b. Field research/lab expenses and supplies	2038224	2035934	2035934	0	100%	
c. Operating expenses	428755	323817	323817	0	100%	
d. Vehicle hire and fuel, oil & maintenance	471250	468750	468750	0	100%	
e. Training/workshop/ seminar etc.	0	0	0	0	100%	
f. Publications and printing	40000	40000	40000	0	100%	
g. Miscellaneous	135375	134825	134825	0	100%	
h. Capital expenses	836500	836500	836500	0	100%	
Total	**5154693**	**5044415**	**5044415**	**0**	**100%**	
BINA Component						
a. Contractual staff salary	736430	736430	736430	0	100%	
b. Field research/lab expenses and supplies	1539283	1539283	1539283	0	100%	
c. Operating expenses	346007	318926	318926	0	100%	
d. Vehicle hire and fuel, oil & maintenance	80000	80000	80000	0	100%	
e. Training/workshop/ seminar etc.	0	0	0	0	100%	
f. Publications and printing	0	0	0	0	100%	
g. Miscellaneous	145000	105000	105000	0	100%	
h. Capital expenses	890100	890100	890100	0	100%	
Total	**3736820**	**3669739**	**3669739**	**0**	**100%**	
BAU Component						
a. Contractual staff salary	1395140	1410519	1410519	0	100%	
b. Field research/lab expenses and supplies	2235000	2210684	2210684	0	100%	
c. Operating expenses	425000	480000	480000	0	100%	
d. Vehicle hire and fuel, oil & maintenance	280000	288220	288220	0	100%	
e. Training/workshop/ seminar etc.	0	0	0	0	100%	
f. Publications and printing	65000	0	0	0	100%	
g. Miscellaneous	110000	114342	114342	0	100%	
h. Capital expenses	230000	229400	229400	0	100%	
Total	**4740140**	**4733165**	**4733165**	**0**	**100%**	
BSMRAU Component						
a. Contractual staff salary	1450445	1450445	1450445	0	100%	
b. Field research/lab expenses and supplies	3099050	3080550	3080550	0	100%	
c. Operating expenses	385468	375973	375973	0	100%	
d. Vehicle hire and fuel, oil & maintenance	624350	624350	624350	0	100%	

Items of expenditure/activities	Total approved budget	Fund received	Actual expenditure	Balance/ unspent	Physical progress (%)	Reasons for deviation
e. Training/workshop/seminar etc.	0	0	0	0		
f. Publications and printing	20000	20000	20000	0	100%	
g. Miscellaneous	146090	146090	146090	0	100%	
h. Capital expenses	997000	997000	997000	0	100%	
Total	**6722403**	**6694408**	**6694408**	**0**	**100%**	
SAU Component						
a. Contractual staff salary	1016000	1016000	1016000	0	100%	
b. Field research/lab expenses and supplies	1278054	1278054	1278054	0	100%	
c. Operating expenses	255446	255196	255196	0	100%	
d. Vehicle hire and fuel, oil & maintenance	141500	141500	141500	0	100%	
e. Training/workshop/seminar etc.	0	0	0	0	0	
f. Publications and printing	0	0	0	0	0	
g. Miscellaneous	101000	101000	101000	0	100%	
h. Capital expenses	184000	184000	184000	0	100%	
Total	**2976000**	**2975750**	**2975750**	**0**	**100%**	

D. Achievement of Sub-project by objectives (Tangible form): Technology generated/developed

BARI Component

General/specific objectives of the sub-project	Major technical activities performed in respect of the set objectives	Output (i.e., product obtained, visible, measurable)	Outcome (short term effect of the research)
1.0 Characterize the bio-physicochemical properties of soil in the climate vulnerable areas of Dumuria (saline), Godagari (drought) and acidic soils of Belabo	**1.1** Quantify biomass C & N in soils of the study areas **1.2** Determine soil physical properties, **1.3** Determinesoil chemical properties	Targeted 63 soil sample from Belabo, 81 from Godagari and 126 from Dumuria were collected and analyzed	Soil fertility status of Belabo, Godagari and Dumuria are find out.
2.0 Evaluate the effect of organic materials for amending acidic soil in Belabo, drought prone soil in Godagari and saline soil in Dumuria.	**2.1** One field trial was conductedfor amending acidic soil in Belabowith six treatment (control, PM @ 3 t/ ha+ IPNS, PM biochar @ 2 t/ha+ IPNS, RH biochar @ 2 t/ha + IPNS, Dolomite	**2.1.** Poultry manure biochar 2 t/ha with IPNS basis chemical fertilizer was found best for crop productivity of Cauliflower-Okra-Indian Spinach cropping pattern in acidic soil of Belabo, Narsingdi. About 190% and	**2.1** Poultry manure biochar decreases soil acidity, improve soil fertility and crop productivity in acidic soil.

General/specific objectives of the sub-project	Major technical activities performed in respect of the set objectives	Output (i.e., product obtained, visible, measurable)	Outcome (short term effect of the research)
	@ 1 t/ha + 100% RF, 100% RF) on cauliflower-okra-Indian spinach cropping pattern.	33.2% total system yield increase over control and 100% RF, respectively was obtained in aforesaid treatment.	
	2.2. One field trial was conducted in drought prone soil of Godagari with six treatments (control, 100% RF, RH biochar + 100% RF, PM biochar @ 2 t/ha+ IPNS, Vermicompost @ 3 t/ha + IPNS, Mazim org fert. @ 3 t/ha + IPNS) on mustard-Boro-T.aman cropping pattern.	**2.2.** Rice husk biochar 2 t/ha with IPNS basis chemical fertilizer was found best for crop productivity of Mustard-Boro-T.aman cropping pattern in drought prone soil of Rajshahi. About 92.5% and 27.7% total system yield increase over control and 100% RF, respectively was obtained in aforesaid treatment.	**2.2** Rice husk biochar increases soil moisture retention, improve soil fertility and crop productivity in drought prone soil.
	2.3. One field trial was conducted insaline soil of Dumuria with six treatments (control, 100% RF, RH biochar + 100% RF, PM biochar @ 2 t/ha+ IPNS, Vermicompost @ 3 t/ha + IPNS, Mazim org fert. @ 3 t/ha + IPNSon sweet gourd-fallow-T.Aman cropping pattern.	**2.3.** Rice husk biochar 2 t/ha with IPNS basis chemical fertilizer was found best for crop productivity of Sweet gourd-Fallow-T.Aman cropping pattern in saline soil of Dumuria, Khulna. About 80.06% and76.67% total system yield increase over control and 100% RF, respectively was obtained in aforesaid treatment.	**2.3** Rice husk biochar decreases soil salinity, improve soil fertility and crop productivity in saline soil.

BRRI Component

General/ specific objectives of the sub-project	Major technical activities performed in respect of the set objectives	Output (i.e. product obtained, visible, measurable)	Outcome (short term effect of the research)
1.To characterize the bio-physico-chemical properties of soil in heavy metal polluted areas of Sripur, Gazipur	A benchmark survey was done in the industrial polluted soil of Sripur, Mirzapur and Pirujali. Initially 30 (composite of 300 soil) samples were collected from 3 study areas. Soils were analyzed for: **Physical properties:** Soil Texture and bulk density.	Soil physical chemical and biological properties of the 3 study sites (Sripur, Mirzapur and Pirujali) was assessed Output described in: • Annual Report,	Soil health of the 3 study sites i. e. industrial polluted area (Sripur, Mirzapur and Pirujali) was assessed.

General/ specific objectives of the sub-project	Major technical activities performed in respect of the set objectives	Output (i.e. product obtained, visible, measurable)	Outcome (short term effect of the research)
	Chemical properties: pH, C, N, P, K, Ca, Mg, Na, Zn, Cu, Mn, Pb, Cd, Cr, and Ni. **Biological Properties:** Biomass C, total population of total bacteria, beneficial bacteria, fungus and actinomycetes.	2018-19 • Annual Report, 2019-20 • Annual review workshop, 2019 • Annual review workshop, 2020 • PCR Leaflet (4)	
2.To determine the mineralization rate of nutrient after organic amendment and evaluate the effect of organic materials for amelioration of heavy metal pollution in Sripur, Gazipur industrial areas	Organic materials (biochar and vermicompost) amended with industrial polluted soils and nutrient mineralization were determined at Laboratory condition Potentiality of vermicompost and biochar for reduction of heavy metals were determined Soil biological change during nutrient mineralization determined	Mineralization rate of amended nutrients, C sequestration and soil biological change in the polluted soil were determined. Output described in: • Annual Report, 2019-20 • Annual review workshop, 2020 • PCR	Soil biological change, carbon sequestration, nutrient mineralization and capability to reduce heavy metal due to biochar and vermicompost amendment in polluted soil was determined.
3. To determine the effect of organic materials on crop yield and soil health	Farmers' fields experiment in the study sites were conduct as • Boro2018-2019 (8 experiments) • T. Aman 2019 (one experiment) • Boro 2019-20 (3 experiments) At the end of 3 years study again soil samples were collected from experimental plots and analyzed the parameters mentioned above.	Farmers field crop yield, soil analyses data. Output described in: • Annual Report, 2018-19 • Annual Report, 2019-20 • Annual review workshop, 2019 • Annual review workshop, 2020 • PCR	The effect of applied organic materials on crop yield and soil heath determined.

BINA Component

General/specific objectives of the sub-project	Major technical activities performed in respect of the set objectives	Output (i.e., product obtained, visible, measurable)	Outcome (short term effect of the research)
Bio-physicochemical characterization of soil in the climate vulnerable and polluted areas,	Collection of 30 soil samples (3 samples/spot) at 0 – 15 cm depth with GPS information from north-western part of drought prone areas completed. Analysis of soil bio-physico-chemical properties analysis completed.	Soil texture (silt loam); moisture (9.82-48.73%); water holding capacity (47.09-48.73%); colour (brown); bulk density (1.57-1.19 g cm^{-3}); porosity (53-41%); soil pH (7.29-8.07); organic carbon (0.48-1.14%); carbon pools (organic carbon: 0.60-1.00, active carbon: 0.30-0.50, passive carbon: 0.20-0.60 and inorganic carbon: 0.05-0.40%); microbial biomass carbon (35-827 kg C ha^{-1}); nitrogen (1.31-1.46% and phosphorus (27-146 ppm). Fe (16.42 – 54.94 ppm), Cu (0.38-1.24 ppm), Mn (1.85-6.17 ppm) and Zn (0.28-1.9ppm).	Farmers will be informed from this information about the use of integrated organic and chemical fertilizers, liming, proper irrigation to improve soil fertility and increase crop production.
Examine potentiality of different organic materials for amending problem soils and improving crop yields in the study areas	Soil was collected from drought prone areas of noth-western part of Bangladesh. 270 pots were used for this study. Four organic materialsCD, BC, OF, and VC including control with FC and CSW were used for this study. The CO_2-C and mineral nitrogen (NH_4-N and NO_3-N) were measured at 0, 3, 7, 15, 30, 45, 60, 90 and 120th day of incubation.	Field capacity and organic fertilizer produce 59.95 and 27.15% more cumulative CO_2 than continuous standing water condition and other organic amendments, respectively. CSW accumulates 31.00 and 18.63% more NH_4-N and NO_3-N in soil.CSW increased 1.01% over field capacity. Organic amendments such as CD, BC, OF and VC produced 18.52, 29.63, 28.40 and 32.10% higher organic carbon over control means only soil. Maximum k value (0.0092 g d^{-1}) was observed in CSW × VC. 250µ size aggregate fraction soil contained the highest organic carbon content in soil. Among the organic amendments, maximum extractable K (98.87 mg K kg^{-1} soil) was found in VC which followed by OF and BC treatments. FC × OF produced the highest extractable K in soil. Maximum Zn availability was found in organic fertilizer in combination with CSW condition.	Farmers will build- up awareness how to minimize CO_2 emission and improvement of nitrogen and other nutrients/elements in soil to mitigate climate change, improve soil fertility and increase crop production.
Quantify the effects of different organic materials on carbon sequestration	Six treatment combination such as T_0= control, T_1= 100% recommended fertilizer (RF), T_2= 100% RF + 2.0	Recommended doses of chemical fertilizers produced higher grain yield (3.98 t ha^{-1}) of rice in Boro season whereas in Aman season recommended fertilizer using IPNS + 3.0 t ha^{-1} poultry manure produced the higher grain yield	Stake holder means farmers will get benefit through the use of organic materials with chemical fertilizers for

General/specific objectives of the sub-project	Major technical activities performed in respect of the set objectives	Output (i.e., product obtained, visible, measurable)	Outcome (short term effect of the research)
	biochar (rice husk), T_3=RF (IPNS) + 3.0 t ha^{-1} poultry manure, T_4=RF (IPNS) + 3.0 t ha^{-1}vermicompost and T_5= RF(IPNS) + 3.0 t ha^{-1} standard organic fertilizer for experiment 1. Two treatment such as T_1= 100% recommended fertilizer (RF) and T_2=RF (IPNS) + 3.0 t ha^{-1} poultry manure for experiment 2. Crop yield and soil analysis were completed.	(6.53 t ha^{-1})of rice. At 15-30cm soil depth, the highest total nitrogen and potassium contents was recorded from T_4 and T_5 treatment, respectively. Maximum organic carbon was found in 0-15cm soil depth. Maximum Zn content (0.35 and 0.20 ppm) was obtained from T_1 and T_5 treatments, respectively. In Rabi season, recommended fertilizer using IPNS + 3.0 t ha^{-1} poultry manure produced higher grain yield (1.77 t ha^{-1}) of mustard.	increasing crop production and improvement of soil fertility.

