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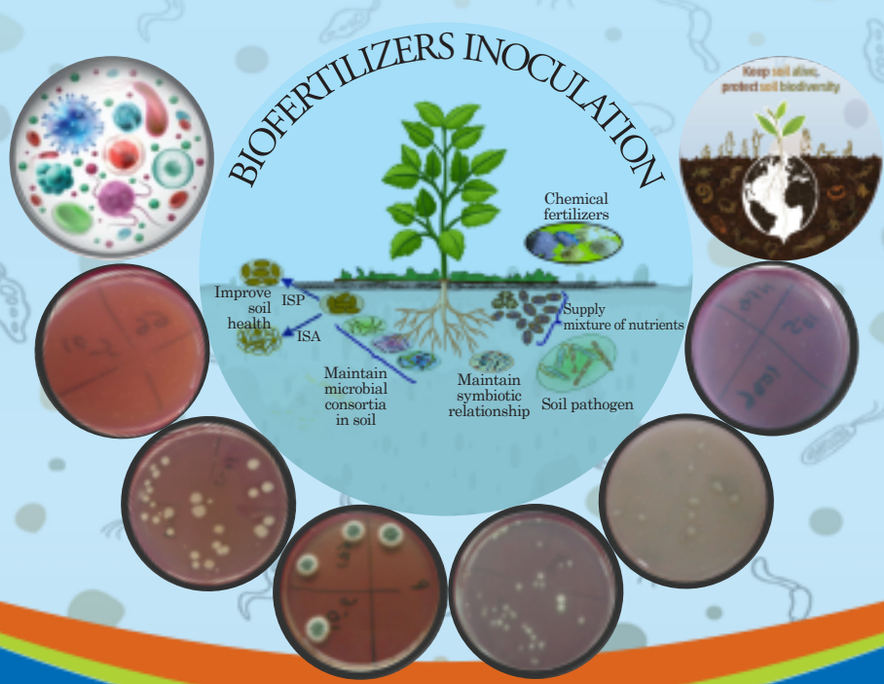
Sub-project Completion Report

on

MICROBIAL CHARACTERIZATION OF BANGLADESH SOIL AND DEVELOPMENT OF CLIMATE SMART BIOFERTILIZERS FOR CROP PRODUCTION AND SOIL FERTILITY



Sub-project Duration

October 2019 to December 2022

Coordinating Organization

Soils Unit, Natural Resources Management Division (NRM)
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

Soil Science Division
Bangladesh Agricultural Research Institute

Soil Science Division
Bangladesh Rice Research Institute

Soil Science Division
Bangladesh Institute of Nuclear Agriculture

Soils and Nutrition Division
BangladeBangladesh Sugarcrop Research Institute

Project Implementation Unit
National Agricultural Technology Program-Phase II Project
Bangladesh Agricultural Research Council
Farmgate, Dhaka-1215

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Abbreviation and Acronyms

Sl. No.	Abbreviation and Acronyms	Full meaning
1.	%	Percentage
2.	AEZ	Agro-Ecological Zone
3.	AMs	Actinomycetes
4.	BARC	Bangladesh Agricultural Research Council
5.	BARI	Bangladesh Agricultural Research Institute
6.	BRRI	Bangladesh Rice Research Institute
7.	BINA	Bangladesh Institute of Nuclear Agriculture
8.	BSRI	Bangladesh Sugarcrop Research Institute
9.	B. Rhizo	Bradyrhizobium
10.	C	Carbon
11.	C:N	Carbon to Nitrogen Ratio
12.	°C	Celsius or Centigrade temperature
13.	cfu	Colony Forming Unit
14.	CO_2	Carbon Dioxide
15.	CV	Coefficient of Variation
16.	CEC	Cation Exchange Capacity
17.	Co-PI	Co-Principal Investigator
18.	dw	Dry weight
19.	EC	Electrical Conductivity
20.	F	Fungus
21.	FLNFB	Free living N_2 fixing bacteria
22.	FAO	Food and Agriculture Organization
23.	FC	Field Capacity
24.	FRG	Fertilizer Recommendation Guide
25.	g	Gram
26.	GPS	Global Positioning System
27.	ha	Hectare
28.	IAA	Indoleacetic acid
29.	IFAD	International Food and Agriculture Organization
30.	IPNS	Integrated Plant Nutrition System
31.	kg	Kilogram
32.	KCl	Potassium Chloride
33.	L	Liter
34.	LS	Level of significance
35.	LSD	Least significant difference
36.	LB	Luria Burtani
37.	M	Molar
38.	meq	Mili Equivalent
39.	N	Nitrogen
40.	n	Number
41.	NA	Nutrient Agar
42.	NATP	National Agricultural Technology Program

43.	NH_4-N	Ammonium Nitrogen
44.	NO_3-N	Nitrate Nitrogen
45.	OM	Organic Matter
46.	OC	Organic Carbon
47.	PCR	Polymerase Chain Reaction
48.	P	Phosphorus
49.	PP	Procurement Plan
50.	ppm	Parts per million
51.	PSB	Phosphate Solubilizing Bacteria
52.	PI	Principal Investigator
53.	PIU	Project Implementation Unit
54.	PBRG	Program Based Research Grant
55.	TSP	Triple Super Phosphate
56.	TN	Total Nitrogen
57.	TB	Total Bacteria
58.	w/v	Weight by Volume
59.	wt.	Weight
60.	µg	Micro Gram
61.	c mol kg^{-1}	Centimole per kilogram
62.	Available P	Available Phosphorus
63.	Available K	Available Potassium
64.	Available S	Available Sulphur

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Executive Summary

Soil microorganisms are the most abundant of all the biota in soil and are responsible for driving nutrient cycling and organic matter decomposition, soil fertility improvement, soil health restoration, plant nutrient release, and availability and ecosystem dynamics. Beneficial microorganisms promote nutrient mineralization and availability, produce plant growth hormones, and are antagonists to plant pests, parasites, or diseases. In addition, the fertility and productivity of the soil mainly depend on soil organic matter and greatly on soil microbial activity. However, the microbial properties of the soils of Bangladesh have not yet been systematically studied. The soils of the country are being utilized very intensively to produce higher amounts of food to feed 165 million people in the country. As such, due to overexploitation, the health of the soil is deteriorating day by day. Moreover, the present climate change imposes further adverse pressure on the soil resource. Under the above perspective, the present project was initiated on 15 October 2019 upon the signing of the Letter of Agreement (LoA) with the total approved project cost of BDT 30318343 (Three crores three lakhs eighteen thousand three hundred forty-three) as revised. The PBRG sub-project was continued up to December 2022. The project was coordinated by BARC whereas; BARI, BRRI, BINA, and BSRI components functioned as the implementing organizations. The project was commenced with general objectives: **i)** to study physical, chemical, and microbial properties of soil of different AEZs of Bangladesh; **ii)** to isolate and characterize (biochemical and molecular characterization) climate-smart i.e., saline, acidic, and drought-tolerant Nitrogen-fixing and plant growth promoting bacteria/microbes from the root, nodules and rhizosphere soils of Bangladesh; and **iii)** to develop biofertilizer for cereal, pulse, oilseed, sugarcane and test efficacy for crop productivity and soil fertility.

Implementing all components followed a unified soil sampling protocol covering 30 AEZs of Bangladesh covering 39 districts, Each AEZ includes two districts and in each district were taken 2 upazila (10 locations of each upazila) and each upazila followed 2 unions (5 locations of each union dividing the equal distance of total union). A total of 1123 soil samples (310 samples from BARI from 8 AEZs, 253 samples from BRRI from 8 AEZs, 320 samples from BINA from 7 AEZs, and 240 samples from BSRI from 7 AEZs) were collected with GPS records along with crop history. Unified standard analytical methods were followed to analyze soil texture, soil pH, Soil Organic C, Total N, Total Bacteria, Fungus, Actinomycetes, N_2- Fixing Bacteria, Phosphate Solubilizing Bacteria (PSB), and Identification of isolated strains. Isolation of organisms, characterization and biofertilizer production, and pot and field experiments were done in respective soil laboratories and fields of BARI, BRRI, BINA, and BSRI. However, the component-wise activities and outputs of the project are summarized below:

BARI component; the study report of this component revealed that the total bacteria populations range was the highest (6.0×10^5 to 2.2×10^9 cfu/g soil) in the soil of Diginala upazila of Khagrachari district under AEZ-29 and the lowest (3.0×10^5-5.0×10^6 cfu/g soil) was in Cox's Bazar Sadar upazila soils under AEZ-23. The lowest total fungus population range was recorded in the collected soils of AEZ-30. On average, Actinomycetes populations were low in all the tested soils of different AEZs. The populations of free-living N_2-fixing bacteria were higher than the *Rhizobium* and *Bradyrhizobium* populations. However, populations of phosphate-solubilizing bacteria were higher than free-living N_2-fixing bacteria. The soils of AEZ 18 (mostly Bhola) appeared to be alkaline while the soils of Rangpur under AEZ 3 were found to be acidic. The majority of soils of different AEZs were reported to be practically slightly acidic to neutral and neutral to slightly alkaline. The highest organic carbon range (0.5 to 1.9%) and total N range (0.04 to 0.11%) were recorded in soils of Kurigram under AEZ-2. The majority of the studied soils were found to be sandy loam, sandy clay loam, clay loam, and loam in texture. Application of biofertilizer resulted in higher crop performance in groundnut and lentil over uninoculated control in all locations. In case of groundnut, the highest nut yields 27.60 g/plant and 27.31 g/plant were recorded by using *Rhizobium* sp. FAGR241 and *Rhizobium* sp. FAGR102 during 2020-2021 and 2021-2022, respectively under pot study. However, in case of a field trial, at Cox's Bazar the higher groundnut yield (2.28 t ha-1) was obtained with *Rhizobium* sp. BARIRAh808 while in Gazipur *Rhizobium* sp. FAGR318 gave a higher nut yield (2.10 t/ha) during 2021-2022 compared to

a lower one in 2020-2021. In case of lentil, the highest seed yields 1.76 g/plant and 0.67 g/plant were recorded by using *Rhizobium* sp. FALR114 and during 2021-2022 and 2020-2021, respectively under pot study. In case of the field experiment, the highest seed yield (1.33 t/ha) in Gazipur was obtained with T5 (*Rhizobium* sp. FALR328) while at Pabna the highest seed yield (1.81 t/ha) of lentil was recorded from both *Rhizobium* sp. FALR114 and *Rhizobium* sp. FALR317 during 2021-2022, which was significantly higher over all other strains except T6 in 2020-2021 at Pabna. The groundnut nodulated bacterial gene sequences result showed that *Rhizobium* sp. FAGR308, *Rhizobium* sp. FAGR318, *Rhizobium* sp. FAGR322 were similar with *Rhizobium* miluonense CCBAU41251T (EF061096) and *Rhizobium* sp. FAGR254, *Rhizobium* sp FAGR102, and *Rhizobium* sp BARIRAh808 were similar to *Rhizobium* miluonenseCCBAU41251T (EF061096) bacterial sequence. Similarly, the lentil nodulated bacterial gene sequences result represented that *Rhizobium* sp. FALR114, *Rhizobium* sp. FALR319, *Rhizobium* sp. FALR328 were similar to *Rhizobium* hainanenseI66T (U71078) and *Rhizobium* sp. FALR315, *Rhizobium* sp FALR317, *Rhizobium* sp. FALR317, *Rhizobium* sp. BARIRLc107 were similar to *Rhizobium* pusense NRCP10T (FJ969841) bacterial sequence. All bacterial sequences were belonging to the bacteria kingdom, proteobacteria phylum, alpha-proteobacteria class, rhizobiales order, rhizobiaceae family, and genus *Rhizobium*.

BRRI component; the study report showed that the range of total bacterial populations was significantly high in the Decreerchar union of AEZ-10 (2 x 10^6 to 2 x 10^9 cfu/g soil), Panisara union of AEZ-11 (2 x 10^7 to 2 x 10^9 cfu/g soil), and Deorghachi union of AEZ-22 (7 x 10^6 to 1 x 10^9 cfu/g soil). The lowest total bacteria range was in AEZ-13. The total fungus population range was comparatively lower in the AEZ-10, AEZ-13, AEZ-15, AEZ-16, and AEZ-27. On average, Actinomycetes populations were low in all the tested AEZs. The populations of free-living N_2-fixing bacteria were higher than the *Rhizobium* populations. However, populations of phosphate-solubilizing bacteria were higher than free-living N2-fixing bacteria. The dominant potential bacteria from each AEZ were identified and tested for bio-molecular characteristics. From 20 potentially identified bacteria, *Bacillus spp.* and *Stentrophomonas* spp. was found as dominant strains. Among the strains, the highest N_2 fixation (28 ppm NH4) was recorded by *Bacillus thuringiensis* (B49) isolated from AEZ-27 and *Pseudomonas geniculata* (B61) isolated from AEZ-15. The highest 3746 ppm P was solubilized by the *Stentrophomonas maltophilia* (B53), isolated from Shahjahnpur Upazila of AEZ-27. The highest amount of indoleacetic acid (144 ppm) was produced by strain B59 isolated from the Shyamshiddhi union of Sreenagar upazila (AEZ-15). Isolated 15 potential strains were coated with TSP and Urea fertilizer and named as 'Bio-coated urea' and 'Bio-coated TSP' biofertilizer, respectively. In the glasshouse, pot experiments were conducted for testing the efficacy of the developed biofertilizer in the soil plant system. About 36% grain yield increased in BRRI dhan28 and saved 50% TSP fertilizer by the application of 'Bio-coated TSP' in acid soil compared to TSP fertilizer only. Application of Bio-coated urea improved grain yield by 10.53% of BRRI dhan99 over chemical fertilizer in the Saline soil. Nutrient mineralization from Bio-coated fertilizer and survival of the bacteria during the incubation study and plant growth period (glasshouse study) were at a satisfactory level. Among the tested eight AEZs, the highest organic matter (3.90%) and total N (0.21%) was recorded in the Chadnighat union of Moulvibazar Sadar upazila in AEZ-22. In conclusion, among the tested eight AEZs, the populations of beneficial bacteria (free-living N_2 fixing, *Rhizobium*, and phosphate solubilizing bacteria), soil organic matter, and total N were lower than any healthy agricultural soil. The results of one season glasshouse study proved that the application of 'Bio-coated urea' in saline soil and 'Bio-coated TSP' in acid soil can improve rice productivity (about 10 to 39%) and save 50% chemical fertilizer in saline and acid soil, respectively.