BAU Component

General/specific objectives of the sub-project	Major technical activities performed in respect of the set objectives	Output (i.e. product obtained, visible, measurable)	Outcome (short term effect of the research)
1. To characterize the biological and physico-chemical properties of problem soils of charland (Char Dadna, Islampur) and acidic soils (Madhupur);	• Initial soil sampling at three different depths • Meetings with farmers' about existing cropping patterns and soil related problems • Laboratory analysis of soils for physico-chemical properties	• Soil related problems in acid and char land are known	• Based on the existing cropping patterns new patterns have been selected and practiced for two years that has increased cropping intensity, diversity and system productivity
2. To prepare and characterise biochars from different organic sources for amending acid and char land soils;	• A well-equipped biochar plant has been installed at BAU • Biochars have been produced and charaterised for physical and chemical properties	• Well-equipped biochar plant	• Biochar plant will be used to supply biochar for the future resaerch or farmers' demonstration and training

General/specific objectives of the sub-project	Major technical activities performed in respect of the set objectives	Output (i.e. product obtained, visible, measurable)	Outcome (short term effect of the research)
3. To investigate effect of biochars and other organic amendments on crop yields, soil health and carbon sequestration;	• Crops were grown in acidic (mustard – Boro - T. Aman) and in char land site (Maize – Jute – T. Aman) for consecutive two years during 2018-2020 with different organic and inorganic amendments as shown in the methodology section	• Poultry manure biochar and dolomite were found best treatments along with the chemical fertilizer to improve soil health and crop productivity in acidic soil site • Poultry manure biochar and vermicompost were found best treatments for char land	• Cropping intensity and crop yields were increased • soil health in terms of soil biological population, physical properties and chemical conditions improved • soil organic carbon stock increased
4. To measure carbon and N mineralization rate and to evaluate the effect of organic materials for amending acid soils of Madhupur and Charland of Islampur.	• 540 soil samples collected from the two selected sites were incubated at two different moisture for 120 days and analysed on nine sampling events with destructive sampling for C, N P and S mineralization	• Biochars were found as a slow mineralizing and slow nutrient releasing compounds that enhances C sequestration	• Poultry manure biochar was found a simply produced low cost product that improves soil health in acidic and char land soils

BSMRAU Component

General/specific objectives of the sub-project	Major technical activities performed in respect of the set objectives	Output (i.e., product obtained, visible, measurable)	Outcome (short term effect of the research)
Characterize and the improvement of bio-physicochemical properties of soil in the climate vulnerable Dekar haor areas of Sunamganj, arsenic area of Faridpur sadar,	**Expt. I.** Physicochemical characteristics of the climate vulnerable Dekar haor of Sunamganj. **Expt. II.** Assessment and Improvement of Bio-physicochemical characteristics of different soils of	I. Evaluated the nutrient dynamics through measuring nutrients status in upper ridge, middle point and basin areas of the Dekar haor. II. The bio-physicochemical properties of different soils significantly increased after two years using different organic materials	I. Fertility status found better in basin followed by middle and upper ridge. II. Improved soil health after two years' application of different OMs in different types of soils but biochar showed best

General/specific objectives of the sub-project	Major technical activities performed in respect of the set objectives	Output (i.e., product obtained, visible, measurable)	Outcome (short term effect of the research)
saline areas of Batiaghata and heavy metal polluted areas of Bhaluka using different organic amendments	the climate vulnerable arsenic area of Faridpur sadar, saline areas of Batiaghata and heavy metal polluted areas of Bhaluka after using different organic amendments.		performence.
Objective II: Evaluate the adsorption and desorption isotherms of heavy metals using organic materials including biochar for amending heavy metals in Bhaluka.	**Expt. I.** Study on mechanisms of the adsorption-desorption of heavy metal using different organic materials in contaminated soils heavy metal polluted areas of Bhaluka **(partial done but experiment is going by Ph.D. student)**	I. The highest adsorption of heavy metal was observed in biochar than others organic materials. II. While the trend of heavy metals (Pb, Cd and Ni) adsorption and desorption capacities were found with the following orders of RHB>VC>CD>CDS>TC and TC>CDS>CD>VC>RHB, respectively.	I. Biochar could be the best organic materials to hold heavy metal on their surface and reduced heavy metal uptake by plants from the contaminated soils.
Objective III: Mineralization study of organic materials and their effects of climate vulnerable and arsenic and heavy metal polluted areas on soil properties and crop productivity and carbon sequestration in the selected	**Expt. I.** Nitrogen and carbon mineralization dynamics using different organic materials in different climate vulnerable soils of arsenic area of Faridpur sadar and saline areas of Batiaghata. **Expt. II.** Pot experiment on nitrogen and carbon	I. The similar mineralization trends of carbon and nitrogen maintained the order of CDS>CD>VC>TC>BI>RHB>Control and CDS>CD>VC>TC>BI>RHB>Control respectively both in the laboratory and field conditions. II. After consecutive two seasons the average grain yield in all organic matter treated plots of both T. aman and boro rice was increased by 33-40% over control treatment in all sites. III. The significantly positive impact exhibited in different organic maters on carbon sequestration in	I. Biochar showed the pronounced potential regarding to increase MBC, MBN, carbon stock, carbon sequestration, soil aggregate stability and also abosortion of heavy metals as compared to other organic materials.

General/specific objectives of the sub-project	Major technical activities performed in respect of the set objectives	Output (i.e., product obtained, visible, measurable)	Outcome (short term effect of the research)
areas	mineralization dynamics using different organic materials in climate vulnerable soils of heavy metal polluted area of Bhaluka **(Ph.D student experiment).** **Expt. III.** Field study on nitrogen and carbon mineralization dynamics using different organic materials in climate vulnerable soils of heavy metal polluted area of Bhaluka **(Ph.D student experiment).** **Expt. IV.** Impact of different organic materials on crop productivity in Rice-Rice cropping pattern of the climate vulnerable arsenic area of Faridpur sadar, saline areas of Batiaghata and heavy metal polluted areas of Bhaluka using different organic amendments.	soil and highest was observed in biochar treated plot. Similar trend of results was found in case of stable aggregate content in soils. IV. But significantly highest grain yield was recorded in PM treated plot followed by vermicompost and biochar treated plots.	II. Organic matter especially biochar application with IPNS basis could be potential approach for sustainable soil health and crop production and also mitigating global warming by reducing C emission.

General/specific objectives of the sub-project	Major technical activities performed in respect of the set objectives	Output (i.e., product obtained, visible, measurable)	Outcome (short term effect of the research)
	Expt. V. Soil aggregate stability, storage of organic carbon and carbon sequestration in different climate vulnerable soils using different organic materials at Dekar haor areas of Sunamganj, arsenic area of Faridpur sadar, saline areas of Batiaghata and heavy metal polluted areas of Bhaluka.		

SAU Component

General/specific objectives of the sub-project	Major technical activities performed in respect of the set objectives	Output (i.e., product obtained, visible, measurable)	Outcome (short term effect of the research)
Characterize the bio-physico-chemical properties of soil in the saline prone areas of Kalapara, Patuakhali	30 soil samples were collected in September 2018. All soil samples were analyzed for biological, physical and chemical properties. Again soil samples were collected from the experimental plots from 3 soil depth (0-15, 15-30 and 30-45 cm) for physical, chemical and biological analysis.	Bulk density, particle density, Soil textural class, porosity, pH, EC, total N, exchangeable K, Na, Available S, Organic carbon, number of Rhizobium, Azotobacter, Phosphate solubilising bacteria were analysed.	Two more soil salinity vulnerable places of Nilgonj and Latachapli union were identified for conducting experiments.
Mineralization study of selected organic materials and assess the effect of organic materials on carbon	Mineralization study was conducted using 4 different types of organic materials	In both moisture regimes (field capacity and continuous standing water) the NH_4^+- N and NO_3^-- N mineralization followed the order as poultry manure >	Biochar is more stable organic amendments than other organic

General/specific objectives of the sub-project	Major technical activities performed in respect of the set objectives	Output (i.e., product obtained, visible, measurable)	Outcome (short term effect of the research)
sequestration.	maintaining 2 moisture regimes. The study was conducted for 9 incubation periods (0, 3, 7, 15, 21, 30, 45, 60, 90 and 120 days). Two factors a) Organic materials (biochar, poultry manure, vermicompost, organic fertilizer) b) Moisture regime (field capacity and continuous standing water)	vermicompost > organic fertilizer> biochar. The results showed that that the lowest N mineralization was found in biochar amended soil.	materials.
Evaluate the effect of organi materials for amending saline soils in the coastal areas of Kalapara, Patuakhali.	Six treatments were, T_1= Control, T_2 = 100% RDCF (Recommended Dose of Chemical Fertilizer) T_3 = 100% RDCF + Biochar (2 t/ha) T_4 = Poultry manure 3 t/ha + rest of the nutrients from chemical fertilizers T_5 = Vermicompost 3 t/ha + rest of the nutrients from chemical fertilizers T_6 = Organic fertilizer 3 t/ha + rest of the nutrients from chemical fertilizers Two crops were Maize and T. aman	The results found that among all the organic amendments biochar is more stable in soil. On the other hand, biochar reduce the soil EC and Na in a lower limit than other organic amendments as a result the highest crop yield was found in biochar treated plot.	Biochar is a new technology to reduce soil salinity and increase crop yield in saline soils.

E: Information/knowledge generated/policy generated

BARI Component

General/specific objectives of the sub-project	Major technical activities performed in respect of the set objectives	Output(i.e. product obtained, visible, measurable)	Outcome (short term effect of the research)
Mineralization study of organic materials and assess their effect on carbon sequestration, soil properties improvement and crop productivity in the selected areas	**1.** Production of biochar using different available sources and their characterization **2.** Carbon and nitrogen mineralization rate of commonly used organic materials in soils of Belabo, Godagari and Dumuria are studied under field capacity and continuous standing water condition.	**1.** Biochar are produced from 8 types of crop straw and 1 type of manure. **2.** Produced biochar are analyzed. **3.** Nutrient releasing capacity of eight type of organic materials viz. Rice husk biochar, Poultry manure biochar, Vermin-compost, Cow dung, Cowdung slurry, Mazim organic fertilizer, Poultry manure are studied.	**1.** Chick pea straw biochar is found best in nutrient composition among all the crop straw biochar.