BINA component reported that the total bacteria populations were highest in AEZ-14 (Roghunathpur union (12.6×10^7-15.8×10^7) cfu/g soil), Rangpur union (12.6×10^7-19×10^7 cfu/g soil) and Gabindapur union (11.8×10^7-18.5×10^7 cfu/g soil). The lowest total bacteria were in AEZ-17. Overall, Actinomycetes populations were low in all the tested AEZs. The populations of free-living N_2-fixing bacteria were higher over *Rhizobium*, *Bradyrhizobium*, Fungi, and Actinomycetes. *Rhizobium* and *Bradyrhizobium* populations were found to be higher over PSB, Fungi, and

Actinomycetes. PSB population was recorded higher over Fungi and Actinomycetes. The fungi population was found higher than Actinomycetes. Soils of AEZ 3, AEZ 7, AEZ 9, and AEZ 25 were found acidic in reaction while soils of AEZ 12, AEZ 14, and AEZ 26 showed alkaline. AEZ 17 showed neutral in soil reaction. Soil organic matter was found low (below 2%) in AEZ-7, AEZ-9, AEZ-17, AEZ-25, and AEZ-26 where AEZ-3, AEZ-12, and AEZ-14 contain medium (above 2%) soil organic matter. AEZ-14 showed the highest organic matter content (3.62%) in soil among 8 AEZs. Total nitrogen in soils of most AEZ was found low except AEZ 14. The highest soil nitrogen (3.35%) is contained in AEZ 14. Soil textures of different AEZs were found sand, loamy sand, sandy loam, loam, clay loam, sandy clay loam, and clay where most were sandy loam, sandy clay loam, clay loam, and loam. Among the tested eight AEZ's, the populations of beneficial bacteria (free-living N2 fixing, *Rhizobium*, *Bradyrhizobium*, and phosphate solubilizing bacteria), soil organic matter, and total N were lower than any healthy agricultural soil. Fifteen salt-tolerant Rhizobia strains were isolated and characterized biochemically. Salinity-tolerant biofertilizer was developed for the production of soybean in saline areas. Through the application of salinity-tolerant biofertilizer, soybean yields were increased by 40-60% in saline areas which saved 50 kg of nitrogenous fertilizer.

BSRI component reported that the higher total range of bacteria (23.57×10^5-18.92×10^9), the actinomycetes (9.15×10^5-10×10^7), *Rhizobium* (8.6×10^7-8.9×10^8), and the phosphate solubilizing bacteria (9.5×10^4-8.5×10^7) were found in AEZ 8. The soil texture was silt loam containing a higher range of organic matter (1.48-1.89%), total nitrogen (0.10-0.15%), and soil pH (5.55-6.15). But the higher range of fungus (19×10^7-20.20×10^7) was found in AEZ 5. The soil texture was silt clay containing a higher range of organic matter (1.43-1.69%), total nitrogen (0.07-0.10%), and soil pH (5.80-6.52). The higher range of nitrogen-fixing bacteria (5×10^7-10.35×10^7) was found in AEZ 28 where the cropping pattern occupied sugarcane in high land. The soil texture was clay containing a higher range of organic matter (1.40-1.80%), total nitrogen (0.09-0.15%), and soil pH (6.55-6.99). The diazotroph isolated from sugarcane rhizosphere and roots were tested for Gram reaction. Among the 9 isolated strains 6 of them were found as Gram-negative and 3 were Gram-positive. Two of the diazotroph isolates were found as positive for phosphate solubilization activity. The bacterial isolates produced higher IAA which varied from 65 to 162 μg mL^{-1}. Based on the 16S rRNA gene sequencing, the isolated strains were identified as *Bacillus pumilus* BS37a, *Bacillus pumilus* BS37b, *Bacillus pumilus* BS34a and *Bacillus pumilus* BS34b, had the highest similarity 99% type strain *Bacillus pumilus* and *Kocuria rosea* BSBR1 and *Kocuria rosea* BSBR2 had the highest similarity 99% type strain *Kocuria rosea*. The highest number of millable cane (114.03x103) and sugarcane yield (108.25 t/ha) was found in the T_5 treatment. So, 75% RFD along with nitrogen-fixing inoculants gave a better performance.

Concluding statement/recommendations:

- **i.** Microbial population count and their biodiversity in soils under different AEZs of Bangladesh need to be intensively studied;
- **ii.** In depth studies on morphological, biochemical, and molecular characterization of effective beneficial microorganisms should be needed for the production of biofertilizers for sustaining crop yield and improving soil health under changing climate;
- **iii.** Promising biofertilizers should be well distributed among the farmers for proper use through extension channels providing with training and protocols;
- **iv.** Long-term follow-up projects should be formulated for the continuation of this noble work.

Key words: Agro-ecological zones, Total bacteria, Free-living N_2 fixing bacteria, Phosphate solubilizing bacteria, *Rhizobium*, Biofertilizer.

PBRG Sub-project Completion Report (PCR)

A. Sub-project Description

1. **Title of the PBRG sub-project:** Microbial Characterization of Bangladesh Soil and Development of Climate Smart Biofertilizers for Crop Production and Soil Fertility.

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

1. Coordination component : BARC
2. Soil Science Division **:** BARI
3. Soil Science Division **:** BRRI
4. Soil Science Division **:** BINA
5. Soils and Nutrition Division **:** BSRI

3. **Name and full address with phone, cell and E-mail of Coordinator, Associate Coordinator and PI/Co-PI (s):**

Coordinator	**Date**
1. Dr. Md. Monowar Karim Khan Member Director Bangladesh Agricultural Research Council Farmgate, Dhaka 1215 Cell: 01717100616 E-mail: monowarkk@yahoo.com	From 15-10-2019 to 30-12-2020
2. Dr. Md. Baktear Hossain Member Director Natural Resources Management Division Bangladesh Agricultural Research Council Farmgate, Dhaka 1215 Cell: 01711201441 E-mail: m.baktear@barc.gov.bd	From 25-01-2021 to December 2022
Associate Coordinator	
1. Dr. Faridul Alam Principal Scientific Officer Soils Unit, Natural Resources Management Division Bangladesh Agricultural Research Council Farmgate, Dhaka, Cell: 01819338131 E-mail: farid443@barc.gov.bd	From 24-01-2022 to December 2022
2. Dr. Md. Khairul Alam Principal Scientific Officer Soils Unit, Natural Resources Management Division Bangladesh Agricultural Research Council Farmgate, Dhaka 1215, Cell phone: 01761383121 E-mail: khairul.alam@barc.gov.bd	From 03-02-2021 to December 2022

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4. Sub-project budget (Tk.):

4.1 Total: (Tk.**27067000.00** (Two crore seventy lakhs sixty-seven thousand) approved

4.2 Latest Revised: (Tk.**30318343.00** (Three crore three lakh eighteen thousand three hundred forty-three)

5. Duration of the sub-project:

5.1 Start date (based on LoA signed): October, 2019

5.2 End date: December, 2022

6. Background of the sub-project:

Soil is a large sink for organic carbon and soil microorganisms are responsible for most of the nutrient release from organic matter for plants. Due to global climate change, agriculture needs to change its structure. Crops production system requires climate suitable plant nutrition and soil management practices. The interaction among plants, soil and microorganisms is considered to be the major driver of ecosystem functions (Suleiman *et al*., 2013). Improved understanding of the soil microbiome will help identify management practices to optimize soil functions e.g. nutrient availability, optimize fertilizer practices and reduce environmental impacts of farming. Physico-chemical properties of soils of Bangladesh have been documented, but very little information is available on microbial community structure and dynamics, and their interactions with soils and plants. Long term indiscriminate use of agrochemicals and the changing climate affect soil microbial diversity resulting in an adverse soil health and lower resource use efficiency, crop productivity and sustainability. It is reported that total bacteria, urease and phosphatase activities, population of ammonia-oxidizing bacteria (Ali *et al*., 2013), methanotrophs (Dai *et al*., 2013) and denitrifiers (Tang *et al*., 2010) shifted due to long-term chemical fertilizer applications. The microbial populations of Bangladesh soils vary from AEZs to AEZs (Bhuiyan *et al*., 2015). Proposed project will greatly increase our understanding of the underlying microbial processes underpinning nutrient biogeochemistry in soils under diverse crops and cropping patterns, and will help optimize nutrient use efficiency, improve resilience to climate change, and refine greenhouse gas mitigation options.

Soil salinity is increasing in costal saline areas day by day. A vast area of Noakhali, Chattogram, Khulna, Satkhira, Bagerhat, Bhola, Barishal, Barguna, Patuakhali are now affected by salinity. Some areas like Madhupur and a part of hilly areas are highly acidic. Western part of country i.e. Chapainawabgonj and part of Rajshahi district is going under drought prone belonging high temperature and low moisture regime. Stress tolerant crop varieties are being developed for cultivation in that area. But there is no such soil management practice for plant nutrition system. Biofertilizers can function as key player in sustainable crop production by improving soil fertility, plant tolerant and crop productivity. Biofertilizers such as N- fixing, P- solubilizing and quick composting are very important tools for crop production and fertility sustaining in those areas. These stress tolerant potential endospheric and exospheric (N-fixing, P solubilizing) bioinoculants smartly work in those soils for better crop production and soil fertility management. This is the high time to formulate potential climate smart bioinoculant for cereal, pulses and oil seed crop production and soil fertility sustaining.

Rice production in Bangladesh is chemical fertilizer and pesticide based, which impaired soil quality, ecosystem biodiversity, and environmental pollution. Loses of biodiversity is related to deterioration of soil health as nutrient cycling is the direct contribution of microbial activity. Soil health reflects the status of soil physical, chemical and biological attributes and processes. Till

now, all of the reports are on soil nutrients status, salinity and soil reaction that are apparently related to crop yield. However, correction of only nutrients deficiency in all kind of soil is the short- term management of nutrient degraded soil, but if we consider soil health, breaking yield sealing and sustainable rice production for the future, we need to correlate the soil biology and soil physics with soil chemistry. It is true that the genetic potential of a high yielding variety will express yield performance only if the soil is healthy and productive.

The study on the biological component of rice soil in Bangladesh is new. Not much work has been reported to restore biological properties through biofertilizer for rice soil and breaking yield ceiling. Most effort has been provided to breed new varieties and soil chemistry. Unfortunately, yield is still plateau even with so many improved rice varieties. Understanding the microbial community and composition following long-term fertilization may have significant implications for the development of better fertilizer regime in any agro-ecosystems which is the primary requirement of national food security. In this context, elucidation of rice soil biology and replenish soil with beneficial microbes using rice based biofertilizer is important to maintain long-term soil fertility, soil health and improve crop productivity.

Pulse crops are important for supplying protein to the human diet every day. Pulse proteins are easily digestable and free from fat or cholesterol. It is cheaper than animal protein. It takes short time in growing season and do not need irrigation in growing period. It can be grown in most of areas of the country and all types of soils. Oil seed crop like soybean is an important one due to its short duration and deciduas in nature. It can be grown round the year. In Bangladesh soybean is grown in winter and autumn. It is used in so many forms like soyameat, soya milk, soya bisket, piazu etc. Most of the areas soybean can be grown. It increases soil fertility through decomposing leaves, shoot, root and nodule etc. These pulse and oil seed crops contain nodule in their root through which fix atmospheric nitrogen and supply to host plants according to their need. Isolating these effective bacteria biofertilizers were formulated and being used in sweet soil areas. But now a days a vast area of the country have gone under salt affected in coastal area due to global climate change. They need pulse and oil seed production in those coastal saline areas besides Bay of Bengal. Salinity and drought tolerant pulse and oil seed crop varieties were developed for production in those areas but no salt or drought tolerant biofertilizers were developed for stress areas. Biological nitrogen fixation process supplies more than 60% nitrogen in pulse crops (Evans, 2005). More than 85% nitrogen requirement could be made by inoculating effective rhizobial strains (Bisen *et al*, 1980).

The indigenous strains are better adapted to the adverse soil and climatic conditions. The physiological characteristics of Rhizobium associated with such adaptation are complex. It is possible that the strains adapted to local saline or acid soil and climate in Bangladesh will generally be tolerant to high salt conditions. There are large local variations in the soil characteristics in different parts of Bangladesh. It is expected that there will be a great variability among the indigenous *Rhizobium* strains with respect to their adaptation to various salinity stress soils and weather conditions as well as more nitrogen fixing ability.

Sugarcane (S*accharum officinarum*) is an important cash-cum industrial crop of Bangladesh. It is grown mostly in the north-western part of the country. Sugarcane is the only source of white sugar in Bangladesh, cultivated over an area of about 0.12 million hectares annually with an average low yield of 38.25 tons per hectare According to FAO recommendation about 13 kg sugars per capita in each year is required to human diet for balanced nutrition. To meet up the requirement of 1.95 million ton of sugar for 150 million people, 24.37 million ton of sugarcane will be needed. Sugarcane is a long duration and exhaustive crop required high amount of nutrient for its growth and development.

Biological nitrogen fixation (BNF) helps in improving soil fertility by using nitrogen, which is in abundance in the atmosphere (~78%). Since soils of Bangladesh are mostly deficient in nitrogen, application of inorganic N-fertilizer as urea is essential to obtain optimum yield of sugarcane. Tropical agriculture might be expected to be more dependent on N-fertilizers than agriculture in temperate regions, since heavy rains and more rapid decomposition of organic matter causes leaching and rapid loss of N- fertilizers. Nitrogenous chemical fertilizers account for as much as 30% of total crop fertilizers. However, nitrogenous fertilizers are becoming more scarce and costly. Biological N_2-fixation is one of the possible biological alternatives to N-fertilizers and could lead to more productive and sustainable in agriculture without harming the environment.

Phosphorous is known to be essential nutrients for plant growth and development. The production of P chemical fertilizers is a highly energy-intensive process using large amounts of fossil energy. High-input farming practices achieving high yields have created environmental problems and degradation in natural resources. Large quantities of chemical fertilizers are used to replenish soil P, resulting in high costs and severe environmental contamination. Consequently, there has recently been a growing level of interest in sustainable agricultural practices to alleviate detrimental effects of intensive farming practiced.

In Bangladesh, the cost of N fertilizer is increasing day by day and P fertilizer is imported from abroad with the exchange of native currency. Besides, unbalanced and injudicious use of chemical N and P fertilizer by our farmers creates economically loses, environmental pollution, damage soil health and hampering crop productivity. For these reasons, there has been a development of an alternative form of supplying N and P as a plant nutrient which will know as N-fixing and P solubilizing bacteria or inoculants or biofertilizer. Therefore, an attempt is necessary to undertake a comprehensive study on nitrogen fixing and phosphate solubilizing bacteria for making biofertilizers for sugarcane cultivation.

Black gram *(Vigna mungo*L.Hepper) is a grain legume widely cultivated in both tropical and sub-tropical countries of the world. It is apart of diet for millions of people in many countries and a cheap source of protein with 17-34% of protein in seeds (Gour,1993). An important feature of this plant is its ability to establish a symbiotic partnership with specific bacteria, setting up the biological N_2-fixation process in root nodules by *Rhizobia* that may supply the plant's needs for N (Mahmood and Athar, 2008; Mandal *etal.,*2009). Beneficial role of *Rhizobium-Legume* symbiosis are well known. However, all the legume crops are not sustaining the same strains of the bacteria and the influences of these different strains of bacteria on growth and yield of pulse crops may not be equal. Examination of the differential roles of different strains of *Rhizobium* isolates on each and every crop is therefore significant to understand the best suitable strain for the optimum growth and productivity of the crop under a particular environmental condition. Survival of a large population of inoculated *Rhizobium* on the surface of legume seeds is necessary for improving the chance of root-hair infection and thereby nodulation. Currently, a real challenge for the workers in the field of agricultural research is to stop the use of expensive agrochemicals/chemical fertilizers, which negatively affect the environment as well as human health. Chemical fertilizers are used to replenish soil N, in large quantities, they are highly costly and contaminate environment severely (Dai *et al,* 2004). Biofertilizers are one of the best modern tools for agriculture. It is a gift of our modern agricultural science. Biofertilizers contains microorganisms which promote the adequate supply of nutrients to the host plants to ensure their proper development of growth and regulation in their physiology. Living microorganisms are used in the preparation of bio- fertilizers (Mishra and Singh, 2013).

Today, global agriculture is at crossroads and this is the consequence of climatic change, increased

population pressure and detrimental environmental impacts and new mechanism must be found to ensure food security through sustainable crop production system that will supply adequate nutrition without harming the agroecosystem. In recent years, biofertilizers have emerged as a promising component of integrating nutrient supply system in agriculture (Nalawde and Bhalerao, 2015). To prevent the environment pollution from extensive application of chemical fertilizers the biofertilizer could be recommended to farmers to insure the public health and a sustainable agriculture. The economy of Bangladesh is based on agriculture, industry and services. The agriculture sector contributes a major share in the GDP, which is about 20.6% and employs about 48.10% of the working force. (BBS, 2009). Though Bangladesh is relatively smaller in extent but it has surprisingly wide range of soils. About 465 soil series have been identified according to soil depth during the reconnaissance soil survey (RSS) of the country (SRDI, 2013) and data has been compiled in RSS report but soil microbiological data scarcity has yet been found all over the country. So, the study was considered to generate the soil microbiological data over the country and increase of soil fertility through climate smart biofertilizers.

7. Sub-project general objective (s):

i. To study physical, chemical and microbial properties of soil of different AEZs of Bangladesh.

ii. To isolate, biochemical and molecular characterize of climate smart i.e. saline, acidic and drought tolerant Nitrogen-fixing and plant growth promoting bacteria from root, nodules and rhizosphere soils of Bangladesh.

iii. To develop biofertilizer for cereal, pulse, oilseed, sugarcane and test efficacy for crop productivity and soil fertility.

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

BARC

-To coordinate, supervise, monitor and evaluate the project activities of the component organizations.

-To compile, edit and finalize the reports and submit to PIU-BARC

BARI

-To determine physico-chemical properties of soils and asses soil microbial population count under climate vulnerable area of different AEZs of Bangladesh.

-To characterize N- fixing and plant growth promoting bacteria isolated from roots and rhizosphere soils

-To develop and validate climate smart biofertilizers for high yielding varieties of oil seeds, and pulses

-To provide training among farmers and extension personnel for successful use of biofertilizers.

BRRI

-To assess soil bio-physico-chemical properties of different AEZ's of Bangladesh and characterization of potential plant growth promoting bacteria (PGPB)

-To develop bio-fertilizer using potential microbes for rice based cropping system

-To evaluate efficacy of developed biofertilizer in different AEZ's for the improvement of soil fertility and crop productivity

BINA

-To determine physico-chemical and microbiologicsl properties of soils of different AEZs of Bangladesh.

-To characterize nitrogen fixing isolates from root nodules of oil seed crop (soybean)

-To develop salt tolerant nitrogenous bio-fertilizer for oil seed crop (Soybean)

-To determine the effect of biofertilizer on growth, biomass production and yield of Oil seed crop (Soybean)

BSRI

-To isolate region specific beneficial microorganisms from soils of different agro-ecological zones of Bangladesh.

-To characterize nitrogen fixing and phosphate solubilizing bacteria isolated from soils, roots, stems and rhizosphere soils of sugarcane.

-To develop nitrogenous biofertilizers for sugarcane plant.

-To determine the effect of biofertilizers on growth and biomass production of sugarcane genotypes grown in N and P stressed conditions.

9. Implementing location (s):

Org. Study location

BARI: Kurigram and Rangpur (AEZ-2), Naogaon and Chapainawabgonj (AEZ-6), Khulna, Satkhira (AEZ-13), Patuakhali, Barishal and Bhola (AEZ-18), Bandorban and Khagrachori (AEZ-29), Chattogram, Cox's Bazar (AEZ-23), Saint Martin (AEZ-24), and Brahmanbaria and Habiganj (AEZ-30). Biofertilizer production and laboratory and pot study were completed at Microbiology laboratory, Soil Science Division, BARI, Gazipur. The filed experiments on groundnut and lentil were conducted at Gazipur, Cox's Bazar, and Gazipur, Pabna, respectively.

BRRI: Faridpur (AEZ-10), Jashore- Rajshahi (AEZ-11), Satkhira (AEZ-13), Munshiganj (AEZ-15), Brahmanbaria- Munshiganj (AEZ-16), Comilla-Kishoreganj (AEZ-19) and analysed in the soil microbiology laboratory of Soil Science Division of BRRI Gazipur.

BINA: Rangpur and Nilphamari (AEZ-3), Kurigram and Sirajganj (AEZ-7), Mymensingh and Netrakona (AEZ-9), Faridpur and Pabna (AEZ-12), Gopalganj and Khulna (AEZ-14), Chandpur and Laxmipur (AEZ-17), Bogura and Naogaon (AEZ-25), Chapainawabganj and Rajshahi (AEZ-26) and analysed in the Soil Microbiology laboratory of Soil science division of BINA Mymensingh.

BSRI: Thakurgaon-Dinajpur (AEZ-1), Sirajgonj- Pabna (AEZ-4), Naogoan-Natore (AEZ-5), Sherpur-Norshingdi (AEZ-8), Habigonj- Sylhet (AEZ-20), Sunamganj-Habigonj (AEZ-21) and Tangail-Gazipur (AEZ-28) and analysed in the Soil and Nutrition Division of BSRI, Ishurdi, Pabna.

10. Methodology in Brief (with appropriate pictures):

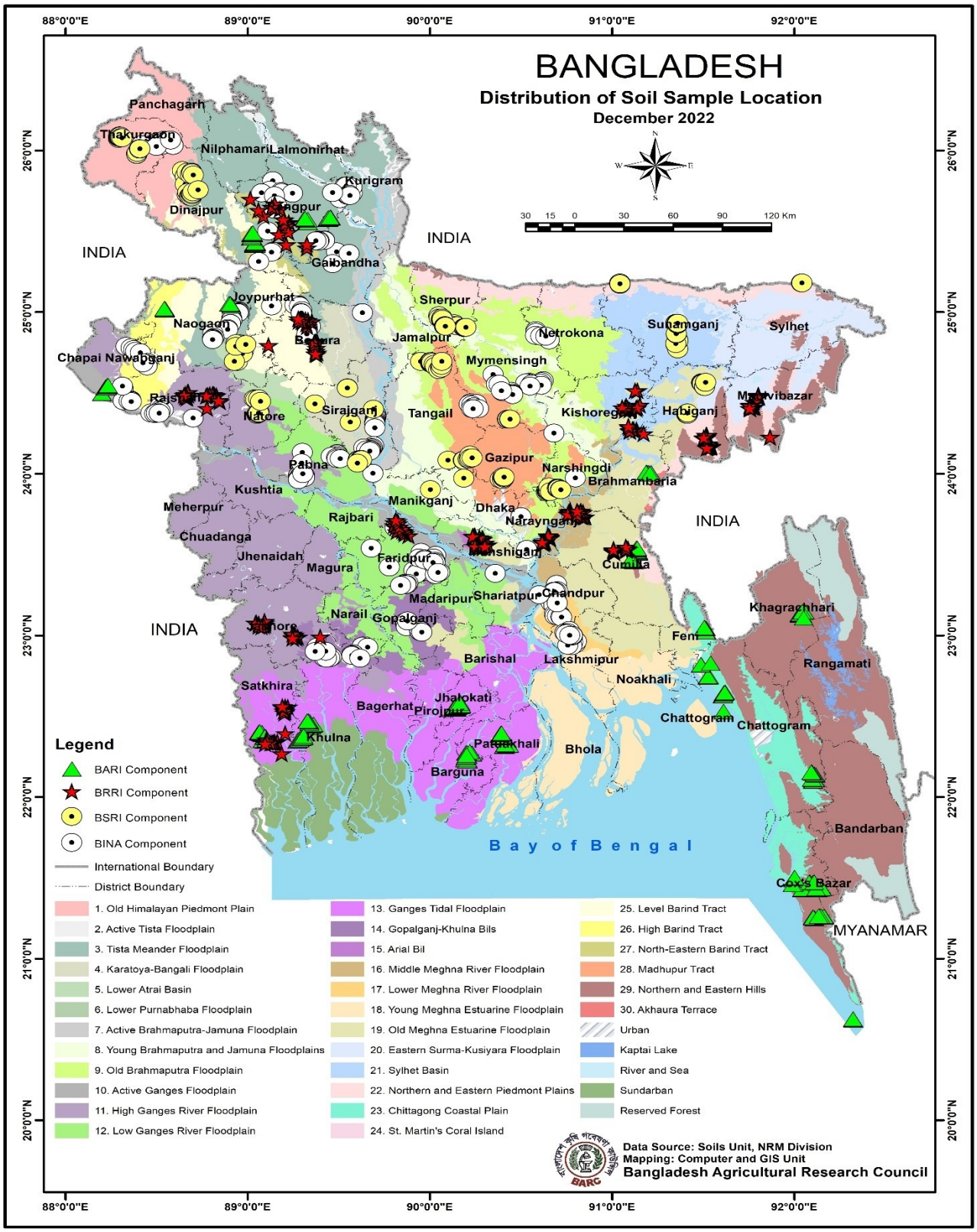


Fig. 01. Location map of soil sample collection sites done by BARI, BRRI, BINA, and BSRI

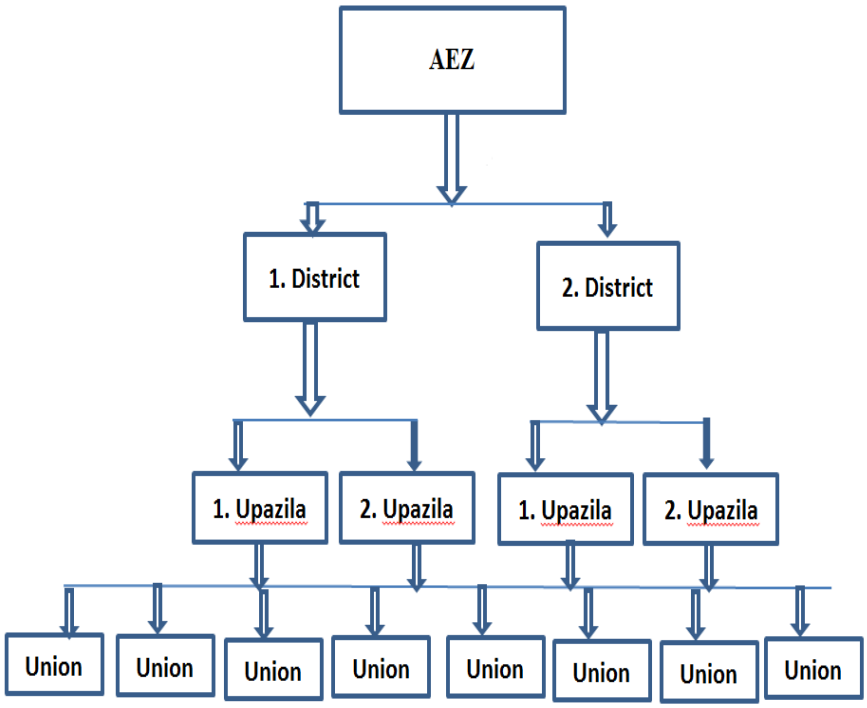


Fig. 02. Flow diagram of soil sample collection

BARI Component

Soil Sample collection:

Soil Science Division of Bangladesh Agricultural Research Institute (BARI) collected soil samples from 8 Agro-ecological zones (AEZ) namely AEZ 02 (Active Tista Floodplain) soils of Kurigram and Rangpur, AEZ 06 (Lower Purnabhaba Floodplain) soils of Naogaon and Chapainawabganj, AEZ 13 (Ganges Tidal Floodplain) soils of Khulna, Satkhira, Patuakhali, Barishal, AEZ 18 (Young Meghna Estuarine Floodplain) soils of Patuakhali, Barishal and Bhola, AEZ 29 (Northern and Eastern Hills) soils of Bandarban and Khagrachari, AEZ 23 (Chattogram Coastal Plain) soils of Chattogram, Cox's Bazar, AEZ 24 (Saint Martin's Coral Island) soils, Saint Martin, Cox's Bazar and AEZ 30 (Akhaura Terrace) soils of Brahmanbaria and Hobiganj district of Bangladesh. A total of 310 soil samples were collected taking 2 upazila (10 locations of each upazila) from each district while 2 unions (5 locations of each union dividing the equal distance of total union) were sampled from each upazila. Soil samples were collected using a global positioning system (GPS) record along with spot history. Soil samples were analyzed in the Soil Science laboratory of BARI, for important physico-chemical and micro-biological properties.

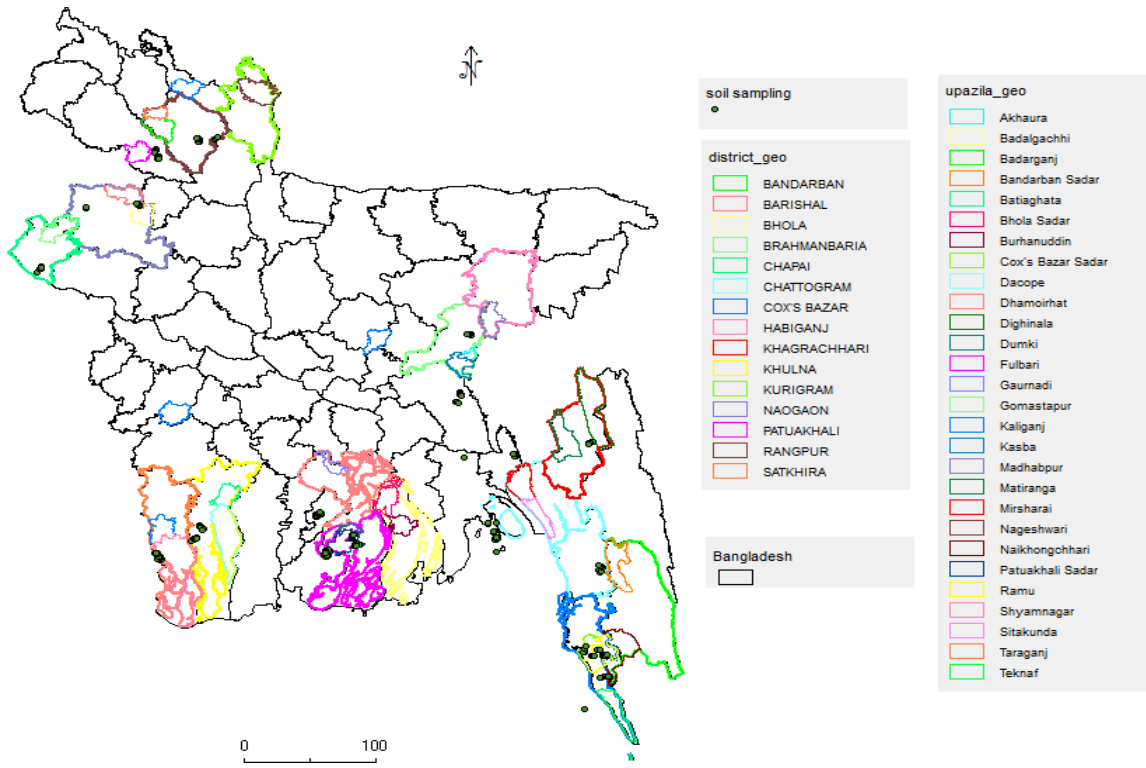


Fig. 03. **Samples collection sites of 8 Agro-ecological zones (AEZ)** ie, AEZ 02 (Active Tista Floodplain) soils of Kurigram and Rangpur, AEZ 06 (Lower Purnabhaba Floodplain) soils of Naogaon and Chapainawabganj, AEZ 13 (Ganges Tidal Floodplain) soils of Khulna, Satkhira, AEZ 18 (Young Meghna Estuarine Floodplain) soils of Patuakhali, Barishal and Bhola, AEZ 29 (Northern and Eastern Hills) soils of Bandarban and Khagrachari, AEZ 23 (Chattogram Coastal Plain) soils of Chattogram, Cox's Bazar, AEZ 24 (Saint Martin's Coral Island) soils of Saint Martin, Cox's Bazar and AEZ 30 (Akhaura Terrace) soils of Brahmanbaria and Hobiganj district of Bangladesh

Processing of Soil Samples

The collected soil samples were processed through air drying, removal of unwanted materials, grinding, sieving and storing for further chemical analysis. A portion of all soil samples were preserved in the refrigerator (-20^{0}C) for bacterial population study.