BRRI Component

General/ specific objectives of the sub-project	Major technical activities performed in respect of the set objectives	Output	Outcome (short term effect of the research)
1.To characterize the bio-physico-chemical properties of soil in heavy metal polluted areas of Sripur, Gazipur	A benchmark survey was done in the industrial polluted soil of Sripur, Mirzapur and Pirujali. Initially 30 (composite of 300 soil) samples were collected from 3 study areas. Soils were analyzed **Physical properties:** Soil Texture and bulk density. **Chemical properties:** pH, C, N, P, K, Ca, Mg, Na, Zn, Cu, Mn, Pb, Cd, Cr, and Ni. **Biological Properties:**	Output described in : • Annual Report, 2018-19 • Annual Report, 2019-20 • Annual review workshop, 2019 • Annual review workshop, 2020 • PCR • Leaflet (4)	Soil health of the 3 study sites i. e. industrial polluted area of Sripur, Mirzapur and Pirujali was assessed and found • Soil was highly contaminated with heavy metals and not suitable for agricultural production • Poor soil biology • Channel water is not suitable for crop

General/ specific objectives of the sub-project	Major technical activities performed in respect of the set objectives	Output	Outcome (short term effect of the research)
	Biomass C, total population of total bacteria, beneficial bacteria, fungus and actinomycetes.		irrigation
2.To determine the mineralization rate of nutrient after organic amendment and evaluate the effect of organic materials for amelioration of heavy metal pollution in Sripur, Gazipur industrial areas	• Organic materials (biochar and vermicompost) amended with industrial polluted soils and nutrient mineralization were determined at Laboratory condition • Potentiality of vermicompost and biochar for reduction of heavy metals were determined • Soil biological change during nutrient mineralization determined	Mineralization rate of amended nutrients, C sequestration and soil biological change in the polluted soil were determined. Output described in: • Annual Report, 2019-20 • Annual review workshop, 2020 • PCR	• Vermicompost increased C mineralization • Biochar reduced soil Cd, Cu, Pb and Fe^{+2} mineralization rates however still remain toxic level of WHO permissible limit.
3. To determine the effect of organic materials on crop yield and soil health	Farmers' fields experiment in the study sites were conduct as • Boro2018-2019 (8 experiments) • T. Aman 2019 (one experiment) • Boro 2019-20 (3 experiments) At the end of 3 years study again soil samples were collected from experimental plots and analyzed the parameters mentioned above.	Farmers field crop yield, soil analyses data. Output described in: • Annual Report, 2018-19 • Annual Report, 2019-20 • Annual review workshop, 2019 • Annual review workshop, 2020 • PCR	The effect of applied organic materials on crop yield and soil heath determined and found applied organic materials were not capable to reduce heavy metal pollution in the studied area.

BINA Component

General/specific objectives of the sub-project	Major technical activities performed in respect of the set objectives	Output	Outcome(short term effect of the research)
Bio-physicochemical characterization of soil in the climate vulnerable and polluted areas	Analysis of soil bio-physico-chemical properties of 30 soil samples analysis was completed using standard methods.	Bio-physico-chemical properties of 30 soil samples were dertermined. Bulk density is high. Soil pH is neutral to mild alkaline in nature. Microbial biomass carbon, total nitrogen content is low. Organic carbon content is medium. P, K and Fe content is very high. Mn and Cu content is optimum.	Improvement of soil quality is possible if we consider all the studied information and follow the improve soil management practices like introduction of diverse with high biomass crops, organic fertilizers, cover crops, reduce tillage and rotational and cost-effective irrigation system.
Examine potentiality of different organic materials for amending problem soils and improving crop yields in the study areas	Four organic materialsCD, BC, OF, and VC including control with FC and CSW were used for this study. The CO_2-C and mineral nitrogen (NH_4-N and NO_3-N) were measured at 0, 3, 7, 15, 30, 45, 60, 90 and 120^{th} day of incubation.	CSW along with organic materials increase the NO_3-N content and organic carbon in soil. Continuous standing water conditions reduce carbon dioxide from the soil and 250µ size aggregate fraction soil contains the highest organic carbon content in soil.	Farmers will build- up awareness how to minimize CO_2 emission and improvement of nitrogen and other nutrients/elements in soil to mitigate climate change, improve soil fertility and increase crop production.
Quantify the effects of different organic materials on carbon sequestration	Six treatment combination such as T_0= control, T_1= 100% recommended fertilizer (RF), T_2= 100% RF + 2.0 biochar (rice husk), T_3=RF (IPNS) + 3.0 t ha^{-1} poultry manure, T_4=RF (IPNS) + 3.0 t ha^{-1}vermicompost and T_5= RF(IPNS) + 3.0 t ha^{-1} standard organic fertilizer for experiment 1. Two treatment such as T_1= 100%	Integrated plant nutrition system (IPNS) along with organic fertlizer increase crop production and improve soil fertility.	Stake holder means farmers will get benefit through the use of organic materials with chemical fertilizers for increasing crop production and improvement of soil fertility.

General/specific objectives of the sub-project	Major technical activities performed in respect of the set objectives	Output	Outcome(short term effect of the research)
	recommended fertilizer (RF) and T_2=RF (IPNS) + 3.0 t ha^{-1} poultry manure for experiment 2. Crop yield and soil analysis were completed.		

BAU Component

General/specific objectives of the sub-project	Major technical activities performed in respect of the set objectives	Output	Outcome (short term effect of the research)
I.To characterize the biological and physico-chemical properties of problem soils of charland (Char Dadna, Islampur) and acidic soils (Madhupur);	• Initial soil sampling at three different depths • Meetings with farmers about existing cropping patterns and soil related problems • Laboratory analysis of soils for physico-chemical properties	• Soil related problems and existing cropping patterns in acid soil in Madhupur and char land soils in Islampur are known	• New cropping patterns have been selected and practiced for two years that has increased cropping intensity, diversity and system productivity
II. To prepare and characterise biochars from different organic sources for amending acid and char land soils;	• A well-equipped biochar plant has been installed at BAU • Biochars have been produced and charaterised for physical and chemical properties	• A well-equipped biochar plant is established. It shows how to prepare biochar easily with a low cost using locally available organic sources like poultry manure, rice straw, rice husk, sugarcane bagasse etc.	• Farmers can easily produce biochar with locally available organic sources at home
I. To investigate effect of biochars and other organic amendments on crop yields, soil health and carbon sequestration;	• Crops were grown in acidic (mustard – Boro - T. Aman) and in char land site (Maize – Jute – T. Aman) for consecutive two years during 2018-2020 with different organic and inorganic amendments as shown in the methodology section	• Poultry manure biochar and dolomite were found best treatments along with the chemical fertilizer to improve soil health and crop productivity in acidic soil site • Poultry manure biochar and vermicompost were	• Cropping intensity and crop yields were increased • soil health in terms of soil biological population, physical properties and chemical

General/specific objectives of the sub-project	Major technical activities performed in respect of the set objectives	Output	Outcome (short term effect of the research)
		found best treatments for char land	conditions improved • soil organic carbon stock increased
IV. To measure carbon and N mineralization rate and to evaluate the effect of organic materials for amending acid soils of Madhupur and Charland of Islampur.	• 540 soil samples collected from the two selected sites were incubated at two different moisture for 120 days and analysed on nine sampling events with destructive sampling for C, N P and S mineralization	• Biochars were found as a slow mineralizing and slow nutrient releasing compounds that enhances C sequestration	• Poultry manure biochar was found a simply produced low-cost product that release nutrient slowly and enhances C sequestration in acidic and char land soils

BSMRAU Component

General/specific objectives of the sub-project	Major technical activities performed in respect of the set objectives	Output	Outcome (short term effect of the research)
Objective I: Characterize and the improvement of bio-physico-chemical properties of soil in the climate vulnerable Dekar haor areas of Sunamganj, arsenic area of Faridpur sadar, saline areas of Batiaghata and heavy metal polluted areas of Bhaluka using different organic amendments	❖ Benchmark survey and soil samples collection from the four climate vulnerable areas of Dekar haor, industrial polluted area of Bhaluka upazila, arsenic poluuted area of Faridpur sadar and saline area of Bhatiaghata for bio-physicochemical analysis. ❖ Evaluating the improvement of soil health using the different organic materials at the end of project after two years.	❖ Delineated the chemical, physical and biological properties of the selected problem soils. ❖ Significantly increased soil health including physical, chemical and biological properties	❖ Organic materials especially "biochar" could be used as potential organic materials in sub-tropical weather condition for sustainable soil health.
Objective II: Evaluate the adsorption and desorption isotherms of heavy metals using organic materials including biochar for amending heavy	❖ Mechanisms study on adsorption-desorption kinetics of heavy metals using different organic materials (partially dine)	❖ Organic materials especially biochar showed very good potential to adsorb heavy metals.	❖ Biochar could be used as organic material at the contaminated soil for reducing heavy metal

General/specific objectives of the sub-project	Major technical activities performed in respect of the set objectives	Output	Outcome (short term effect of the research)
metals in Bhaluka.			uptake by plant.
Objective III: Mineralization study of organic materials and their effects of climate vulnerable and arsenic and heavy metal polluted areas on soil properties and crop productivity and carbon sequestration in the selected areas	❖ Carbon and nitrogen mineralization study using different organic materials both in laboratory and field conditions at different types of soils. ❖ Field studies in rice-rice cropping pattern using different organic materials in different problem soils	❖ Slow mineralization of C and N observed in biochar than PM and vermicompost. ❖ Increased soil aggregate stability and carbon sequestration especially by applying biochar. ❖ Increased crop productivity using different organic materials.	❖ Organic matter application especially biochar with IPNS basis could be the potential and best approach for sustainable soil health and crop production and also mitigating global warming by reducing C emission in our sub-tropical condition.

SAU Component

General/specific objectives of the sub-project	Major technical activities performed in respect of the set objectives	Output	Outcome (short term effect of the research)
Mineralization study of selected organic materials and assess the effect of organic materials on carbon sequestration and	Mineralization study was conducted using 4 different types of organic materials maintaining 2 moisture regimes. The study was conducted for 9 incubation periods (0, 3, 7, 15, 21, 30, 45, 60, 90 and 120 days).	The lowest C mineralization was found by using rice husk biochar in both moisture regimes (field capacity and continuous standing water) in crop field of rice and maize The lowest N (NH_4^+- N and NO_3^--N**)** mineralization was found by using rice husk biochar in both moisture regimes (field capacity and continuous standing water) in crop field of rice and maize	Biochar is the most resistant organic amendments among other organic materials
Evaluate the effect of organic materials for amending saline soils in the coastal areas of	Six treatments were, T_1= Control, T_2 = 100% RDCF (Recommended	Biochar reduces the soil EC and Na in a lower limit than other organic amendments as a result the highest crop yield was found in biochar	Biochar improves the soil health in saline eco-

General/specific objectives of the sub-project	Major technical activities performed in respect of the set objectives	Output	Outcome (short term effect of the research)
Kalapara, Patuakhali.	Dose of Chemical Fertilizer) T_3 = 100% RDCF + Biochar (2 t/ha) T_4 = Poultry manure 3 t/ha + rest of the nutrients from chemical fertilizers T_5 = Vermicompost 3 t/ha + rest of the nutrients from chemical fertilizers T_6 = Organic fertilizer 3 t/ha + rest of the nutrients from chemical fertilizers	treated plot.	systems