Physical and chemical characterization of soil

Collected soil samples were analyzed to know the physio-chemical properties following standard methods. Soil properties like organic corbon (wet oxidation method) of Walkely and Blakhk (1934) and Total N (Kjeldahl method) of Bremner (1960), pH (glass electrode method (Jackson, 1926)), EC (KCl extraction method) of Gartley (2011), texture (hydrometer method) of Huluka *et al* (2014) were followed.

Serial dilution for enumeration of soil bacteria

Serial Dilution technique (Aneja, 2003) was adopted for enumeration of soil bacteria. A 10-fold series of dilution was prepared up to 10^{-7}. From the series of dilution 0.1 mL aliquot was transferred into Nutrient Agar medium plates from higher dilution to lower dilution.

The number of colonies appearing on dilution plates was recorded and calculated its number as following equation (Somasegaran, 1985):

Number of cells/ mL = (Number of colonies ÷ Amount plated) × dilution

Fig. 04. Serial dilution method

Preparation of bacterial media

Nutrient agar medium:

Nutrient agar medium contained the following constituents:

Nutrient agar 28 g/L

Distilled water up to 1.00 L

The ingredients of the medium were mixed in a natural glass flask with required amount of distilled water. The initial pH of the medium was adjusted to 7.0. The medium was dissolved by boiling and it was autoclaved at 121^0C for 15 minutes.

YEMA media

YEM agar medium contained the following ingredients: K_2HPO_4 0.5 g, $MgSO_4.7H_2O$ 0.2 g, NaCl 0.1 g, $CaCl_2.6H_2O$ 0.2 g, $FeCl_3.6H_2O$ 0.01 g, mannitol 10 g, yeast extract 0.5 g, agar powder 15.00 g, distilled water 1 L. The initial pH of the medium was adjusted to 7.0 by adding 0.1 N HCl solution. Agar used in this medium was dissolved by boiling and the medium was autoclaved at 121^0C for 15 min.

PSB media

The plates were prepared with Pikovaskya's medium. Composition of Pikovskaya medium in 1 liter: Glucose 10 g, $Ca_3(PO_4)_2$ 5 g, $(NH_4)_2SO_4$ 0.5 g, NaCl 0.2 g, $MgSO_4.7H_2O$ 0.1 g, KCl 0.2 g, yeast extract 0.5 g, $MnSO_4.H_2O$ 0.002 g, $FeSO_4.7H_2O$ 0.002 g and agar 15 g (Pikovskaya, 1948). Agar used in this medium was dissolved by boiling and the medium was autoclaved at 121^0C for 15 min

Actinomycetes agar media

The plates were prepared with Actinomycetes agar medium. Composition of Actinomycetes agar medium in 1 liter was 21.7 g Actinomycetes agar with 5 ml glycerol. The initial pH of the medium was adjusted to 7.0 by adding 0.1 N HCl solution. Agar used in this medium was dissolved by boiling and the medium was autoclaved at 121^0C for 15 min.

PDA media

The plates were prepared with PDA medium. Composition of PDA medium in 1 liter was 39 g. The initial pH of the medium was adjusted to 7.0 by adding 0.1 N HCl solution. Agar used in this medium was dissolved by boiling and the medium was autoclaved at 121^0C for 15 min. After autoclaved, 10 ml lakhtic acid was mixed in per litre media.

NFB media

The plates were prepared with Nitrogen free bacterial medium. Composition of Nitrogen free bacterial medium in 1 liter: Malic acid 5 g, K_2HPO_4 0.5g, NaCl 0.1 g, $MgSO_4.7H_2O$ 0.2 g, $CaCl_2$ 0.02g, 5% BTB in .02 N KOH 2ml and 8 ml,1.64% FE-EDTA 4 ml and agar 20 g. The initial pH of the medium was adjusted to 7.0 by adding 1 N KOH solution. Agar used in this medium was dissolved by boiling and the medium was autoclaved at 121^0C for 15 min.

PDA and YMA media preparation

NFB and Actinomycetes media preparation

PSB media preparation

NA media preparation

Fig. 05. Different Microbial Media

Isolation of bacterial strains:

Highly potential N- fixing, growth hormone producing, P- solubilizing bacterial strains were isolated from root, nodule and endosphere and rhizosphere soils collected from stress prone areas (salinity, acidic and drought) using a global positioning system record along with cropping pattern

and land type history. Isolation of bacteria was done using selective media and standard methodology.

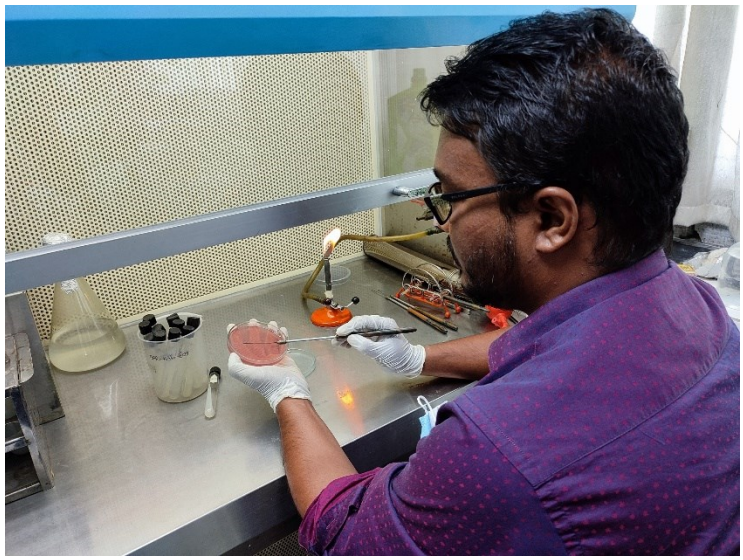


Fig. 06. Isolation of Bacterial strains

Purification and preservation of the isolated strains:

The isolated strains were then purified by streak plate method. The purified strains were transferred to agar slants and preserved as stock culture in a refrigerator at 4^0C. In addition, culture mixed with glycerol were kept in -80^0C for long time preservation.

Slants in refrigerator at 4^0C

Strains were preserved with glycerol in -80^0 freeze

Fig. 07. Purified microbial strains preservation

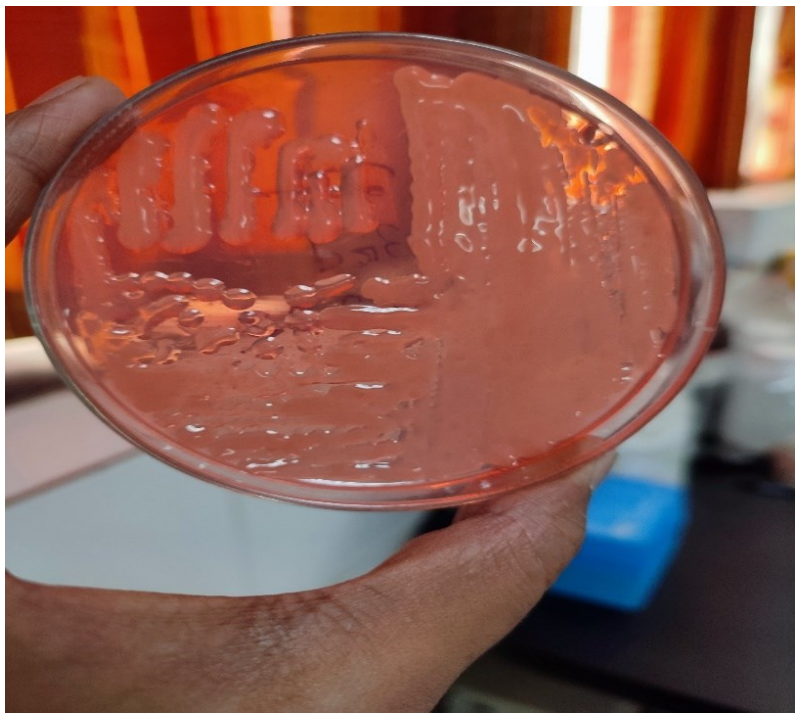


Fig. 08. Purification of Rhizobacteria

Morphological characterization of bacterial isolates

Colony morphology

The isolates were examined for colony morphology on plates containing YMA medium. After an incubation of 3 days at 30°C, individual colonies were observed and characterized based on colony color, shape, elevation, surface, margin and individual bacterial cell shape as stated by Aneja (2003).

Growth on YMA medium containing Congo red

YMA medium containing congo red were used. The initial pH of the medium was 6.5 which was adjusted to 7.0 by adding 0.1 N NaOH solution. Agar used in this medium was dissolved by boiling and the medium was autoclaved at 121^0C for 15 minutes. The medium was inoculated with the isolated bacterial strains and incubated at 26^0C for one week. Colonies on plates were observed for their morphology and appearance.

Biochemical characterization of bacterial isolates

Gram staining

Gram staining was done to divide bacterial cells into two major groups, Gram positive and Gram negative. Forty-eight hours old pure bacterial isolates were tested for Gram staining reaction. From a single colony, small number of bacteria was transferred to the surface of a clean glass slide with the help of a sterile loop and spreaded over a small area following heat fixed. Then smear of bacteria was flooded with two drops of crystal violet for 1 min. The crystal violet was then gently washed off with sterilized distilled water. The smear was sealed with iodine for one minute followed by washing with water. Using a Pasteur pipette alcohol solution was gently dropped to remove the stain. After washing with water, the smear was counter stained with safranin for 30 second. The slides were washed with sterilized distilled water and air dried. The stained smear was observed under the light microscope using oil emulsion at 10X to 100X

magnification. Gram positive bacteria retained the primary stain (crystal violet) and did not take the secondary stain (safranin), causing it to look violet/purple under a microscope. The Gram-negative bacteria lost the primary stain and took secondary stain, causing it to appear red when viewed under a microscope.

Effectivity tests:

For effectivity analysis, nodulation was tested. Nodulation test was done by using Nutrient medium.

Fig. 09. Seed germination for effectivity test

Fig. 10. Effectivity test for Groundnut

Indole Acetic Acid

The property of synthesizing IAA is considered as an effective tool for screening beneficial microorganisms suggesting that IAA producing bacteria have profound effect on plant growth.

To determine the amounts of IAA produced by each isolate, a colorimetric technique was performed with Van Urk Salkowski reagent using the Salkowski's method (Ehmann, 1977). The isolates were grown in Nutrient Broth and shaking at 28 °C for 4 days. The broth was centrifuged after incubation. Supernatant was reserved and 1ml was mixed with 2ml of Salkowski's reagent (2% 0.5 $FeCl_3$ in 35% $HCLO_4$ solution) and kept in the dark. The optical density (OD) was recorded at 700 nm after 7 minutes.

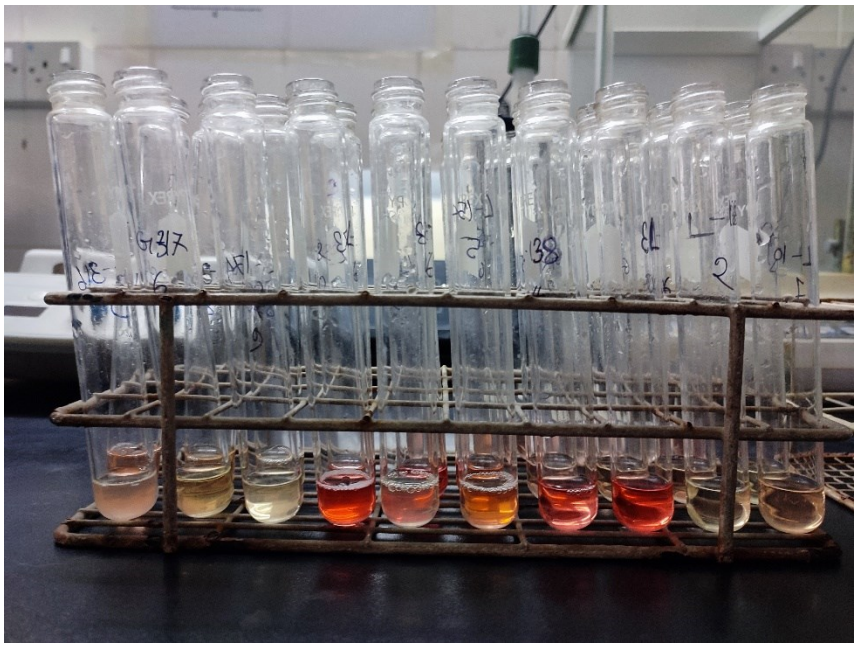


Fig. 11. Indole Acetic Acid formation by bacterial isolate

Molecular characterization of *Rhizobium* strains

Cultivation of bacteria and DNA extraction

Selected twenty effective bacteria were cultured in test tubes containing 3 ml in YEM liquid broth by shaking in a rotary shaker at 180 rpm, 30°C, for 48 hours, and the cultures were centrifuged at 18,000 g for 5 minutes at 4°C. Genomic DNA was extracted from the pellet using DNA isolation kit (Promega, USA) and DNA yield was quantified using a spectrophotometer. The extracted bacterial DNA was used as a template for PCR amplification.

Olegonucleotide primers

One pair of bacterial universal primers (27F/1492R; 5′-AGAGTTTGATCCTGGCTCAG-3′/5′-CTACGGCTACCTTGTTACGA-3′), which were specific for the house keeping gene (16S rRNA) of every morphologically and biochemically identified bacteria, were used to amply a fragment of 16S rRNA gene by PCR.

PCR amplification

About 50 ng of template DNA was used to amply fragments of the 16S rRNA gene by PCR. PCR was carried out in a final volume of 25 µL containing 1 µL template DNA, 12.5 µL master mix (including polymerase, buffer, dNPT, Mg^{2+}, promega company), 1 µl forward primer, 1 µl reverse primer, 9.5 µL sterile water. PCR amplification was performed staring with 5 min denaturing step

at 95°C, followed by 30 cycles of denaturation at 95°C for 30 sec, annealing at 48°C for 30 sec, extension at 72°C for 1.5 min, and final extension 72°C for 5 min. The PCR products were assessed by electrophoresis on 1% agarose gel. DNA bands were visualized by UV illumination and photographed with gel documentation system. PCR products were purified using gel purification Kit and were kept for sequence.