F. Materials Development/Publication made under the Sub-project:

Publication	Number of publications		Remarks (e.g., paper title, name of journal, conference name, etc.)
	Under preparation	Completed and published	
BARI Component			
Technology bulletin/ booklet/leafletlflyer etc.		1	জলবায়ু পরিবর্তন মোকাবেলায় ও মাটির উর্বরতা রক্ষায় বায়োচার
Joumal publication: 2 **1.** Effect of different organic amendments and dolomite in amending acidic soil and improve crop productivity of cauliflower-okra-Indian spinach cropping pattern **2.** Effect of different organic amendments in retaining moisture of drought prone soil and improve crop productivity of mustard-boro-t. Aman cropping pattern			
Video clip/TV program	N/A	N/A	N/A
News Paper/Popular Article	N/A	N/A	N/A
Other publications, if any	N/A	N/A	N/A

Publication	Number of publications		Remarks (e.g., paper title, name of journal, conference name, etc.)
	Under preparation	Completed and published	
BRRI Component			
Technology bulletin/booklet/leaflet/flyer etc.	**Leaflet (4):** **১.** শ্রীপুরের কারখানার বর্জ্যে নষ্ট কৃষি জমির মাটির পরিবর্তিত ভৌত, রাষায়নিক ও জৈবিক গুণাবলী **২.** মির্জাপুরের কারখানার বর্জ্যে নষ্ট কৃষি জমির মাটির পরিবর্তিত ভৌত, রাষায়নিক ও জৈবিক গুণাবলী **৩.** পীরোজপুরের কারখানার বর্জ্যে নষ্ট কৃষি জমির মাটির পরিবর্তিত ভৌত, রাসায়নিক ও জৈবিক গুণাবলী **৪.** কারখানার বর্জ্যে নষ্ট খালের পানি যা উক্ত এলাকার কৃষি জমির সেচের একমাত্র উৎস । **Poster:** Biochemical properties of the rice soils of Sripur–Gazipur industrial area		Materials will be published soon
Journal publication	Biochemical properties of the rice soils of Sripur–Gazipur industrial area	Submitted 31/12/2020	"Biochemical properties of the rice soils of Sripur–Gazipur industrial area" Rice Journal.
	Determination of heavy metal load in the Industrial polluted soils of Sripur Gazipur	Not completed	not submitted
Video clip/TV program	Not done	-	-
Newspaper/ popular Article	Not done	-	-
Other publications, if any	Not done	-	-
BINA Component			
Technology bulletin/ booklet/leaflet/flyer etc.	1		
Journal publication	3		
Video clip/TV program			
News Paper/Popular Article			
Other publications, if any			
Technology bulletin/ booklet/leaflet/flyer etc.	Under preparation	-	-

Publication	Number of publications		Remarks (e.g., paper title, name of journal, conference name, etc.)
	Under preparation	Completed and published	
BAU Component			
Technology bulletin/ booklet/leaflet/flyer etc.	**1.** Improvement of crop productivity and soil health in char land through poultry manure biochar application; **2.** Improvement of crop productivity and soil health in acidic soil through poultry manure biochar and dolomite application		
Journal publication	**1.** Biochar Amendment Reduces Net Nitrogen Release under Contrasting Soil Types and Moisture Regimes: A Laboratory Incubation Study, submitted, Journal name: Front. Environ. Sci. **2.** Biochar and Compost Based Integrated Nutrient Management: A Potential for Carbon and Microbial Enrichment in Degraded Acidic and Charland Soils, submitted in (journal) Sustainability **3.** Integrated Nutrient Management Enhances System Productivity and Nitrogen Use Efficiency of Crops with Subsequent Improvement in Physicochemical Properties of Acidic and Charland Soils, submitted in (journal) Agronomy		
Video clip/TV program	How to prepare biochar in a simple biochar plant		
News Paper/Popular Article	N/A	N/A	N/A
Other publications, if any	N/A	N/A	N/A
BSMRAU Component			
Journal publication	Could be published 3-4 papers after finishing the dissertation researches including additional data produced from the project works.		
Video clip/TV program	-	-	-
News Paper/Popular Article	Could be published at the end of the research.	-	-
Other publications, if any	-	-	-
SAU Component			
Technology bulletin/ booklet/leaflet/flyer etc.			
Journal publication			
Video clip/TV program			
News Paper/Popular Article			
Other publications, if any			

G. Description of generated Technology/knowledge/policy:

BARI Component

i. Technology Fact Sheet (title, introduction, description, suitable location/ecosystem, benefits, name and contact address of author)

1. Title of technology	:	**Application of Biochar in acidic soils of Narsingdi region to alleviate soil acidity and increase productivity of Cauliflower-Ladies finger-Indian Spinach cropping pattern**
Introduction	:	**1.** Biochar can be produced from crop residues (e.g., rice husk, straw, black gram, mustard, barley, groundnut etc.), poultry liter and use intothe soil. **2.** Lime or dolomite is commonly used for acidic soils amelioration. But those have to be applied at least 15 days prior to sowing/transplanting for complete chemical reaction in the soil. In addition, seeds or seedlings can be sown immediately after using biochar which can reduce soil acidity as well as enriches the soil with carbon and maintains the health of the soil. **3.** Biochar can be used at any time of the year. **4.** Use of biochar increases the use efficiency of inorganic fertilizers in the soil.
The suitability of the technology	:	Biochar technology can be used in acidic soils of all over Bangladesh for amelioration of soil acidity instead of chemical lime or dolomite. For example, AEZ-28.
Description of Technology		

Cropping pattern	**Cauliflower**	**Ladies finger**	**Indian spinach**
Variety	Snow White	Greenfinger	Bari Puishak-1
Season	Rabi	Kharif-1	Kharif-2
Sowing Time / Planting	First week of November	First week of March	First week of June
Sowing / planting method Row to row (cm) Plant to plant (cm)	Transplanting-35 days old seedlings 50 50	Sowing-2 seeds 20 20	Transplanting-35 days old seedlings 20 15
Irrigation	as required	as required	as required
Weed control	as needed	as needed	as needed
Disease and insect control	as needed	as needed	as needed
Harvest time	From last week of January to second week of February	First week of April to last week of May	Last week of July to first week of October

Fertilizer rate:

Fertilizer	**Cauliflower**	**Ladies finger**	Indian spinach
Urea (kg / ha)	270	160	150
TSP (kg / ha)	140	70	50
MOP (kg / ha)	160	90	45
Gypsum (kg / ha)	130	55	0
Zinc sulphate (monohydrate)	5	3	0

(kg / ha)				
Boric acid (kg / ha)	2	0	0	
Poultry liter biochar (t /ha)	2	0	0	

Biochar application:
At the time of final land preparation, 2 tons / ha of poultry liter biocharshould be applied and mixed thoroughly with the soil.
Fertilizer application method
Cauliflower:
Full amount of TSP, MoP, gypsum, zinc sulphate (monohydrate), boric acid and biochar and 1/3 of urea should be applied as basal dose during the final land preparation. Rest of urea should be applied in two equal installments at 25-30 and 50-55 days after transplanting.
Ladies finger:
Full amount of TSP, MoP, gypsum, zinc sulphate (monohydrate) and 1/3 of urea should be applied as basal dose during the final land preparation. Rest of urea should be applied in two equal installments at 25-30 and 50-55 days after sowing.
Indian spinach:
Full amount of TSP, MoP and 1/3 urea should be applied as basal dose during the final land preparation. The remaining urea should be applied in two equal installments at 25-30 and 50-55 days after transplanting.

Output of the Technology :

Yield	Recommended fertilizer (t/ha)	Biochar with Recommended fertilizer(t/ ha)
Cauliflower	27.74	35.75
Ladies finger	13.16	16.57
Indian spinach	20.14	24.17
Total System productivity (eq. yield of cauliflower)	57.55	74.69

- The application of 2 t/ha of poultry liter biochar increases the pH of the soil by> 1.00 units.
- Application of 2 t/ha of poultry liter biochar, the total system productivity of the pattern is 74.69 t/ha (equivalent yield of cauliflower) which is 29.8% higher than the recommended fertilizer treated yield.

Impact :

- Poultry liter biochar acts as a liming material. Applying 2 t of Poultry liter biochar per hectare decreases soil acidity of the acidic soil.
- Increases soil fertility.
- Increases total system productivity of the cropping pattern.

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Fig. Cauliflower-Ladies finger-Indian Spinach cropping pattern

2. Title of technology	:	**Application of biochar in drought prone areas of Barind region to preserve soil moisture and increase productivity of Mustard-Boro-Aus cropping pattern**
Introduction	:	**1.** Biochar can be produced from crop residues (e.g. rice husk, straw, black gram, mustard, barley, groundnut etc.), poultry liter and use intothe soil. **2.** Biochar sustainssoil health and does not require extra time for seed sowing or seedlings transplanting. **3.** Use of biochar in soil increases soil microorganisms as the soil is rich in carbon as well as preserves soilmoisture. **4.** Biochar in soil for crop production can be used at any time of the year. **5.** Biochar increases the use efficiency of the applied inorganic fertilizers in soil.
The suitability of technology	:	Biochar technology can be used in drought prone soils of barind region of Bangladesh for soil moisture preservation. For example,AEZ-26.
Description of Technology		

Cropping pattern	**Mustard**	**Boro**	**Transplanted Aus**
Variety	BARIShorisha-14	BRRI dhan28	BRRI dhan88
Season	Rabi	Kharif-1	Kharif-2
Sowing / planting time	First week of November	First week of February	Second week of May
Sowing / planting method	Seed sowing	35 days old seedlings	25 days old seedlings
Row to row distance(cm)	30	20	20
Seed / Seedling distance (cm)	5	20	15
Irrigation	3	4	4
Disease and insect control	As required	As required	As required
Weed control	As required	As required	As required
Harvest time	Last week of January	First week of May	Last week of July

Fertilizer rate:

Fertilizer	Mustard	Boro Rice	T. Aus rice
Urea (kg / ha)	200	160	100
TSP (kg / ha)	120	80	35
MOP (kg / ha)	140	80	35
Gypsum (kg / ha)	80	30	20
Zinc sulphate (monohydrate) (kg / ha)	9	4	4
Boric acid (kg / ha)	5.5	0	0
Rice husk biochar (t / ha)	2	0	0

Biochar application:

At the time of final land preparation, 2 t / ha of rice husk biochar should be applied and mixed thoroughly with the soil.

Fertilizer application method

Mustard:

For mustard cultivation, except urea all other fertilizers should be applied during the final land preparation and mixed with the soil. Urea should be applied in three equal installments at 10, 20 and 40 days after sowing.

Boro Rice:

Except urea, all other fertilizers should be applied at the time of final land preparation. Urea should be applied in three equal installments at 6, 35 days (tillering stage) and 52 days (5-6 days before flowering) after transplanting.

Transplanted Aus:

Except urea, all other fertilizers should be applied at the time of final land preparation. Urea should be applied in three equal installments at 10, 30 (at tillering stage) and 45 days (5-6 days before flowering) aftertransplanting.

Output of the Technology :

Yield	Recommended fertilizer (t/ha)	Biochar with Recommended fertilizer (t/ha)
Mustard	1.13	1.45
Boro rice	5.33	6.35
T.Aus	3.82	4.32
Total System Productivity (Equivalent yield of boro rice)	13.67	17.47

- Applying 2 t of ricehusk biochar per hectare acts as mulch and increases the soil water holding capacity and requires less irrigation for crop production.