Sequencing and phylogenetic analysis

DNA sequencing was performed using an Applied Biosystems 3730 automated sequencer with the M13 primer to obtain nearly full-length bacterial 16S rDNA sequences. The bidirectional gene sequences were compiled using DNAMAN software (DNAMAN version 4.11, Lynnon Biosoft, San, Ramon, CA, USA), and the sequences were analyzed using MEGA 5.2 software. The consensus sequences were used in a BLAST search of the NCBI Gene Bank database. Phylogenetic analysis was conducted using MEGA version 5.2, and a neighbor-joining tree were constructed using Kimura 2-parameter distances with 1000 replicates to estimate bootstrap support. The compiled sequence of the *Rhizobium* strains was deposited in the Gene Bank database and assigned accession number.

Methodology of Experiments

Pot experimental methodology for groundnut

The experiment was conducted at the net house of Soil Science Division, Bangladesh Agricultural Research Institute, Joydebpur, Gazipur (24.00^{o} N latitude, 90.25^{o} E longitude and 8.4 m elevation) during rabi season of 2020-2021 and 2021-2022. The experiment was laid out in Complete Randomized Design (RCD) with three replications. There were 7 treatments viz. T_1: *Rhizobium* sp. FAGR102, T_2: *Rhizobium* sp. FAGR241, T_3: *Rhizobium* sp. FAGR254, T_4: *Rhizobium* sp. FAGR308, T_5: *Rhizobium* sp. FAGR318, T_6: Reference strain *Rhizobium* sp. BARIRAh808, T_7: Control. The tested crop was groundnut (cv. BARI Chinabadam-8). Seeds were sown on 05 December 2020 and 13 December 2021. The pot soil belongs to the Chiata series of Grey Terrace Soil. Peat based rhizobial inoculum containing 10^8 cells g^{-1} inoculum was used. Seeds were mixed thoroughly with inoculum (20:1 ratio) before sowing. Six seeds were sown in each pot in 1 cm soil depth. Phosphorus, potassium, sulphur, zinc and boron @ $P_{42}K_{40}S_{40}Zn_5B_1$ kg ha^{-1} were used in the form of TSP, MoP, gypsum, zinc sulphate and boric acid, respectively. All P, K, S, Zn, B were applied at the time of pot preparation. All the intercultural operations such as irrigation, weeding, insect control etc. were done as and when necessary. Nodules were collected by uprooting carefully and five sample plants were selected randomly from each unit plot at the 50 percent flowering stage. Nodules were separated from the roots, counted and then oven-dried and weighed. Data on yield and yield components were recorded at maturity. The crop was harvested on 02 April 2021 and 12 April 2022. For judging the initial fertility status of soil used in the pot trail, the representative samples (0-15 cm depth) were collected from the field and analyzed following standard methods.

Field experiment methodology for groundnut

The field experiment was conducted during rabi season of 2020-2021 and 2021-2022. The experiment was set up in two locations at BARI central farm, Joydebpur, Gazipur on 10 December 2020 and 05 December 2021 and at Khuruskul, Cox's Bazar on 20 December 2020 and 11 December 2021. The experiment was laid out in Randomized Complete Block Design (RCBD) with three replications. The treatments were 5 *Rhizobium* isolates alongwith one reference strain and control which were replicated into three blocks. Therefore, altogether there were 7 treatments viz. T_1: *Rhizobium* sp. FAGR102, T_2: *Rhizobium* sp. FAGR241, T_3: *Rhizobium* sp. FAGR254, T_4: *Rhizobium* sp. FAGR308, T_5: *Rhizobium* sp. FAGR318, T_6: Reference strain *Rhizobium* sp.

BARIRAh808, T_7: Control. The test crop was groundnut (cv. BARI Groundnut-8). Peat based rhizobial inoculum containing 10^8 cells g^{-1} inoculum was used at the rate of 1.5 kg ha^{-1}. Seeds were mixed thoroughly with inoculum (20:1 ratio) before sowing. Seeds were used at the rate of 75 kg ha^{-1}. Phosphorus, potassium, sulphur, zinc and boron @ $P_{42}K_{40}S_{40}Zn_5B_1$ kg ha^{-1} were used in the form of TSP, MoP, gypsum, zinc sulphate and boric acid, respectively. All P, K, S, Zn, B were applied at the time of land preparation. All the intercultural operations such as irrigation, weeding, insect control etc. were done as and when necessary. At the 50 percent flowering stage, nodules were collected by carefully uprooting five sample plants selected randomly from each unit plot. Nodules were separated from the roots, counted and then oven-dried and weighed. Data on yield and yield components were recorded at maturity. The groundnut was harvested on 12 May 2021 and 16 May 2022 at Cox's Bazar. Similarly, the groundnut was harvested on 07 May 2021 and 13 May 2022 at Gazipur. The initial soil samples at a depth of 0-15 cm from the experimental fields were collected and analyzed following standard methods (Table 01).

Table 01. Initial fertility status of the soil samples of the pot soil

Soil Properties	pH	OM %	Ca	Mg	K	Total N %	P	S	B	Cu	Fe	Zn
			meq $100g^{-1}$				µg g^{-1}					
Cox's Bazar	5.9	1.3	5.1	1.7	0.13	0.07	3.2	26	0.22	2.0	78	1.86
Gazipur	6.5	0.98	6.1	2.4	0.18	0.05	16	18	0.24	1.4	102	3.9
Critical level	-	-	2.0	0.5	0.12	-	7	10	0.20	0.20	4	0.6

Pot experiment methodology for lentil

The experiment was conducted at the net house of Soil Science Division, Bangladesh Agricultural Research Institute, Joydebpur, Gazipur (24.00° N latitude, 90.25° E longitude and 8.4 m elevation) during rabi season of 2020-2021 and 2021-2022. The experiment was laid out in Complete Randomized Design (RCD) with three replications. There were 7 treatments viz. T_1: *Rhizobium* sp. FALR114, T_2: *Rhizobium* sp. FALR315, T_3: *Rhizobium* sp. FALR317, T_4: *Rhizobium* sp. FALR319, T_5: *Rhizobium* sp. FALR328, T_6: Reference strain *Rhizobium* sp. BARIRLc107, T_7: Control. The test crop was groundnut (cv. BARI Lentil-8). Seeds were sown on 15 November 2020 and 13 November 2021. The pot soil belongs to the Chiata series of Grey Terrace Soil. Peat based rhizobial inoculum containing 10^8 cells g^{-1} inoculum was used. Seeds were mixed thoroughly with inoculum (20:1 ratio) before sowing. Six seeds were sown in each pot in 1 cm soil depth. Phosphorus, potassium, sulphur, zinc and boron @ $P_{22}K_{42}S_{20}Zn_5$ kg ha^{-1} were used in the form of TSP, MoP, gypsum, zinc sulphate and boric acid, respectively. All P, K, S, Zn, B were applied at the time of pot preparation. All the intercultural operations such as irrigation, weeding, insect control etc. were done as and when necessary. Nodules were collected by uprooting carefully and five sample plants were selected randomly from each unit plot at the 50 percent flowering stage. Nodules were separated from the roots, counted and then oven-dried and weighed. Data on yield and yield components were recorded at maturity. The crop was harvested on 12 February 2021 and 22 February 2022. For judging the initial fertility status of soil used in the pot trail, the representative samples (0-15 cm depth) were collected from the field and analyzed following standard methods.

Field experiment methodology for lentil

The field experiment was conducted during rabi season of 2020-2021 and 2021-2022. The experiment was executed in two locations at BARI central farm, Joydebpur, Gazipur on 10 December 2020 and 05 December 2021 and at Gangarampur, Pabna on 20 December 2020 and 11 December 2021. The experiment was laid out in Randomized Complete Block Design (RCBD) with three replications. The treatments were 5 *Rhizobium* isolates alongwith one reference strain

and control which were replicated into three blocks. As such, altogether there were 7 treatments viz. T_1: *Rhizobium* sp. FALR114, T_2: *Rhizobium* sp. FALR315, T_3: *Rhizobium* sp. FALR317, T_4: *Rhizobium* sp. FALR319, T_5: *Rhizobium* sp. FALR328, T_6: Reference strain *Rhizobium* sp. BARIRLc107, T_7: Control. The carrier-based *Rhizobium* inoculum was used in field experiments. The test crop was groundnut (cv. BARI Lentil-8). Peat based rhizobial inoculum containing 10^8 cells g^{-1} inoculum was used at the rate of 1.5 kg ha^{-1}. Seeds were mixed thoroughly with inoculum (20:1 ratio) before sowing. Seeds were used at the rate of 45 kg ha^{-1}. Phosphorus, potassium, sulphur, zinc and boron @ $P_{22}K_{42}S_{20}Zn_5$ kg ha^{-1} were used in the form of TSP, MoP, gypsum, zinc sulphate and boric acid, respectively. All P, K, S, Zn, B were applied at the time of land preparation. All the intercultural operations such as irrigation, weeding, insect control etc. were done as and when necessary. At the 50 percent flowering stage, nodules were collected by uprooting five sample plants carefully those were selected randomly from each unit plot. Nodules were separated from the roots, counted and then oven-dried and weighed. Data on yield and yield components were recorded at maturity. The groundnut was harvested on 20 February 2021 and 25 May 2022 at Pabna. Similarly, the harvesting was aslo done on 15 February 2021 and 23 February 2022 at Gazipur. The initial soil samples at a depth of 0-15 cm from the experimental fields were collected prior to sowing and analyzed following standard methods.

Methods of chemical analysis

Organic carbon was determined by wet oxidation method (Walkley and Black, 1965). Total N was determined by modified Kjeldahl method. Soil pH was measured by a combined glass calomel electrode (Jackson, 1958). Calcium, K and Mg were determined by NH_4OAc extraction method. Copper, Fe, Mn and Zn were determined by DTPA extraction followed by AAS reading. Boron was determined by $CaCl_2$ extraction method. Sulphur was determined by $CaH_4(PO_4)_2.H_2O$ extraction followed by turbidimetric turbidity method with $BaCl_2$. Phosphorus was determined by Bray and Kurtz method (Acid soils) and Modified Olsen method (Neutral and Calcareous soils).

Statistical analysis

All data were statistically analyzed using two factor analysis. Treatment effects on measured variables were tested by analysis of variance (ANOVA), and comparisons among treatment means were made using the least significant difference (LSD) multiple range test calculated at 5% level of probability ($P \leq 0.05$). Statistical procedures were carried out with the software program Statistix 10™.

BRRI Component

Approach:

Soil samples from rice-based crop cropping pattern were collected from eight different AEZ's: AEZ-10 (Faridpur), AEZ-11 (Jashore- Rajshahi), AEZ-13 (Satkhira), AEZ-15 (Munshiganj), AEZ-16 (Brahmanbaria-Munshiganj), AEZ-19 (Cumilla-Kishoreganj), AEZ-22 (Moulavibazar-Habiganj) and AEZ-27 (Rangpur-Bogura). The soil samples were collected (0-15 cm depth) from each district, following 2 upazila (10 locations of each upazila) under 2 different AEZs (Fig. 1 and Fig.2). A number of 253 soil samples (2530 points) were analyzed in Soil Science laboratory of BRRI, for physico-chemical and biological properties. Beneficial and plant growth promoting (PGPB) bacteria were isolated. A biofertilizer was developed using potential microbes. Study was comprised in three steps- in the first phase soil biology was assessed and beneficial microbes were characterized and identified, in second phase, biofertilizer developed using beneficial isolated strains, and in third phase biofertilizer tested in the soil plant system at glasshouse condition.

Methodology:

Activities of Objective-1

Soil Sample collection: The soil sample (0-15 cm depth) was collected from each AEZ, following 2 upazila (10 locations of each upazila). About 253 soil samples, composite of 2530 sampling points were collected using global positioning system (GPS) record along with plot history and analyzed for total and beneficial microbes. Soil samples were collected randomly and replicated 4 times for analyses of each property.

Fig. 12. Soil sample collection from different AEZ's

Fig. 13. Soil samples preservation before analyses

Soil physico-chemical properties: Soil samples were air dried in shed and sieved through 2 mm mesh for chemical analyses and preserved in plastic pot before analyses. Soil properties such as biomass carbon, soil reaction, and soil organic matter etc. were determined following standard methods (Table 02)

Table 02. Methods of soil physico-chemical and biological analysis

Parameters	**Methods**
Soil texture	Hydrometer methods (Calgon solution) (Bouyoucos, 1962)
Soil pH	Glass electrode pH meter method soil: water (1:2.5) (Jackson 1958)
Organic C	Wet oxidation method (Page *et al*. 1989)
Total N	Kjeldahl systems (Bremner and Mulvaney1982)
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
Identification	16S rRNA partial gene sequencing

Determination of soil texture: Soil texture determined according to the method of Bouyoucos, (1962) using Hydrometer and Calgon solution. Soil texture determined according to sampling union and land type basis.

Determination of soil pH, organic carbon (OC) and total nitrogen

Soil was mixed with distilled water at 1:2.5 ratio followed by stirring with a glass rod for 5 min, which was repeated two times after 1-hour interval and then pH of the solution was determined using a portable pH meter (HANNA, Romania). The OC and total N were determined by wet oxidation method (Walkley and Blakhk, 1935) and Kjeldahl method (Bremner and Mulvaney, 1982), respectively.

Fig. 14. Determination of soil texture

Determination of soil biological properties:

Soil biological properties

After collection of soil, samples were kept at 4^{o}C temperature until analyses. Culturable total bacteria, fungus and actinomycetes population were determined in Nutrient Agar, Potato dextrose agar, and Actinomycetes agar plate. Total population was enumerated following 'total plate count method' (Naher *et al*., 2014). In brief, approximately 10 g soil sample was added into 90 ml sterile distilled water and shacked in a mechanical shaker for 10 minute. About one ml of solution was

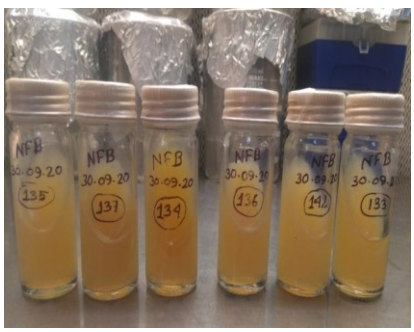
added with nine ml sterile distilled water and a series of dilution were prepared up to 10^{10} dilution. Exactly 0.1 ml of solution from each dilution was spread on respected media plate and incubated for 3 days at 28ºC temperature. Total population was counted and expressed as cfu g^{-1} soil dry weight.

Isolation of Free-living N_2 fixing bacteria: Free living N_2 fixing bacteria were isolated from selected paddy soils of different AEZ's in N-free media according to the protocol of Naher *et al* (2013) and Prasad *et al* (2001). The population was counted after 3 days of incubation following 'Total plate count method'. The media composition was (g/l): 5 g Malic acid, 0.5 g K_2HPO_4, 0.2 g $MgSO_4$. 7 H_2O, 0.1 g NaCl, 0.02 g $CaCl_2$ and 0.5% bromothymol blue in 0.2 N KOH (2 ml), 1.64% Fe-EDTA solution (4 ml), and 20 g agar (pH 7.2).

Isolation of phosphate solubilizing bacteria (PSB): Phosphate solubilizing bacteria were isolated in Pikovskaya media plate according to Panhwar *et al* (2012). The media inoculated with the isolates were incubated for 3 days and observed for the formation of yellow zone around the colony due to the utilization of tricalcium phosphate present in the medium. The composition of Pikovasakaya media was (g L^1): Glucose 10 g, 0.2g NaCl, 0.002 g $MnSO_4.H_2O$, 0.002 $FeSO_4.7H_2O$ 0.1 g $MgSO_4.H_2O$, 0.2 g KCl, 0.25g Bromo-phenol blue, 0.5 g $(NH_4)_2SO_4$ 5 g $Ca_3(PO_4)_2$, and 20 g of bacterial agar

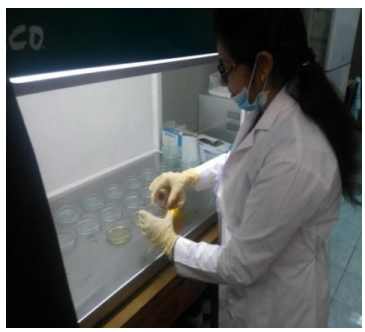
Isolation of *Rhizobium*: *Rhizobium* was grown in YMA media and incubated for 3 days and population counted according to the spread plate count method. Composition of YMA media was (g L^1): 10 g Manitol, 0.5 g K_2HPO_4, 0.2 g $MgSO_4.7H_2O$, 0.1 g NaCl, 0.5 g Yeast, 20 g Agar and 0.025 g Congo red.

Isolation of Total fungus and actinomycetes: Total fungus and actinomycetes were grown in potato dextrose agar media (PDA) and actinomycetes media, respectively and population counted using dilution and spread plate count method.



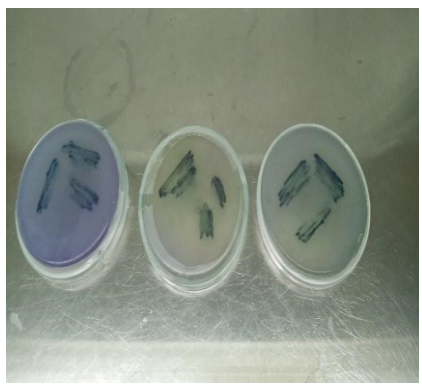
Collected strain

Media Preparation



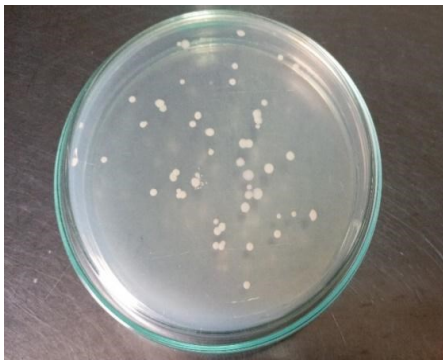
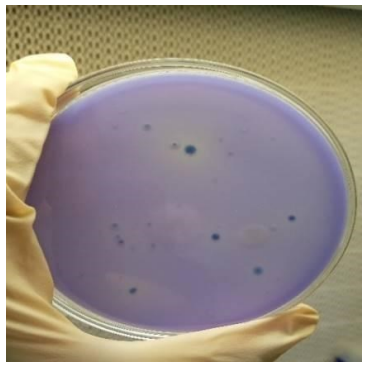
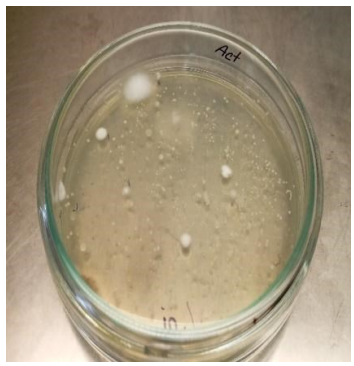
Isolation of microrganism

Free living N_2 fixing bacteria



PSB

Rhizobium

Total bacteria Fungus Actinomycetes

Fig. 15. Isolating media and isolation of microorganisms

Biochemical characterization of isolated potential bacteria

Determination of N_2 fixing activity by production of ammonia: Total N was determined from broth culture following distillation method. The isolated strains that were capable to grow only on N-free medium were cultured in N_2 free broth without adding bromothymol blue at 30°C for 7 days on a rotary shaker (120 rpm). The bacteria culture was then centrifuged 4000 × g for 5 minutes and filtered through 0.22µm filter paper. The filtrate was used to determine total N by distillation method (Naher *et al*. 2012).

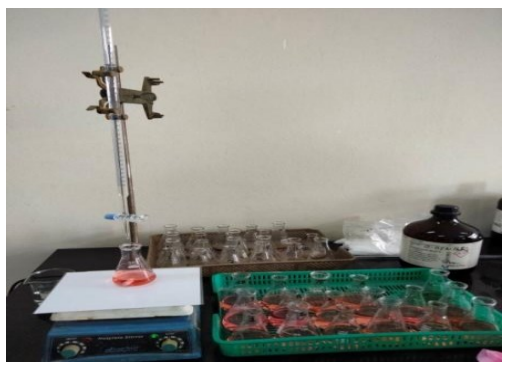



Fig. 16. Ammonia production determined by distillation followed by titration

Determination of P solubilizing activity: P solubilizing activity was determined in National Botanical Research Institute's Phosphate growth medium (NBRIP) broth culture following Nautiyal, (1999); Mehta and Nautiyal (2001). The isolated bacterial strains were cultured in NBRIP broth containing tri-calcium phosphate (TCP) for 5 days. Exactly, 2 ml of samples were taken for P determination. The samples were first allowed to sediment for 15 minutes and were then centrifuged at 4000 × g for 5 minutes. The supernatant was filtered through 0.22 µm filter paper and kept at -20^0C until analysis. The available P was determined using the procedure described by Murphy and Riley (1962).

Fig.17. Determination of P solubilizing by phosphate solubilizing bacteria

Determination of indoleacetic acid (IAA) production: The bacteria isolates were grown in nutrient broth with addition of 2 mg L^{-1} tryptophan for three days. After 3 days of incubation broth cultures were centrifuged, filtered and IAA was determined following colorimetric technique according to Gordon, and Weber, 1951.

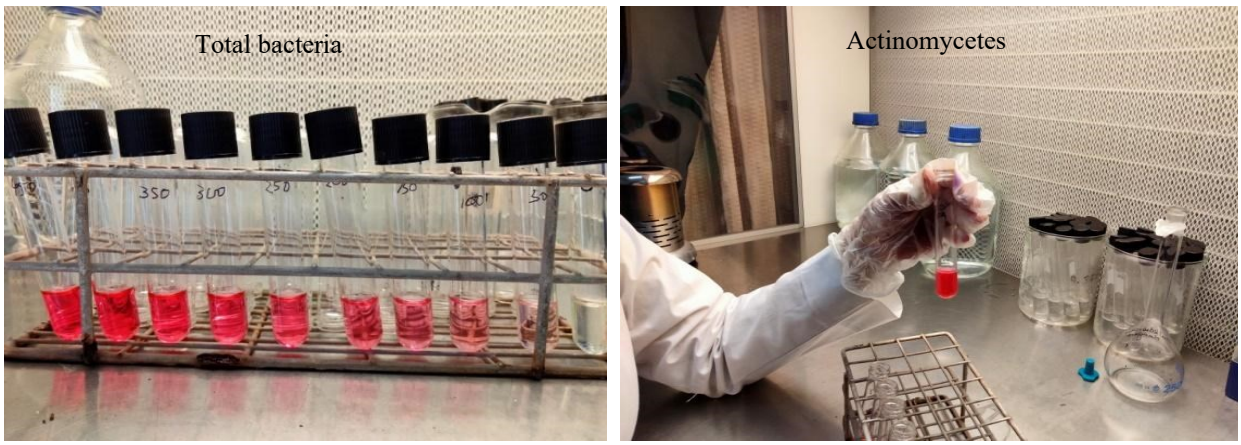


Fig. 18. Determination of Indoleacetic acid production by the bacteria

Identification of Bacteria: Potential bacteria were identified using molecular techniques (16S rRNA gene amplification and sequencing using appropriate primers, (Table 03). Finally, the purified product was sent to "Macrogen" Korea for the identification of strain (s).

Table 03. Primer selection

Types of Strain	**Primer**	
	Forward primer	Reverse primer
PSB	D1: 5-AGA GTT TGA TCC TGG CTC AG-3	P2: 3- ACG GCT ACC TTG TTA CGA CTT-5
N_2 - fixing	4F: 5-GCAGCCGCGGTAATAC -3	4R: 5-CCGTCAATTCCTTTGAGTTT-3

Fig. 19. DNA extraction, Gel documentation and PCR

Design of Experiments and methods of data analyses: Data generated from soil physical chemical and biological properties was analyzed for ANOVA following completed randomized design (CRD) and means of replicated samples were separated using LSD statistical tool.

Activities of Objective-2

Formulation of biofertilizer:

A number of 15 mixed potential bacteria (free-living N_2 fixing, phosphate solubilizing and indoleacetic acid producing bacteria) including bacillus spore were grown in broth culture was coated on urea and TSP and mixed with wheat flour, sucrose, gypsum and zeolite. Molasses was used as binding agent. The bacteria were used in the biofertilizer were isolated from different AEZ's.

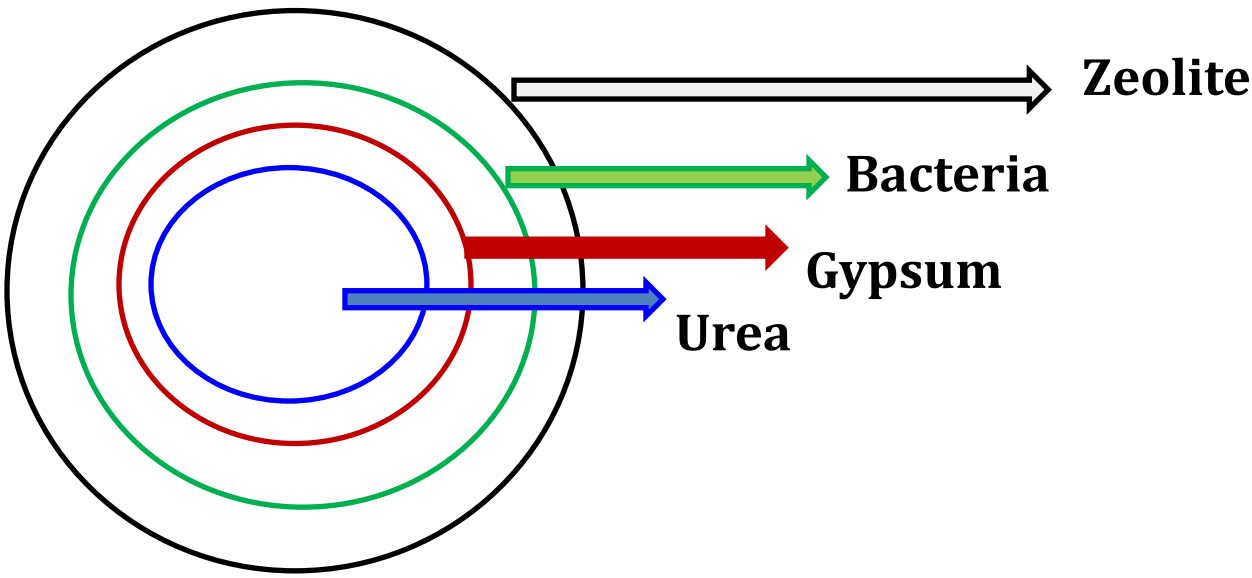


Diagram of Bio-coated Urea/TSP

Bio-coated Urea for saline soil Bio-coated TSP for acid soil

Fig. 20. Bio-coated Urea/TSP

Activities of Objective-3

Evaluation of climate smart biofertilizer in the soil plant system:

Expt. 1: Evaluation of Bio-coated TSP fertilizer for the improvement of phosphorus fertilizer use efficiency and rice yield in acid soil.

Combine technology of microbial carrier and chemical fertilizer termed as Bio-based chemical fertilizer. Bio-inoculant coated with commercial triple super phosphate, might trigger more fertilizer use efficiency (FUE). Hence present study was conducted with the objective to

1. Evaluate the efficacy of formulated bio-coated TSP (BCP) in the acid soil.

Methodology:

Formulated bio-coated TSP (BCP) was subjected to mineralization study in the acid soil for determination of available P. Acid soil (pH, 4.5) was collected from Komolganj, Habiganj. Collected soil was air dried, meshed and sieved before study. Laboratory mineralization and glasshouse study were conducted following completely randomized design with 6 replications.

Study 1.A: Nutrient mineralization in acid soil: Exact 250g of acid soil was mixed with the treatments and incubated at 28±2°C. Soil moisture regime was maintained at saturated level. Treatments were as; T_0= Control, T_1= Bio-coated TSP (@30kgP /ha) @ 140-30-80-10, T_2 = Bio-coated TSP (@ 20kg P /ha), T_3= Bio-coated TSP (@10kgP /ha), T_4 = TSP fertilizer @ 20kg P/ha). However, NKS (kg/ha) @ 140-80-10 were applied as flat dose for all of the treatments except control. Here urea, triple super phosphate, muriate of potash and gypsum were used as source of NPKS, respectively. Bio-coated TSP (BCP) was used as P source in the T_1, T_2 and T_3 treatments. Treatments were assigned as completely randomized design with six replications. Soil samples were collected at initial, 1, 2, 3, 7, 10, 15, 20 and 30 day of incubation and analyzed for NH_4^+ and available P, and populations of phosphate solubilizing and free-living N_2 fixing bacteria.

Study 1.B: Glasshouse study: Thirty days old rice plant (BRRI dhan28) was transplanted in to the pot containing 2.5 kg soil (pH=4.5), that was collected from Komolganj, Habiganj. The experiment was conducted following CRD with 6 replications. Same treatments of incubation study were applied in the Pot experiment: T_0= Control, T_1= Bio-coated TSP (@30kgP /ha) @ 140-30-80-10, T_2 = Bio-coated TSP (@20kg P /ha), T_3= Bio-coated TSP (@10kgP /ha), T_4 = TSP fertilizer @ 20 kg P/ha). However, NKS (kg/ha) @ 140-80-10 were applied as flat dose for all of the treatments except control.All treatments were applied during transplanting. Urea was applied in 3 equal splits; 1/3 during transplanting, 1/3 at maximum tillering stage and rest of the 1/3rd was applied at panicle initiation stage. Plant was harvested at the maturity stage. Standard agronomic practices were done. Plant height, root length, tiller number, panicle number, panicle length, straw and grain weight/plant were recorded.

Expt. 2: Evaluation of Bio-coated urea fertilizer for the improvement of rice yield in saline soil

Exopolysaccharide (EPS) producing plant growth promoting bacteria (PGPR) can play a significant role in alleviating salinity stress (Ashraf *et al*., 2004; Upadhyay *et al*., 2011). EPS binds with cations, such as Na^+ and decreases bioavailable ions for plant uptake and promote plant growth. Combination technology of microbial carrier and chemical fertilizer termed as Bio-based chemical fertilizer. Bio-inoculant coated with commercial urea might trigger more fertilizer use efficiency (FUE) and plant growth in the saline soil. Hence present study was conducted with the objective

i) to evaluate the efficacy of formulated 'Bio-coated urea' (BCU) in saline soil.

Methodology:

Formulated 'Bio-coated urea' was subjected to mineralization study in the saline soil for NH_4^+ release. Saline soil was collected from Kaliganj, Satkhira having EC value of 6 ds/m. Laboratory mineralization and glasshouse study were conducted following completely randomized design with 6 replications.