Impact	:	• Application of 2 t/ha of rice husk biochar, the total system productivity of the pattern is 17.47 t / ha (equivalent yield of boro rice) which is 27.8% higher than the recommended fertilizer treated yield . • Increases soil fertility. • Increases soil water holding capacity by preserving soil moisture
Name and Address of the researcher	**:**	Dr. Sohela Akhter Chief Scientific Officer and Head Soil Science Division, BARI Mob: 01922242737 Email: sohela_akhter@yahoo.com

Fig. Mustard-Boro-Aus cropping pattern

3. Title of technology	:	**Biochar application in saline soils of Khulna region to reduce soil salinity and increase productivity of sweet gourd-fallow-Transplanted aman cropping pattern**
Introduction	:	**1.** Biochar can be produced from crop residues (e.g. rice husk, straw, black gram, mustard, barley, groundnut, etc.), poultry liter and use in the soil. **2.** Biochar increases the water holding capacity of the soil thus reducing salinity as well as enriching the soil with carbon and acting as a habitat for soil microorganisms. Seeds can be sown or transplanted immediately after the application of biochar in the soil. **3.** Biochar can be used at any time of the year. **4.** Biochar increases the use efficiency of applied inorganic fertilizers in the soil.
The suitability of the technology	:	Biochar technology can be used in saline soils of Bangladesh for decrease soil salinity. For example, AEZ-13.
Description of Technology		

Cropping pattern	**Sweet gourd**	**T.Aman**
Variety	Monica	BRRI dhan78
Season	Rabi	Kharif -2
Transplanting time	First week of December	First week of July
Transplanting of seedling	20-day old seedlings in pit Row to row - 3.0 m Pit to pit - 1.5 m	35 days old seedlings are transplanted Row to row - 20 cm Plant to plant- 20 cm
Irrigation	As required	As required
Disease and insect control	As required	As required
Harvest time	Second week of February to third week of March	Last week of November

Fertilizer rate:

Fertilizer	**Sweet Gourd (2222 pit/ha)**	**Transplanted Aman**
Urea (kg/ha)	200	120
TSP (kg/ha)	180	40
MOP (kg/ha)	160	40
Gypsum (kg/ha)	100	20
Zinc sulphate (monohydrate) (kg/ha)	10	4
Boric acid (kg / ha)	8	0
Rice husk biochar (t / ha)	2	0

Biochar application:
At the time of final land preparation, 2 t / ha of rice husk biochar should be applied and mixed thoroughly with the soil.
Fertilizer application method:
Sweet Gourd:
All TSP, MoP, gypsum, zinc sulphate (monohydrate), boric acid and biochar and 1/4 ofurea should be applied as basal dose during the final land preparation. The remaining urea should be applied in three equal installments at 20-25, 40-45 and 60-65 days after transplanting.

Transplanted Aman:
Except urea all other fertilizers should be applied in soil at the time of final land preparation. Urea should be applied in soil in three equal installments at 7,35 (tillering stage) and 55 (5-6 days before flowering) days after transplanting.

Output of the Technology :

Crops	Recommended fertilizer application (t /ha)	Biochar application with recommended fertilizer application (t /ha)
Sweet Gourd	15.34	19.21
T. Aman	3.18	3.60
Total system productivity (equivalent yield of transplanted aman)	9.32	11.28

- Applying 2t / ha of rice husk biochar increases the soil water holding capacity and requires less irrigation.
- Rice husk biochar acts as a mulching material in soil. This reduces the evaporation of capillary water from the soil which restricts the upward salinity movement. Salt does not come out of the subsoil.

Impact :

- Application of 2 t/ha rice husk biochar, the total system productivity of the pattern is 11.28 t /ha which is 21% higher than the recommended fertilizer treated yield.
- The salinity of the saline soil can be reduced using biochar as it acts as mulch on the soil.
- Increases soil fertility.

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Fig. Sweet gourd-T.Aman cropping pattern

ii. Effectiveness in policy support (if applicable):

BRRI Component

ii. Technology Fact Sheet (title, introduction, description, suitable location/ecosystem, benefits, name and contact address of author):

Not applicable

i. Effectiveness in policy Support (if any):

Strong policy support needed to stop pollution of irrigation channel from factory discharge. The studied soil of this industrial area is not suitable for agricultural crop production as Fe^{+2}, Pd, and Cd concentration were above the WHO threshold level. Nevertheless, the heavy metal concentration of Mn, Cu, Cd, and Cr of the polluted irrigation channel is above toxic level which increases risk of heavy metal accumulation in such soil. With the present technologies amelioration of such soil is quite tough as in the rainy season the agricultural lands become inundated with the polluted irrigation channel water.

BINA Component

i) Technology Fact Sheet (title, introduction, description, suitable location/ecosystem, benefits, name and contact address of author):

Title of the Technology

Soil health and carbon management

Introduction

Soil organic matter (SOM) status is generally low in Bangladesh. Soil health is in jeopardy due to the loss of organic matter content and the continuous use of unbalanced chemical fertilizers for crop production. As a result, cutting carbon emissions as part of the fight against climate change should be a key priority for the agriculture sector. The net reduction in CO_2 emission means increased soil C

storage, which is commonly known as C sequestration in agriculture. It has been emphasized that C sequestration is essential to recover soil quality, augment agronomic productivity, and use efficiency of inputs like fertilizers and water and thus helping maintain or restore the capacity of soil to achieve maximum production and a healthy environment. Therefore, C sequestration is the prime requirement to conserve soil organic matter (SOM) not only for a source of plant nutrients but also to act as a potential sink of atmospheric CO_2. Control mineralization of organic materials is depended on the composition or quality of residues added and water availability. The rate of soil C emission and nutrient status is strongly influenced by the amount and properties of added organic materials and water availability. Information on field capacity and continuous standing water-dependent decomposition of different organic materials is needed to predict the carbon mineralization and soil C stocks, and improve soil quality.

Description of the Technology

A pot experiment was conducted in the laboratory of the soil science division at Bangladesh Institute of Nuclear Agriculture (BINA), Mymensingh, Bangladesh. The experiment comprised of two factors, viz. organic materials (CD: cowdung, BC: biochar, OF: organic fertilizer and VC: vermicompost including control), and moisture levels (FC: field capacity and CSW: continuous standing water). Organic materials were mixed with soil at 2.5 g C kg^{-1} soil and 0.2 kg soil was used in each pot. The CO_2-C and mineral nitrogen (NH_4-N and NO_3-N) were measured at 0, 3, 7, 15, 30, 45, 60, 90, and 120^{th} day of incubation. The emission of CO_2 and the availability of mineral nitrogen results varied among the treatments. FC has emitted a 59% higher CO2 emission rate than CSW conditions. Cowdung, biochar, organic fertilizer, and vermicompost produce 13.27, 9.97, 24.57, and 16.32% higher CO2 emission rates than control treatment means no use of organic material in soil, respectively. In respect of organic carbon in the soil, CSW increases 4.12% over FC. Cowdung, biochar, organic fertilizer, and vermicompost produce 15, 7, 7, and 15% higher organic carbon over control means no use of organic materials, respectively. CSW and FC produce 150 and 115 mg NH_4-N and NO_3-N per kg soil. So, CSW increases 35% NH_4-N per kg soil. On the other hand, control, cowdung, biochar, organic fertilizer, and vermicompost produce 112, 114, 114, 141, and 136 mg NH_4-N per kg soil. CSW accumulates 32 and 19% NH_4-N and NO_3-N in soil. CSW inhibits the respiration process of denitrifiers due to a lack of oxygen as well as low temperature in the soil. Slower decomposition of cowdung, biochar, and vermicompost with flooding conditions is an effective crop production technology that can be considered as an effective way to manage mineral nitrogen and CO2 emission from soil.

OF CD VC BC pot experiment

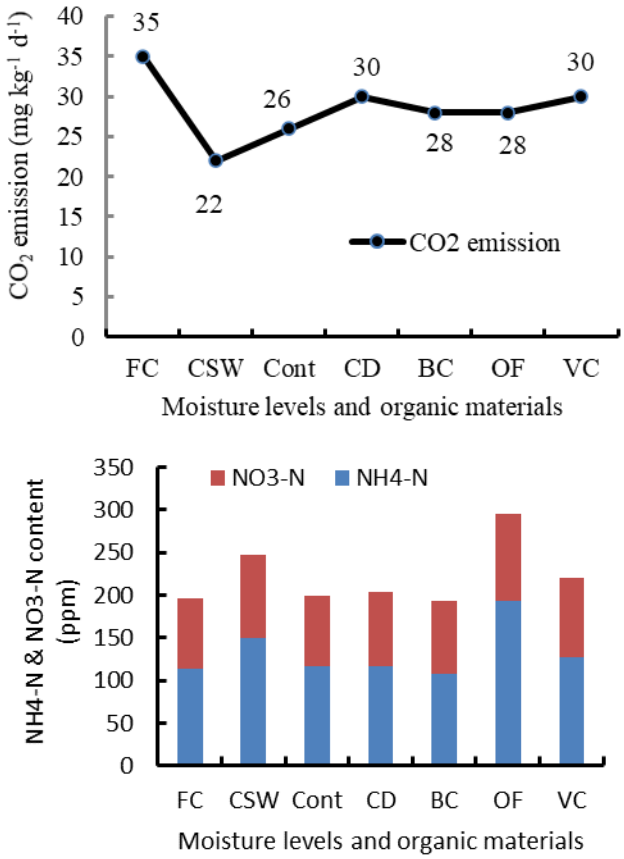

Fig. 1 Different organic materials, design of experiment, CO_2 emission rate and mineral nitrogen content in soil

Biochar, organic fertilizer, vermicompost increased the availability of Cu, Fe, Mn in CSW conditions except for cowdung. Inconsistent results were obtained for Zn availability in different treatments. Maximum Zn availability was found in organic fertilizer in combination with CSW conditions. The lowest Zn availability was observed in control with FC. So, CSW and biochar, organic fertilizer, vermicompost improve the soil health means a nutrient status in soil.

Suitable Area/Location

Organic materials and CSW means flooding condition have the potential capacity to build up the soil carbon and inhibit de-nitrification in water-dependent crop especially rice-growing areas of Bangladesh.

Benefit of the Technology

Continuous standing water condition means flooding condition increases nitrate concentration in the soil by inhibiting the de-nitrification process. Cowdung, biochar, and vermicompost increase soil organic carbon in the soil. So, the application of cowdung, biochar, and vermicompost in flooding conditions can be considered the effective mineral nitrogen management process as well as climate-smart soil management practices that might help in reducing CO2 emission and enriching organic carbon in the soil.

Title of the Technology:

Water saving and profitable cropping pattern in drought prone area of Bangladesh

Introduction

Bangladesh is an agro-based country. It is therefore important to have a profitable, sustainable, and environment-friendly agricultural system in order to ensure long-term food security for people. But the agriculture of the country is suffering from various problems due to the wide range and greater complexity of lands and climatic conditions. Among the problems, drought is an extreme and frequent event in the northwest region of Bangladesh, and the effect of droughts on agriculture is significant in Bangladesh. About 75% of irrigation water in the north-western region comes from groundwater. Excessive utilization of groundwater for irrigation and domestic purposes results in the depleted trend of the groundwater table. This causes a great threat to the irrigated agricultural system because of overdrawn aquifers, lowered water tables, reduced stream flow, and the possibility of underground water pollution. On the other hand, the cropping intensity in the drought-prone area is comparatively lower than in other parts of Bangladesh.

Description of the Technology

Field experiment was conducted at Nachole, Chapainawabganj to increase cropping intensity and reduce the irrigation water in drought prone area of Bangladesh. Treatments, T_1= 100% recommended fertilizer (RF) and T_2=RF (IPNS) + 3.0 t ha^{-1} poultry manure using T. aman-Boro- (wheat/mustard/lentil) cropping pattern. IPNS based treatment (chemical + poultry manure) treated plot produced the higher grain yield of boro rice and wheat. In T. aman, lentil, and mustard experiments, maximum seed yield was observed in recommended fertilizer.

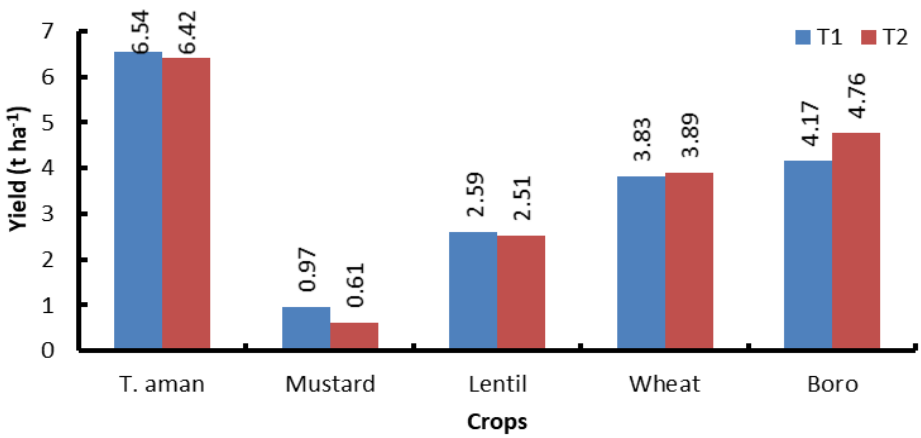

Figure 1. Effect of chemical and it's combination with organic fertilizers on yield of different crops

Suitable Area/Location
Drought-prone areas mean the northwestern part of Bangladesh is suitable for this technology.

Benefit of the Technology
T. aman – (wheat/mustard/lentil) - boro cropping pattern will increase the cropping intensity (50%) and ensure food security in Bangladesh. This cropping pattern can reduce about 25% irrigation water over the existing cropping pattern (T. aman – boro).

ii) Effectiveness in Policy Support (if applicable):

BAU Component

i) Technology Fact Sheet (title, introduction, description, suitable location/ecosystem, benefits, name and contact address of author):

1) Title of the Technology:

Improvement of crop productivity and soil health in Char land through poultry manure biochar application

Introduction

Char land soils are characterized as nutrient poor, low carbon content, high nutrient leaching, and erosion prone soils resulting in low cropping intensity. However, appropriate soil and crop management technology can improve soil health and crop intensity resulting in increased cropping intensity. Soils were treated with biochar, vermicompost and organic fertilizer for two consecutive years with a higher cropping intensity (maize – jute – T. Aman).

Description of the Technology

Poultry manure biochar, produced from locally available poultry manure by a simple pyrolysis method, can increase crop productivity through enhanced diversification and intensification of crops in a pattern. This technology does not only increase crop productivity but also improves soil health through increasing nutrient and water holding capacity and soil pH.

Suitability: This technology has shown experimental evidence of its suitability to be practiced in AEZ 9

Cropping patter: Maize – Jute – Transplanted Aman

Management practices for Maize:

- Sowing time: First week of November
- Seed rate: 20-25 kg
- Variety: Kavery 50
- Fertilizer rate: 2 ton biochar per ha plus all chemical fertilizers as recommended dose (FRG 2012) after compensating with the nutrient content in biochar
- Fertilizer rate: N, P, K, S, Mg, Zn and B @ 225, 40, 80, 30, 5, 2 and 1 kg per ha, respectively
- Fertilizer application time and method: One third of the N and all other nutrients have to be applied during the final land preparation. Biochar @ 2 ton per ha should be mixed well with the soil during the land preparation. Rest of the N needs to be applied in two equal splits at 30-35 and 50-60 days after seed sowing following irrigation water supply.
- Irrigation management: Depending on soil type and crop requirement 4-5 irrigation is required
- Pest management: Contact insecticide like Ripcord 10 EC and DCC 100 EC may be required to use if necessary
- Crop harvesting: Crop can be harvested in the last week of April
  Yield: 10-11.5 ton per ha

Management practices for Jute:

- Sowing time: Last week of April
- Seed rate: 5-6 kg per hectare
- Variety: Tosha Paat
- Fertilizer rate: 2 ton biochar per ha plus all chemical fertilizers as recommended dose (FRG 2012) after compensating with the nutrient content in biochar
- Fertilizer rate: N, P, K and S @ 90, 6, 50 and 8 kg per ha, respectively
- Fertilizer application time and method: Half of the N and all other nutrients have to be applied during the final land preparation. Biochar @ 2 ton per ha should be mixed well with the soil during the land preparation. Rest half of the N needs to be applied at 40-45 days after seed sowing.
- Irrigation management: There is no need for irrigation. If moisture is not sufficient enough in the field after sowing of seeds or before sowing of seeds, light irrigation is given for proper germination. Later on, this crop is irrigated when the plants are 10 to 12 cm tall and 3-4 leaves are formed. Supplemental irrigation may be given to the crop according to requirement of the crop.
- Pest management: Diazinon 60 EC, Karate 2.5 EC and Dithane M-45 may be required to control major diseases and pests if infestations appear.
- Crop harvesting: Crop can be harvested in August
- Yield: 3.3-3.5 ton per ha

Management practices for T. Aman:

- Transplanting time: Mid-August
- Seed rate: 80-100 g seeds per 1 m2 seedbed
- Variety: BRRI dhan71
- Fertilizer rate: 2 ton biochar per ha plus all chemical fertilizers as recommended dose (FRG 2012) after compensating with the nutrient content in biochar
- Fertilizer rate: N, P, K, S and Zn @ 90, 6, 50, 8 and 1 kg per ha, respectively
- Fertilizer application time and method: Biochar @ 2 ton per ha and all the nutrients except N have to be applied during the final land preparation. N fertilizer should be applied in three equal splits at 7-10 days after transplanting, maximum tillering stage and 5-7 days before panicle initiation, respectively
- Irrigation management: Depending on soil type and crop requirement 4 irrigation is required
- Pest management: Brifer 5G and Pretilachlor have been used for controlling Rice Yellow Stem Borer and weed management, respectively
- Crop harvesting: Crop can be harvested from the last week of October to the first week of November
- Yield: 5.5 ton per ha

Suitable Area/Location: In the charland

Benefit of the Technology: Increases soil pH by producing bicarbonate and reducing H+ in the soil solution by adsorbing it on to the surface of biochar particles. Reduces carbon and nitrogen mineralization rate and thus improve carbon and nitrogen content in soil. Biochar increases nutrient and water holding capacity of soil. It improves soil biological properties through enhancing microbial biomass carbon and nitrogen and microbial population.

Title of the Technology: Improvement of crop productivity and soil health in Acidic soil through poultry manure biochar application

Introduction

Acidic soils are characterized as nutrient poor, low carbon content, high nutrient leaching, and erosion prone soils resulting in low cropping intensity. However, appropriate soil and crop management technology can improve soil health and crop intensity resulting in increased cropping intensity. Soils were treated with biochar, vermicompost and organic fertilizer for two consecutive years with a higher cropping intensity (maize – jute – T. Aman).

Description of the Technology

Nature of the technology: Poultry manure biochar, produced from locally available poultry manure by a simple pyrolysis method, can increase crop productivity through enhanced diversification and intensification of crops in a pattern. This technology does not only increase crop productivity but also improves soil health through increasing nutrient, water holding capacity, and soil pH.

Suitability: This technology has shown experimental evidence of its suitability to be applied in AEZ 28

Cropping patter: Mustard – Boro – Transplanted Aman

Management practices for Mustard:

- Sowing time: Mid October to November
- Seed rate: 6-7 kg per hectare
- Variety: BARI Shorish-14
- Fertilizer rate: 2 ton biochar per ha plus all chemical fertilizers as recommended dose (FRG 2012) after compensating with the nutrient content in biochar
- Fertilizer rate: N, P, K, S and Zn @ 90, 18, 40, 5 and 1.5 kg per ha, respectively
- Fertilizer application time and method: Half of the N and all other nutrients have to be applied during the final land preparation. Biochar @ 2 ton per ha should be mixed well with the soil during the land preparation. Rest half of the N needs to be applied during the flowering stage thorough broadcasting method. At this time, sufficient moisture should be present in the soil.
- Irrigation management: First irrigation should be provided at 20-25 days after sowing (before flowering) and second one within 55 days after seed sowing (during fruit setting).
- Pest management: To control Alternaria leaf blight, seeds should be treated with Provax-200 before sowing. Ripcord 10 EC should be sprayed to control cut worm.
- Crop harvesting: Crop can be harvested in mid-January to mid-February (75-80 days after seed sowing)
- Yield: 1.3-1.5 ton per ha

Management practices for Boro:

- Sowing time: Mid-February
- Seed rate: 80-100 g seeds per 1 m2 seedbed
- Variety: BRRI dhan28
- Fertilizer rate: 2 ton biochar per ha plus all chemical fertilizers as recommended dose (FRG 2012) after compensating with the nutrient content in biochar
- Fertilizer rate: N, P, K, S and Zn @ 144, 9, 60, 4 and 1.5 kg per ha, respectively
- Fertilizer application time and method: Biochar @ 2 ton per ha and all the nutrients except N have to be applied during the final land preparation. N fertilizer should be applied in three equal splits at 7-10 days after transplanting, early tillering stage and 5-7 days before panicle initiation, respectively
- Irrigation management: Depending on soil type and crop requirement 8 irrigation is required
- Pest management: Virtako or Regent G and Nativo 75 WG have been used for controlling Rice Yellow Stem Borer and Rice Blast management
- Crop harvesting: Crop can be harvested within the first week of May
- Yield: 6.5-7.0 ton per ha

Management practices for T. Aman:

- Transplanting time: August
- Seed rate: 80-100 g seeds per 1 m2 seedbed
- Variety: BRRI dhan71
- Fertilizer rate: 2 ton biochar per ha plus all chemical fertilizers as recommended dose (FRG 2012) after compensating with the nutrient content in biochar
- Fertilizer rate: N, P, K, S and Zn @ 90, 7, 50, 4 and 1 kg per ha, respectively
- Fertilizer application time and method: Biochar @ 2 ton per ha and all the nutrients except N have to be applied during the final land preparation. N fertilizer should be applied in three equal splits at

7-10 days after transplanting, early tillering stage and 5-7 days before panicle initiation, respectively

- Irrigation management: Depending on soil type and crop requirement 4 irrigation is required
- Pest management: Virtako or Regent G and Nativo 75 WG have been used for controlling Rice Yellow Stem Borer and Rice Blast management
- Crop harvesting: Crop can be harvested from the last week of October to the first week of November
- Yield: 6.3-6.5 ton per ha
- Suitable Area/Location: In the acidic soil

Benefit of the Technology: Cropping intensity and total system productivity are increased resulting in higher net profit of the farmers, and physical, chemical and biological properties of the soil like aggregate structure, bulk density and soil porosity are also improved.

ii) Effectiveness in policy support (if applicable):

This technology and science based evidence will provide information about improved management of soils in acidic and char land for better crop production and improved soil health.

BSMRAU Component

i) Technology Fact Sheet (title, introduction, description, suitable location/ecosystem, benefits, name and contact address of author):

Name of the Technology

1. Biochar is the best stable and potential organic material for improving soil health and crop productivity

Introduction:

Bangladesh is one of the most climate vulnerable countries in the world. The effects of climate change in agriculture can no longer be ignored and further climate risks to agriculture are expected to increase in coming decades. Productivity of different crops in Bangladesh has been decreased because of degradation of soil health due to extreme decomposition of organic matter and rapid removal of mineralized products under high leaching conditions and crop removal. Thus stable organic material like biochar could be played the most vital role to sustain soil health and crop production in Bangladesh.

Description:

A series of pot and field experiments were conducted using different organic materials for sustainable soil health and crop production in the following selected climate vulnerable locations of Bangladesh with the following treatments:
T1 = Control, T2 = Recommended Fertilizer, T3 = Rice Husk Biochar (RHB) + Recommended Fertilizer, T4 = Poultry Manure + Chemical Fertilizer, T5 = Vermicompost + Chemical Fertilizer, T6 = Standard Organic Fertilizer + Chemical Fertilizer

Location:

The locations of study areas were climate vulnerable arsenic contaminated area of Faridpur sadar, saline areas of Batiaghata and heavy metal polluted areas of Bhaluka.