Study 2.A: Nutrient mineralization in saline soil: Nutrient mineralization study was conducted for a month in the incubator at 28±2ºC temperature. Soil moisture regime was maintained at saturated level. Exact 450g of saline soil was added with treatments as; T_1= control, T_2 = Chemical fertilizer (CF_1): NPKS (kg ha^{-1}) @120-20-50-20, T_3 = Chemical fertilizer (CF_2): NPKS (kg ha^{-1}) @120-20-120-20, T_4= NPKS (kg ha^{-1}) @120-20-50-20, T_5 = NPKS (kg ha^{-1}) @120-20-120-20. Bio-coated urea (BCU) was applied as N source in the T_4 and T_5 treatments and incubated for 30 days and incubated for 30 days. Considering saline soil K dose doublled in the CF_2 treatment Treatments were assigned as completely randomized design with six replications. Soil samples were collected at initial, 1, 2, 3, 7, 10, 15, 20 and 30 day and analyzed for NH_4^+ and beneficial bacteria populations. Here urea, triple super phosphate, muriate of potash and gypsum were used as source of NPKS, respectively. Bio-coated urea (BCP) was used as N source in the T_4, and T_5 treatments.

Study 2.B: Glasshouse study: Thirty days old rice plant (BRRI dhan99) was transplanted in to the pot containing 2.5 kg soil (6 ds/m), and that was collected from Kaliganj, Satkhira. The experiment was conducted following CRD with 6 replications. Treatment were imposed as T_1= control, T_2 = Chemical fertilizer (CF_1): NPKS (kg ha^{-1}) @120-20-50-20, T_3 = Chemical fertilizer (CF_2): NPKS (kg ha^{-1}) @120-20-120-20, T_4= NPKS (kg ha^{-1}) @120-20-50-20, T_5 = NPKS (kg ha^{-1}) @120-20-120-20. Bio-coated urea (BCU) was applied as N source in the T_4 and T_5 treatments. Considering saline soil K dose doublled in the CF_2 treatment. Urea was applied in 3 equal splits; 1/3 during transplanting, 1/3 at maximum tillering stage and rest of the 1/3rd was applied at panicle initiation stage. Intercultural operations were done as per cop requirement. Plant was harvested at the maturity stage. Here urea, triple super phosphate, muriate of potash and gypsum were used as source of NPKS, respectively. Plant height, root length, tiller number, panicle number, panicle length, straw and grain weight/plant were recorded.

BINA Component

Approach:

Soil samples from different crop locations were collected from eight different AEZ's: AEZ-3 (Rangpur and Nilphamari), AEZ-7 (Kurigram and Sirajganj), AEZ-9 (Mymensingh and Netrakona), AEZ-12 (Faridpur and Pabna), AEZ-14 (Gopalganj and Khulna), AEZ-17 (Chandpur and Laxmipur), AEZ-25 (Bogura and Naogaon) and AEZ-26 (Chapainawabganj and Rajshahi).

The soil samples were collected (0-15 cm depth) from each district, following 2 upazila (10 locations of each upazila) under 2 different unions (Fig. 21). A number of 320 soil samples were analyzed in Soil Science laboratory of BINA, for physico-chemical and biological properties. Beneficial salt tolerant nodulating bacteria were isolated. A biofertilizer was developed using potential microbes. Study was comprised in three steps- in the first step soil biological properties were assessed and beneficial rhizobia were characterized and identified, in second step, biofertilizer developed using salt tolerant isolated strains, and in third step biofertilizer tested in the soil plant system at glasshouse condition and field test in different saline areas.

Methodology:

Activities of Objective-1

Soil Sample collection: The soil sample (0-15 cm depth) was collected from each AEZ, following 2 upazila (10 locations of each upazila). About 320 soil samples, were collected using global positioning system (GPS) record along with plot history and analyzed for total and beneficial microbes. Soil samples were collected randomly and replicated 4 times for analyses of each property.

Fig. 21. Soil sample collection from different AEZ's

Fig. 22. Preservation of soil for microbiological analysis

Soil physico-chemical properties:
Soil samples were air dried in shed and sieved through 2 mm mesh for chemical analyses and preserved in plastic pot before analyses. Soil properties such as soil texture, soil reaction, total nitrogen and soil organic matter etc. were determined following standard methods (Table 04)

Table 04. Methods of soil physico-chemical and biological analysis

Parameters	**Methods**
Soil texture	Hydrometer methods (Calgon solution) (Bouyoucos, 1962)
Soil pH	Glass electrode pH meter method soil: water (1:2.5) (Jackson 1958)
Organic C	Wet oxidation method (Page *et al*. 1989)
Total N	Kjeldahl systems (Bremner and Mulvaney1982)
Total Bacteria	Nutrient Agar (total plate count)
Rhizobium-Bradyrhizobium	YMA media (total plate count)
N_2- fixing bacteria	N_2 free media (total plate count)
Phosphate Solubilizing Bacteria (PSB)	Pykovasakaya Agar plate (total plate count)
Fungi	PDA media (total plate count)
Actinomycetes	Acetinimycetes Agar plate (total plate count)
Identification	16S rRNA partial gene sequencing

Determination of soil texture: Soil texture was determined according to the method of Gee and Bauder, (1986) using Hydrometer and Calgon solution. Soil texture was determined according to sampling locations.

Fig. 23. Determination of soil texture and soil nitrogen

Soil pH: Soil pH was measured in a 1:2.5 suspension of soil and water on a glass electrode pH meter using a glass /calomel electrode (Jackson, 1962).

Soil organic matter: Organic carbon content of the soil sample was determind by wet oxidation methed (Nelson and sommers, 1982). Organic matter content was calculated through multiplying persent organic carbon by 1.73 (van Bemmelen factor).

Total nitrogen: Total nitrogen content of the soil was determind following micro-kjeldahl mithod. The sample was digested with concentrated H_2SO_4 and H_2O_2 in persence of catalyst mixture (K_2SO_4: $CuSO_4$. $5H_2O$: Se-100:10:1). Nitrogen in the digest was determind by distilling the digest with 10N NaOH followed by titration of the distelate trapped in H_3BO_3 indicator solution with 0.01N H_2SO_4 (Bremner and Mulvaney, 1982).

Soil biological properties

After collection of soil, samples were kept at 4°C temperature until analyses. Culturable total bacteria, *Rhizobium*, *Bradyrhizobium*, Free living nitogen fixing bacteria, PSB, Fungi and Actinomycetes population were determined in Nutrient Agar, Yeast Mannitol Agar, NFM, Potato dextrose agar and Actinomycetes agar plate, respectively. Total population was enumerated following 'total plate count method' (Naher *et al*., 2014). In brief, approximately 10 g soil sample was suspended into 90 ml sterile distilled water and shaked on a mechanical rotary shaker for 10 minutes. About 1 ml of suspension was added to nine ml sterile distilled water using serial dilution technique up to 10^7 dilutions. Exactly 0.1 ml of solution from each dilution was spreaded on respected media plate and incubated for 3-10 days at 28°C temperature. Total population was counted and expressed as cfu g^{-1} soil dry weight.

Total bacteria: Total bacteria were grown in Nutrient agar media and incubated for 3-7 days and population was counted according to plate count method. Composition of Nutrient agar media was Yeast extract 2g, Peptone 5g, NaCl 5g, Agar 15g per litre (Nagasawa *et al*, 1974).

Rhizobium* and *Bradyrhizobium: *Rhizobium* and *Bradyrhizobium* were grown in Congo-red Yeast Extract Mannitol (CRYMA) media and incubated for 5-10 days and population counted

according to the spread plate count method. Composition of YMA media was (g L^{1}): 10 g Manitol, 0.5 g K_2HPO_4, 0.2 g $MgSO_4.7H_2O$, 0.1 g NaCl, 0.5 g Yeast, 20 g Agar and 0.025 g Congo red.

Free-living N_2 fixing bacteria (FLNFB): Free living N_2 fixing bacteria were counted in N-free media according to the protocol of Naher *et al* (2013) and Prasad *et al* (2001). The population was counted after 3-5 days of incubation following 'Total plate count method'. The media composition was (g/l): 5 g Malic acid, 0.5 g K_2HPO_4, 0.2 g $MgSO_4$. 7 H_2O, 0.1 g NaCl, 0.02 g $CaCl_2$ and 0.5% bromothymol blue in 0.2 N KOH (2 ml), 1.64% Fe-EDTA solution (4 ml), and 20 g agar (pH 7.2).

Phosphate solubilizing bacteria (PSB): Phosphate solubilizing bacteria were isolated in Pikovskaya media plate according to Panhwar *et al* (2012). The media inoculated with the isolates were incubated for 3 days and observed for the formation of yellow zone around the colony due to the utilization of tricalcium phosphate present in the medium. The composition of Pikovasakaya media was (g L^{1}): Glucose 10 g, 0.2g NaCl, 0.002 g $MnSO_4.H_2O$, 0.002 $FeSO_4.7H_2O$ 0.1 g $MgSO_4.H_2O$, 0.2 g KCl, 0.25g Bromo-phenol blue, 0.5 g $(NH_4)_2SO_4$ 5 g $Ca_3(PO_4)_2$, and 20 g of bacterial agar

Fungi: Fungi were grown in potato dextrose agar (PDA) media and population counted using dilution and spread plate count method.

Actinomycetes: Actinomycetes were grown in Actinomycetes agar media and population counted using serial dilution technique and spread plate count method (Subhashini, 2018).

Isolation of salt tolerant *Bradyrhizobium* strain: *Bradyrhizobium* strains were isolated from root nodule of soybean grown in saline soils of Satkhira and Noakhali. Nodules were collected from roots of soybean and washed and surface sterilized using the method of Vincent (1970). Nodules were cut and pink sap was streaked on CRYMA plate and incubate and incubated for 5-10 days and then restreaked on CRYMA and typical colonies were selected as isolate. Composition of CRYMA media was (g L^{1}): 10 g Manitol, 0.5 g K_2HPO_4, 0.2 g $MgSO_4.7H_2O$, 0.1 g NaCl, 0.5 g Yeast, 20 g Agar and 0.025 g Congo red.

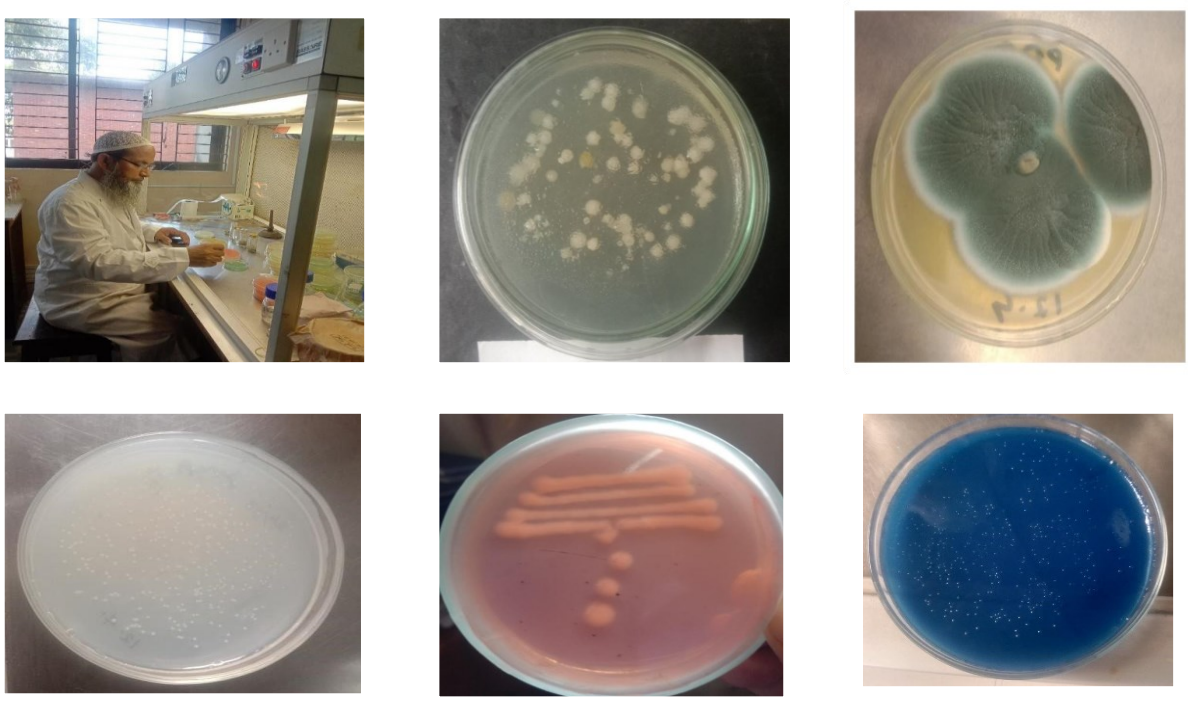


Fig. 24. Isolating media and isolation/counting of microorganisms

Biochemical characterization of isolated salt tolrtant bacteria

Observation of P solubilizing activity: P solubilizing activity was observed on Phosphate growth medium Pikovskaya agar plate.

Observation of indole acetic acid (IAA) production: The bacteria isolates were grown in LB broth with addition of 2 mg L^{-1} tryptophan and amonium nitrate 0.5 gram per litre for ten days. After 10 days of incubation broth cultures were centrifuged, filtered and IAA was determined following colorimetric technique (Malik *et al*, 1998).

Activities of Objective-2

Formulation of biofertilizer:

Individual strains were grown in yeast mannitol broth medium and incubated on rotary shaker for 10 days. After reaching cell concentration of broth culture @ $1x10^9$ cell/ml suspension (Vincent, 1970; Somasegaran and Hoben, 1998) individual strain was injected into sterile peat dust and mixed well. The ratio of peat and bacterial suspension was maintained 1:3 (means 25 ml suspension into 75 gram peat carrier).

Activities of Objective-3

Evaluation of climate smart (salinity tolerant) biofertilizer in the soil plant system:

Expt. 1. Evaluation of salinity tolerant rhizobia inoculation on growth, nodulation anddry matter production of soybean in pot condition

Hence the study was conducted with the objective to:

1. Evaluate the efficacy of bioinoculants on growth, nodulation, drymatter production of host crop soybean in pot environment.

Methodology:

The experiment was set in glass house at Soil Science Division of BINA. Plastic pot containing 4kg sterile sand was used in each pot. Sand was autoclaved and poured into pot-which was sterilized through washing by detergent both rubbing inside and outside using 95% ethyl alcohol solution. Seeds of soybean were surface sterilized by dipping 1 minute into 95% ethyl alcohol solution. Then seeds were dipped into respective inoculant strains suspension for 30 minutes and then used to sow into the sand filled pot and covered by sand. Five wholes were made in sand in each pot. Sands were mixed with nitrogen free seedling solution of half strength @ 200ml seedling solution per pot. Three seeds were sown in each hole and after germination five healthy plants were maintained in each pot. Half strength sterile seedling solution was applied in pot as per requirement aseptically. Pots were maintained free from weed. Data on growth and nodulation and dry matter were recorded 40 and 70 days after sowing (DAS).

Expt. 2: Evaluation of salinity tolerant rhizobia inoculants on plant growth, nodulation and yield of soybean in field environment in saline areas

Hence present study was conducted with the objective:

i) To evaluate the performance of salinity tolerant rhizobia inoculants in saline soil.

Methodology:

Two field experiments were conducted to evaluate the performance of salinity tolerant rhizobia strains in Satkhira and Noakhali. There were eight treatments viz. four rhizobia inoculants STR-1, STR-2, STR-3 and STR-4 in the study. Three nitrogen doses as 15, 30 and 45 kg N/ha were used as chemical nitrogen and one uninoculated control. The treatments were replicated four times in the experiment. The lands were prepared by ploughing and laddering four times. Plots were used 4m x 3m site. Phosphorus, Potassium and Sulphur were applied as basal application @ P_{30}, K_{50},

S_{15}. Data on nodule number, nodule dry weight, plant height, shoot dry weight were recorded at 40 and 70 days after sowing (DAS). Plants were harvested at ripening stage. Yield and yield attributing parameters were recorded and analyzed statistically using Statistics 10 program (Gomez and Gomez, 1984).