Benefit:

Biochar showed the pronounced potential stable pyrolyzed organic material which increases MBC, MBN, carbon stock, carbon sequestration and soil aggregate stability as compared to other organic materials. Moreover, slow mineralization of carbon and nitrogen was observed in biochar treated plot as compared to organic materials treated plot. After consecutive two seasons the average grain yield in all organic matter treated plots of both T. aman and boro rice was increased by 33-40% over control treatment in all sites. But significantly highest grain yield was recorded in PM treated plot

followed by vermicompost and biochar treated plots. Therefore, among the different organic matters especially biochar application as a stable organic material with IPNS basis could be potential approach for sustaining soil health and crop production and also mitigating global warming by sequestering C in soil.

Name of the Technology

2. Biochar is the prospective organic material to adsorb heavy and reduce heavy metal uptake in crop for safe food production.

Introduction:
Applications of different organic materials transform into stable forms of carbon with high adsorption sites which might help heavy metal adsorption and organo-mineral complexation and ultimately helps in environmental amelioration and improves soil health. Above all, biochar is a pyrolyzed stable organic material which can absorb heavy metals because of its large surface area, high cation exchange capacity, as well as enrichment of porous structure and surface functional groups.
Description:
A series of laboratory experiments on heavy metal adsorption-desorption adsorption isotherm studies by different organic materials including biochar and a field experiment using the similar treatments were conducted in a heavy metal polluted industrial area soil to evaluate the mechanisms of heavy metal binding by the potential organic materials with the following treatments:
The concentration of Pb, and Ni: 20, 40, 60, 80, 100, 120, 140, 160, 180 and 200 mg L^{-1} and Cd concentration: 10, 20, 30, 40, 50, 60, 70, 80, 90 and 100 mg L^{-1} were added to 0.5g of cowdung and cowdung slurry for 18 hrs shaking and rice husk biochar, tricocompost and vermicompost for 24 hrs shaking. Then the filtrate were measured to determine adsorbed heavy metal onto different organic materials.

Location:
The location of study area was climate vulnerable heavy metal polluted areas of Bhaluka.
Benefit:
The study indicated that adsorption percentage of Cd^{2+}, Pb^{2+} and Ni^{2+} was increased by addition of different organic materials in polluted soil up to 21 days incubation period. After that, a static data was prevailed from 30 DAI to 120 DAI. During the incubation period the adsorption percentage of Cd^{2+}, Pb^{2+} and Ni^{2+} by different organic materials showed a linear increasing trends. RHB showed the highest Cd^{2+}, Pb^{2+} and Ni^{2+} adsorption rate as compared to all other organic materials. The adsorption rate has followed a trends of RHB>VC>CD>CDS>TC. Kinetic studies show that the adsorption of Cd^{2+}, Pb^{2+} and Ni^{2+} onto cowdung (CD), cowdung slurry (CDS), tricocompost (TC), vermicompost (VC) and rice husk biochar (RHB), poultry manure (PM), and standard organic fertilizer (SOF) fits a Frendlich model. Therefore, addition of pyrolized RHB in heavy metal polluted soils may use as potential to reduce heavy metal uptake in plants by strongly adsorbing, thus safe food production ensured in polluted soils.

ii) Effectiveness in Policy Support (if applicable):

Our published technologies would be used as potential materials to improve soil health and mitigate global warming, which could be used by the policy maker for food security.

SAU Component

i) Technology Fact Sheet (title, introduction, description, suitable location/ecosystem, benefits, name and contact address of author):

Research title: Improvement of Soil Health and Crop Productivity of Salinity Problem Soils of Bangladesh through Organic Amendments.

Significance of the research work

Bangladesh is one of the most climate vulnerable countries in the world. The effects of climate change in agriculture can no longer be ignored and further climate risks to agriculture are expected to increase in coming decades. Productivity of different crops in Bangladesh has been decreased because of degradation of soil health through adverse climatic events and pollution of different sources. Salinity is an environmental problem which is expected to aggravate because of climate change and sea level rise. Soil and water salinity is a burning issue which is increasing at an alarming rate in the coastal areas. In Bangladesh, intensive cropping with modern crop varieties and use of less or no organic manures and crop residues results in decreased soil organic carbon and plant nutrients leading to severe land degradation. In Bangladesh, due to high temperature and high relative humidity the applications of different organic materials transform into stable forms of carbon with high adsorption sites which might help heavy metal adsorption and organo-mineral complexation and ultimately helps in environmental amelioration. But biochar is a highly stable material. So, it can't break down easily by the soil organisms. It can improve soil resilience and increase its productive capacity in the climate vulnerable and polluted areas.

Materials and Methods

1. Field experiments

Study area: Kalapara upazila of Patuakhali district (Saline area)

Fertilizer

100% Recommended chemical fertilizer (soil test basis) with biochar (2 t/ha) was used during final land preparation. But among the chemical fertilizers, urea was applied in three split i.e one in final land preparation and other two split were applied during active vegetative stage and flowering stage.

Crop:

- Maize
- T. aman and
- Other crops

Design: Randomized complete block design with three replications.

2. Mineralization experiment

Treatments

Two factors
a) Organic materials (biochar, poultry manure, vermicompost and organic fertilizer)
b) Moisture regime (field capacity and continuous standing water)

Soil: Saline soil

Design: Completely randomized design with two factors and three replications.

Results

The project started from February, 2018. Department of Soil Science, Sher-e-Bangla Agricultural University conducted research in saline soil of Kalapara under Patuakhali district. Baseline survey on fertility status of saline soil (Kalapara, Patuakhali) was completed. "Improvement of soil health in unfavorable eco-systems (saline soil) with organic amendments for sustainable crop production" was conducted on maize and T. aman at two sites in Nilgonj and in Latachapli union of Kalapara under Patuakhali district. Data from the field experiments of maize under mulch and non mulch condition showed that the highest grain yield was from rice husk biochar (@ 2 t ha^{-1} + 100% chemical fertilizer) treatment in two consecutive years. Maximum grain yield of T. aman was also obtained from rice husk biochar treated plot. From postharvest soil analysis, it is clearly found that the biochar reduced soil salinity at a lowest level than other treatments. It is also found that treatment receiving 100% recommended fertilizer along with 2 t ha^{-1} biochar successfully reduces the accumulation Na ion in soil as well as Na^+ in plant tissue and thus accelerate more uptake of K^+ ion by plant than other

treatments. Besides these, the more organic carbon sequestration has been found in the plot which was treated with biochar organic amendment than other organic materials treated plots. Mineralization study of organic materials showed that biochar is the most resistant organic amendments among other organic materials and so biochar is a useful organic amendment for carbon sequestration in Bangladesh condition.

Conclusion

Biochar is a new technology to reduce soil salinity and increase crop yield in saline soils.

ii) Effectiveness in Policy Support (if applicable):

H. Technology/Knowledge generation/Policy Support (as applied):

BARI Component

i. Immediate impact on generated technology (commodity & non-commodity)

a. Soil related constraints for crop production in acidic soil, drought prone soil and saline soil will be removed.

b. Soil fertility and crop productivity of problem soil area will be increased.

c. Famer's income will be increased.

d. Employment generation will be increased.

ii. Generation of new knowledge that help in developing more technology in future

Three technologies are developed conducting field experiment on one major cropping pattern of acidic soil (cauliflower-okra-Indian spinach), drought prone soil (mustard-boro-t.aman) and saline soil (sweet gourd-fallow-t.aman). There are many cropping pattern in these area. It needs to develop new technology confining other cropping pattern of these problem soil area.

iii. Technology transferred that help increased agricultural productivity and farmers' income

Three technologies are developed for acidic soil, drought prone soil and saline soil conducting field experiment in one upazilla of each problem soil area (Belabo, Godagari and Dumuria). Dissemination of the developed technologies are needed for other upazila belonging acidic soil, drought prone soil and saline soil.

iv. Policy support

- All organic amendments/manure need to promote for crop production along with chemical fertilizers.
- Organic amendments/manure need to be subsidized like Urea, Triple Super Phosphate and Muriate of Potash.
- Organically produced vegetables need higher price for sale

BRRI Component

i. **Immediate impact on generated technology (commodity &non-commodity):** Technology not generated

ii. **Generation of new knowledge that help in developing more technology in future** New research for amelioration of heavy metal polluted soil may generate new information

iii. **Technology transferred that help increased agricultural productivity and farmers' income:** Not applicable

iv. **Policy Support**

The three years' study of that particular area proved that the agricultural soil and irrigation water channel is polluted with certain heavy metal. Soil health is at risk. Need new Policy Support

BINA Component

i. Immediate impact on generated technology (commodity & non-commodity)

Technology will help to mitigate climate change, improve soil fertility and increase cropping intensity.

ii. Generation of new knowledge that help in developing more technology in future

Generated information will help to develop technologies for improving soil fertility and increase cropping intensity for ensuring food security in Bangladesh.

iii. Technology transferred that help increased agricultural productivity and farmers' income

Technology will help to increase crop production and farmers' income through increasing cropping intensity.

iv. Policy Support

Introduction of T. aman –mustard/lentil/wheat – boro (short duration) water savingcroppingpattern instead of T. aman –boro cropping pattern.

BAU Component

i. Immediate impact on generated technology (commodity & non-commodity)

Improved soil and crop management technology that can increase cropping intensity and productivity and soil health

ii. Generation of new knowledge that help in developing more technology in future

Biochar can improve soil physical conditions, biological properties and diversity and chemical properties.

iii. Technology transferred that help increased agricultural productivity and farmers' income

1. Title of the Technology: Improvement of crop productivity and soil health in Char land through poultry manure biochar application
2. Improvement of crop productivity and soil health in Acidic soil through poultry manure biochar application

iv. Policy support

This technology and science based evidence will provide information about improved management of soils in acidic and char land for better crop production and improved soil health.

BSMRAU Component

i. Immediate impact on generated technology (commodity & non-commodity)

Biochar proven as the potential generated technology under this study which could be improved soil health of saline, heavy metal and arsenic contaminated soils by reducing toxicity; increased crop productivity, carbon stock and carbon sequestration. Moreover, generated technology could able to mitigate GHG which helps to reduce global warming.

ii. Generation of new knowledge that help in developing more technology in future

The new knowledge about biochar technology produced for the sub-tropical weather condition under this project could be used to explore the following more new technologies:

a) Potential organic material to increase organic carbon permanently in light soils of north-eastern part of Bangladesh in such humid and hot sub-tropical weather where OM decomposition rate is high.
b) It could be used as the best and nutritious carrier material for producing biofertilizers.
c) Biochar could be used as the prospective material for increasing soil C which enhances microbial activity and soil fertility due to less C and N mineralization.
d) Moreover, biochar could be used as the storage material by holding all cations by which it could be reduced cations loss through leaching and increases soil CEC including soil fertility and food security.
e) Biochar could be with chemical fertilizer for increasing nutrient efficiency and decreasing arsenic and heavy metal uptake in food chain from contaminated soils.

iii. Technology transferred that help increased agricultural productivity and farmers' income

All above mentioned technologies related to biochar could be sustained soil health and crop productivity which would help to increase farmers' income.

iv. Policy Support

World wide organic amendments is considered climate smart practice to improve soil health and crop productivity. Among all other organic amendments under this project, comparatively biochar performed best in relation to improve soil health and crop productivity, highest heavy metal adsorption capacity, increase carbon stock in soil and decrease CHG through carbon sequestration. Therefore, the output of the project especially biochar could be considered as the key climate smart material and extensively disseminate among the stakeholders through proper policy maker.

SAU Component

i. Immediate impact ongenerated technology (commodity & non-commodity)
Farmers can increase crop production in saline soils using rice husk biochar.
ii. Generation of new knowledge that help in developing more technology in future
Use of biochar in different polluted soils will help to amend the soils.
iii. Technology transferred that help increased agricultural productivity and farmers' income

iv. Policy Support

I. Information regarding Desk and Field Monitoring:

BARI Component

i. Desk Monitoring [description & output of consultation meeting, monitoring workshops/seminars etc.) :

Meeting type	Description & output of consultation meeting
1. Technical Division/Unit, BARC (Field visit)	A technical team head by Dr. Aziz Jilani Choudhury visited project activities on 1st April 2019. The team visited experiment analysis, field data, and procurement. A brief presentation was given that time. The team was satisfied with the activities
2. Monitoring and evaluation by PIU-BARC, NATP-2	A technical team visited project activities on 11th November 2020. The team visited field data, and procurement and

	financial progress. A brief presentation was given that time. The team was satisfied with the activities.
3. Inception workshop (April, 2018)	Inception workshop held on April, 2018. Brief presentation about objectives, methodology and work plan were discussed in the meeting in presence of prominent soil scientist. After consultation, site of drought prone area is shifted from Lalpur, Natore to Godagari, Rajshahi. As no drought condition prevail at Lalpur, Natore. Another suggestion was that field trial of saline area should be conducted in the southern site of Dumuria upazila because in norther site no salinity prevails. Both the suggestion are obeyed.
4. Annual review workshop (Year 2019)	Annual progress workshop held on 23rd Juy, 2019. Progress of bench mark survey and crop yield of cauliflower (Belabo), mustard (Godagari) and sweet gourd (Dumuria) 2018-19 presented at BARC
5. Annual review workshop (Year 2020)	Annual progress workshop held on 29th September, 2020. Progress of bench mark survey and crop yield of Boro2019-20 presented at BARC

ii. Field Monitoring (date& no. of visit, name and addresses of team visit and output):

Not done

iii. Weather data, flood/salinity/drought level (if applicable) and natural calamities:

COVID 19 hampered frequent field visit.

BRRI Component

i. Desk Monitoring:

Meeting type	**Description & output of consultation meeting**
1. Technical Division/ Unit, BARC (Field visit)	A technical team visited project activities on 19th February 2019. The team visited experiment analysis, field data, and procurement. A brief presentation was given that time. The team was satisfied with the activities
2. Monitoring and evaluation by PIU-BARC, NATP-2	A technical team visited project activities on 11th November 2020. The team visited field data, and procurement and financial progress. A brief presentation was given that time. The team was satisfied with the activities.
3. Institutional monitoring	An institutional monitoring was done in16th July 2019 in presence of Director General of Bangladesh Rice Research Institute to know the status of the research activities. A power point presentation was given accordingly. BRRI authority was satisfied with the activities.
Annual review workshop (year 2019)	Annual progress workshop held on 23rd July, 2019. Progress of bench mark survey and crop yield of Boro2018-19 presented at BARC
3.Annual review workshop (Year 2020)	Annual progress workshop held on 29th September, 2020. Progress of bench mark survey and crop yield of Boro2019-20 presented at BARC

ii. Field Monitoring: Not done

iii. Weather data, flood/salinity/drought level and natural calamities

: Covid 19

BINA Component

i. Desk Monitoring [description & output of consultation meeting, monitoring workshops/seminars etc.):

ii. Field Monitoring (date& no. of visit, name and addresses of team visit and output):

Date of visit	No. of visit	Name and address of team	Output
07.06.2019	1	Dr. MosharafUdinMollah, PSO, AERS, BARC	
15.12.2019	1	Dr. Md. Abdul Jalil, RMS, PIU/BARC Dr. Md. Abdullah Al Faroque, AM (Admin), PIU/BARC Mr. MunshiMamunurRahman, Doc A, PIU/BARC Mr. Md. AsikurRahman, AM (Accounts), PIU?BARC	

iii. Weather data, flood/salinity/drought level (if applicable) and natural calamities:

BAU Component

i. Desk Monitoring [description & output of consultation meeting, monitoring workshops/seminars etc.)

Desk monitoring:

Monitoring held

First meeting: 17 to 18 February 2019
Comments: The experts commented that it was an academic project; progress of the research work was good

Second meeting: 12.02.2020
Comments: Lab procurement and other management was good

ii. Field Monitoring (date & no. of visit, name and addresses of team visit and output)
Due to the COVID-19 pandemic no such event has taken place

iii. Weather data, flood/salinity/drought level (if applicable) and natural calamities
There was a flood in May 2020 which slightly damaged jute yield in the same year

BSMRAU Component

i. Desk Monitoring [description & output of consultation meeting, monitoring workshops/seminars etc.]: N/A

ii. Field Monitoring (date& no. of visit, name and addresses of team visit and output): N/A

iii. Weather data, flood/salinity/drought level (if applicable) and natural calamities: N/A

SAU Component

i. Desk Monitoring[description & output of consultation meeting, monitoring workshops/seminars etc.):

Description	Output
Consultation Meeting	N/A
Monitoring Workshop	N/A
Seminar	N/A

ii. Field Monitoring (date & visit no., name and addresses of team visit and output):

No. Visit	Date of Visit	Name of Visit team	Output
01.	18. 01. 21	**1.** Dr. Md. Harunur Rashid, Director, PIU-BARC, NATP-2 **2.** Mr. Mohammad Assaduzzaman, Manager (Financial Management) **3.** Mr. Mohammad Shahidul Islam, Procurement Specialist **4.** Dr.Mohammad Abdullah Al Faroque, Assistant Manager (Administration)	1. Need special emphasis to complete the rest of task using alternate plan overcoming the losses due to COVID-19 pandemic situation 2. Should ensure the stock entry of procured goods items 3. Should preserve the bills and finance related documents properly 4. In case of procurement of goods should complete in time 5. Using the checklist of Indicative Fraud & Corruption for RFQ method 6. Should preserved the procurement related documents properly

iii. Weather data, flood/salinity/drought level (if applicable) and natural calamities:

Table 1. Monthly recorded maximum-minimum and average air of the experimental area during the study period in the year of 2018-19 and 2019-20.

Month	Air Temperature (^{0}C)					
	2018-2019			2019-2020		
	Maximum	Average	Minimum	Maximum	Average	Minimum
September	34	32	27	32	30	26
October	33	30	25	31	29	25
November	32	29	24	31	28	24
December	27	24	19	27	23	19

January	29	25	19	26	22	17
February	31	26	20	29	25	18
March	34	30	24	34	30	23
April	38	34	27	38	33	25
May	39	35	28	37	33	27
June	36	33	29	34	32	27
July	33	31	27	32	30	27
August	33	31	27	33	30	27

Table 2. Monthly average rainfall and rain days of the experimental area during the study period in the year of 2018-19 and 2019-20

Month	**Average rainfall (mm) and rain days**			
	2018-2019		2019-2020	
	Rainfall	Rain days	Rainfall	Rain days
July-September	352.89	81	489.07	90
October-December	42.23	16	104.13	27
January-March	33.07	14	14.80	14
April-June	253.63	65	408.07	68

Source: *https://www.worldweatheronline.com/kalapara-weather-averages/bd.aspx*

Salinity level of Project Site: In April-May EC 6.0 to 8.0 ds/m, rainy season <4.0 ds/m
Natural Calamities: Cyclone, heavy rainfall and flooding.

J. Sub-project auditing (covers all types of audit performed):

Types of audit	**Major observation/ issues/ objections raised; if any**	**Amount of Audit (Tk.)**	**Status at the sub-project end**	**Remarks**
BARC Component				
FAPAD Audit 30.10.2019	No	1367890		2018-2019
FAPAD Audit 09-12-2020	No	1359345		2019-2020
FAPAD Audit 11-10-2021	No	1344030		2020-2021
BARI Component				
18/11/2019 (FAPAD)	No	2687499.5		
02/11/2020 (FAPAD)	No	2338879.5		
BRRI Component				
FAPAD Audit	No	2024204	July/2018 to June/2019	
FAPAD Audit	No	1357883	July/2019 to June/2020	
FAPAD Audit	No	1052795	July/2020 to June/2021	

Types of audit	Major observation/ issues/ objections raised; if any	Amount of Audit (Tk.)	Status at the sub-project end	Remarks
BINA Component				
FAPAD Audit	-	312704.00	2018-2019	14.11.2019 to 25.11.2019
FAPAD Audit	-	1072652.00	2019-2020	04.11.2020 to 17.11.2020
BAU Component				
FAPAD Audit	No	1796829	No. Major Problem	
FAPAD Audit	No	1619326	No. Major Problem	
BSMRAU Component				
FAPAD Audit 30.10.2019	No	2656894.00		
FAPAD Audit 09.12.2020	No	2112672.00		
SAU Component				
Financial	N/A	543158	OK	Upto 30.06.2019
Financial	N/A	1197842	OK	Upto 30.06.2020
Financial	N/A	840250	OK	Upto 30.06.2021

K. Lessons Learned:

Lessons	Remarks
i. Biochar is a potential organic material as compared to others in relation to improve soil health, reduce carbon emission, reduce heavy metal uptake from the contaminated soil due to tightly adsorb on the large surface areas of biochar. ii. Better soil and crop management can increase system productivity iii. Discharging untreated industrial effluent to the agricultural fields, which creates heavy metal contamination in soil-water-plant system. iv. Selected farmer of saline soil area are not cooperative. So before conducting project activity one have to be cautious about farmer selection. v. Farmer of drought prone area is educated and having smart phone. So he can inform us any problem (insect, pest, natural calamity) through video which is very much helpful for scientist during COVID-19. So to conduct field experiment in problem soil area, it is important to select those famer having smart phone.	

vi. Site of field experiment in saline and acidic soil are far away from the regional office of NARS institutes which is problem for frequent supervision. So experimental site should be nearer of regional office for frequent supervision. So experimental site should be nearer of regional office for frequent supervision. vii. The expert comments gathered knowledge during workshops, report writing, planning, report presentation, procurement and farmers perception for soil and crop production as well as future planning of research in drought prone areas of Bangladesh. viii. Soil health of Sripur and Gazipur industrial area are at risk and toxic with Pd and Cd. ix. A comprehensive understanding on soils and their bio-physico-chemical properties, crop types and cultivation practices, fertilizer practices, water facility for crop production and BMDC activities was developed through visiting many places during experimentation and soil collection.	

L. Challenges (if any):

Component	Remarks
BARI Component	
i. Natural calamities especially prolonged drought, untimely heavy rainfall and insect pest infestation are major challenges for field trial conduction. Pandemic disease COVID-19 hampered the frequent visit of scientists in the experimental field. Crop pro duction in the problem soil area are expensive and labour-intensive work. As a result, cost of produced crop are high compared to crops produced in favorable eco-system. Suitable resilient variety with appropriate technology are need for this problem soil area. More training and media coverage are needed to popularize these technologies. ii. Stop Industrial Pollution iii. All designed experiments could not complete due to COVID-19 and some of the graduate student's incubation experiments damaged like adsorption-desorption of arsenic and heavy metals during severe condition of COVID-19. iv. Facing problems to handle smoothly in farmer's field experiments due to careless management by the assigned farmers. v. Mass production of biochar in the farmer's field vi. Farmers are not interested to use more costly biochar	

M. Suggestions for future planning (if any):

Component	Remarks
BARI Component	
i. NARS institute have to open new research center on problem soil area and ecologically unfavorable cropping system like saline, drought prone area, water logged area etc. ii. It has already been evaluated and found through different studies under this project that biochar is a potential organic material as a new technology for our sub-tropical	

weather condition which could be improved soil health for sustainable crop production, increased soil pH, reduced heavy metal uptake by plant from the contaminated soils and reduced carbon emission with remarkable increasing carbon stock by sequestering in soil. iii. Research facility of existing research stations of these area should be strengthening. iv. Research should be continued to increase cropping intensity through overcome the shortfall of water scarcity and soil infertile in drought prone areas of Bangladesh. v. Biochar amendment should be continued for longer with higher rate (e.g., > 5 ton per ha) to improve degraded or nutrient poor soils and to enhance cropping diversity and intensity which will eventually increase systems productivity. vi. Pot experiment may be suggested to avoid heavy rainfall and cyclones. vii. Therefore, this new technology should need to popularize in the farmers level through extensive validation researches in AEZ basis for sustainable soil health and crop production as well as reducing GHG to mitigate global warming.	

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