BSRI Component

Activities of Objective-1

Soil Sample collection: The soil samples (0-15 cm depths) were collected using global positioning system (GPS) along with plot history from seven (7) Agro-ecological zones viz. AEZ 1 (Thakurgaon, Dinajpur), AEZ 4 (Sirajganj, Pabna), AEZ 5 (Naogoan, Natore), AEZ 8 (Sherpur, Norshingdi,) AEZ 20 (Habiganj, Sylhet), AEZ 21 (Sunamganj, Habiganj) and AEZ 28 (Tangail, Gazipur) under this study (Fig. 1 and Fig. 2). The soil samples were collected randomly and it were analyzed for chemical, physical and microbiological properties. From each AEZs two districts were randomly selected. From each district two upazila's were selected. From each two union were selected. From each union five soil samples were collected. Thus, from two union ten soil samples were collected. About 240 soil samples were collected from seven AEZs and it was preserved in refrigerator at 4° C temperature. The samples were replicated 4 times for analyses of each property.

Soil sample collection from Sylhet (AEZ20)

Soil sample collection from Habiganj (AEZ20)

Soil sample collection from Thakugaon (AEZ1)

Soil sample collection from Sirajganj (AEZ4)

Soil sample collection from Sherpur (AEZ8)

Soil sample collection from Norsingdi (AEZ8)

Soil sample collection from Sunamganj (AEZ21)

Soil sample collection from Tangail (AEZ28)

Fig. 25. Soil Samples collection from different AEZs of BSRI component

Soil physico-chemical properties: Soil samples were air dried in shed and sieved through 2 mm mesh for chemical analyses and preserved in plastic pot before analyses. Soil properties such as biomass carbon, soil reaction, and soil organic matter etc. were determined following standard methods (Table 05)

Table 05. Methods of soil physico-chemical and biological analysis

Parameters	**Methods**
Soil texture	Hydrometer methods (Calgon solution) (Bouyoucos, 1962)
Soil pH	Glass electrode pH meter method soil: water (1:2.5) (Jackson 1958)
Organic C	Wet oxidation method (Page *et al*. 1989)
Total N	Kjeldahl systems (Bremner and Mulvaney1982)
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
Identification	16S rRNA partial gene sequencing

Determination of soil texture: Soil texture determined according to the method of Bouyoucos, (1962) using Hydrometer and Calgon solution. Soil texture determined according to sampling union and land type basis.

Determination of soil pH, organic carbon (OC) and total nitrogen: Soil was mixed with distilled water at 1:2.5 ratio followed by stirring with a glass rod for 5 min, which was repeated two times after 1-hour interval and then pH of the solution was determined using a portable pH meter (HANNA, Romania). The OC and total N were determined by wet oxidation method (Walkley and Blakhk, 1935) and Kjeldahl method (Bremner and Mulvaney, 1982), respectively.

Determination of soil biological properties:

Soil biological properties: After collection of soil, samples were kept at 4ºC temperature until analyses. Culturable total bacteria, fungus and actinomycetes population were determined in Nutrient Agar, Potato dextrose agar, and Actinomycetes agar plate. Total population was enumerated following 'total plate count method' (Naher *et al*., 2014). In brief, approximately 10 g soil sample was added into 90 ml sterile distilled water and shacked in a mechanical shaker for 10 minutes. About one ml of solution was added with nine ml sterile distilled water and a series of dilution were prepared up to 10^{10} dilution. Exactly 0.1 ml of solution from each dilution was spread on respected media plate and incubated for 3 days at 28ºC temperature. Total population was counted and expressed as cfu g^{-1} soil dry weight (Fig. 26).

Isolation of Free-living N_2 fixing bacteria: Free living N_2 fixing bacteria were isolated from selected soils of different AEZ's in N-free media according to the protocol of Naher *et al* (2013) and Prasad *et al* (2001). The population was counted after 3 days of incubation following 'Total plate count method'. The media composition was (g/l): 5 g Malic acid, 0.5 g K_2HPO_4, 0.2 g $MgSO_4$. 7 H_2O, 0.1 g NaCl, 0.02 g $CaCl_2$ and 0.5% bromothymol blue in 0.2 N KOH (2 ml), 1.64% Fe-EDTA solution (4 ml), and 20 g agar (pH 7.2).

Isolation of phosphate solubilizing bacteria (PSB): Phosphate solubilizing bacteria were isolated in Pikovskaya media plate according to Panhwar *et al* (2012). The media inoculated with the isolates were incubated for 3 days and observed for the formation of yellow zone around the colony due to the utilization of tricalcium phosphate present in the medium. The composition of Pikovasakaya media was (g L^{-1}): Glucose 10 g, 0.2g NaCl, 0.002 g $MnSO_4.H_2O$, 0.002 $FeSO_4.7H_2O$ 0.1 g $MgSO_4.H_2O$, 0.2 g KCl, 0.25g Bromo-phenol blue, 0.5 g $(NH_4)_2SO_4$ 5 g $Ca_3(PO_4)_2$, and 20 g of bacterial agar

Isolation of *Rhizobium*: *Rhizobium* was grown in YMA media and incubated for 3 days and population counted according to the spread plate count method. Composition of YMA media was (g L^{-1}): 10 g Manitol, 0.5 g K_2HPO_4, 0.2 g $MgSO_4.7H_2O$, 0.1 g NaCl, 0.5 g Yeast, 20 g Agar and 0.025 g Congo red.

Isolation of Total fungus and actinomycetes: Total fungus and actinomycetes were grown in potato dextrose agar media (PDA) and actinomycetes media, respectively and population counted using dilution and spread plate count method.

Inocula preperation

Mass preparation of inocula in broth culture

Determination of optical density

Scientists are working in laminar flow hood

Working scientists of BNF lab

Plate counting of organisms

Fig. 26. Determination of *s*oil chemical and biological properties in laboratory

Activities of Objective-2

Isolation of Nitrogen fixing and phosphate solubilizing bacteria from sugarcane rhizosphere soil:

The rhizosphere soil and roots samples were collected form sugarcane variety/clone Isd 37 and B 34-104 and I30-10 at Bangladesh Sugarcrop Research Institute experimental farm (24º8/ N latitude and 92º5/ E longitude). Approximately 10g of soil sample was taken into the 250 mL conical flask with 90 mL sterilized water. Several glass bids were added. Sample mixed thoroughly with the water and mixture was shaking on a shaker for 200 rpm at 30^0C. 1 ml suspension was taken in a vial contained with 9 mL sterile water. For root sample, 1g of healthy roots were weighed, washed with distilled water to remove adhering soil particles and again washed with 3% H_2O_2 for 3 minutes for surface sterilization. Then the roots were washed 6-7 times with sterile water. The roots were finely ground with the pestle and motor with 99 mL sterile water and the mixture were vortex 2 to 3 minutes. For both samples, all procedures were done separately. Serial dilutions of the suspension were made up and formed dilution series of 10^{-2} to 10^{-7}. These were repeated for three times. Then 0.1 mL of each suspension was spread in nitrogen free (NFb) LGIM media. The 6 (six) isolates were isolated from the rhizospheres soil and roots of sugarcane based on their growth on nitrogen-free medium.

Maintenance of working culture:

The isolates were sub cultured in LB agar plates at 15 days interval. Working cultures were kept in 4°C. It was observed that the isolates could be kept alive in 4°C for about month.

Fig. 27. Sample with rhizosphere soils and roots

Morphological characteristics of bacteria and assessment of the population:

Individual colonies of each isolate were obtained by streaking them on LGIM and LB agar plates. The plates were incubated at 30°C for 3 days. After sufficient growth, colonies were observed to determine their morphological characteristics.

Gram's staining:

Gram's staining procedure was performed to observe the cell morphology. Isolates were heat fixed on glass slides, stained by crystal violet, followed by Gram's iodine solution. After washing under tap water, the isolates were destained with 70% ethanol solution and restained with safranin. The glass slides were then washed under running tap water and observed under light microscope. This microscopy determined their Gram reaction and cell morphology (Fig. 28).

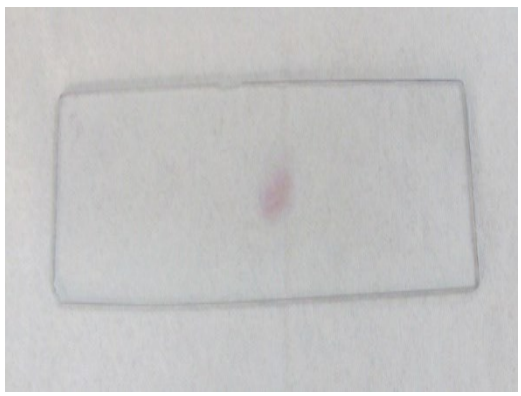


Fig. 28. Microscopic observation of Gram staining

Biochemical test:

Estimation of indoleacetic acid production:

Indoleacetic acid production was estimated by growing the isolates in NFb medium supplemented with NH_4Cl and 100 µg/mL DL-tryptophan at 30°C with shaking for 72 h in the dark. Five milliliter of each culture was centrifuged (20 min, 6,000×g), and indoleacetic acid production was measured as indolic compounds in 2 ml of supernatant by mixing with 2 mL of Salkowski reagent and following the absorbance at 535 nm after 30 min in the dark. A standard curve was used for calibration.

Cellulase activity:

Freshly grown isolated cultures were steaked in a zigzag manner on nutrient agar plates supplemented with 0.2 % carboxy methyl cellulose (CMC). The plates were then incubated at 30 °C for 3 days. After sufficient growth, the plates were overlaid with Congo-red (1 µg/ml) solution for 15 min. The plate surface was washed with 1 M NaCl, and was observed for clear zone around the growth. The formation of clear zone indicated cellulose activity.

Phosphate solubilizing assay:

Test for P-solubilisation was done following Sharma *et al*. (2012). The plates were prepared with Pikovaskya's medium. The cultures of diazotroph isolates were spot inoculated on the plates and incubated in an incubator at 28°C for 3- 5 days. Formation of clear zone around the microbial colonies indicated phosphate solubilization. Composition of Pikovskaya media in 1 litre: Glucose-10 g, $Ca_3(PO_4)_2$-5g, $(NH_4)_2SO_4$-0.5 g, NaCl-0.2 g, $MgSO_4.7H_2O$-0.1 g, KCL-0.2 g, Yeast extract-0.5 g, $MnSO_4.H_2O$-0.002 g, $FeSO_4.7H_2O$-0.002 g and Agar-15 g (Pikovskaya, 1948).

Molecular characterization of nitrogen fixing bacteria:

DNA extraction:

For the genomic DNA extraction, the isolates were grown in nutrient agar medium at 28^0C for 24 h and centrifuged at 12,300×g. The pellets were washed with TE buffer and resuspended in 10 mL of TE (1×) containing 3 mL of 5% SDS in TE (1×) and 3 ml of proteinase K (2.5 mg/ml). The suspensions were incubated 37^0C for 1 h. After 1 h, the cleaned lysates were extracted with phenol: chloroform: isoamyl alcohol (25:24:1). DNA were precipitated by adding 0.1 volume of 3 M sodium acetate (pH 5.2) and 2.5 volumes of ethanol to the supernatant. The dried pellets were dissolved in TE (1×) buffer. The purity was assessed from the A260/A280 and A260/A230 extinction ratios.

PCR amplification and sequencing of 16S rRNA genes:

The 16SrRNA genes were amplified by PCR using universal primers F27 (5′-AGAGTTTGATCATGGCTCAG-3′) and R1492 (5′-TACGGTTACC TTGTTACGACTT-3′). The PCR amplifications were carried out in 50 µL reaction volumes with ddH_2O, 10×buffer, 2.5 mmol/L dNTP, 10µmol/L primer, DNA template and Pyrobest TM DNA polymerase. The reaction was set up as follows: initial denaturation at 95°C for 4 min. Each of the 30 cycles is composed of a denaturation step of 94°C for 30 s, an annealing step of 56°C for 40 s, and an extension step of 72°C for 2 min, and the last cycle was followed by a final extension at 72°C for 6 min. Products were visualized on a 1.5% agarose gel in 1×TBE buffer. The amplicons were purified with a PCR purification kit. The purified PCR products were sequenced bi-directionally with F27 (5′-AGAGTTTGATCATGGCTCAG-3′) and R1492 (5′-TACGGTTACC TTGTTACGACTT-3′) by National Institute of Biotechnology, Savar, Dhaka (figure 6). The BLAST at the National Centre for Biotechnology Information (NCBI) was used for alignment analysis of the nucleotide sequences with the information from GenBank databases.

DNA sequencing and phylogenetic analysis:

DNA sequences were aligned using the multiple alignments CLUSTAL W software (Thompson *et al*. 1994) with 16S rRNA gene sequences of type strains involved in the same genus of the isolates as a result of previous GenBank sequence comparisons. The evolutionary distance was determined by construction of a phylogenetic tree using the Maximum Composite Likelihood method in the MEGA 4 proGram (Tamura *et al*. 2007).

Objectives 3

Preparation of N-fixing biofertilizer

The bacterial strains were grown in respective broth culture for two days. Then the broth was centrifuged at 6000 rpm for 5 minutes. After that supernatant was discarded and cell pellets were washed in to two times with sterile water and were collected in a 30 ml bottle. This solution was centrifuged by vortex mixture to homogenize the strains in sterile water. Bacterial concentration was adjusted using a spectrophotometer at 540 nm and 0.1 ml of suspension containing 10^8 cells was inoculated.

Objectives 4

Combined Effect of Bio-fertilizer and Inorganic Fertilizer on Growth and Yield of Sugarcane

The experiment was conducted at Bangldesh Sugarcrop Research Institute Jamalpur substation. It was designed of Randomized Completely Block design (RCBD) with three replications. It was comprised of 8 (eight) treatments viz. T_1 = No fertilizers and strains, T_2 = Recommended Dose of Fertilizers (RFD), T_3 = 100% N of RFD+N-fixing inoculants, T_4 = 50 % N of RFD + N-fixing inoculants, T_5= 75 % N of RFD + N-fixing inoculants, T_6 = 50% of RFD+ Nitrogen and phosphate solubulizing inoculants, T_7= 75 % of P and full amount of NKSZn + phosphate solubulizing inoculants and T_8 = 50 % of P and full amount of NKSZn + phosphate solubulizing inoculants. The variety was Isd 39. The planting materials were poly bag seedlings. The experiment was set up on 8 February 2020. The necessary inter culture operations and data were recorded when as necessary.

Preparation of inoculants:

The strains were grown in respective broth culture for two days. Then the broth was centrifuged at 6000 rpm for 5 minutes. After that supernatant was discarded and cell pellets were washed into two times with sterile water and were collected in a 30 ml bottle. This solution was centrifuged by vortex mixture to homogenize the strains in sterile water. Bacterial concentration was adjusted using a spectrophotometer at 540 nm and 0.1 ml of suspension containing 10^8 cells was inoculated into liquid LB media.

Setts soaking with inoculants

Two eyed sugarcane setts were soaked in 40 L suspension containing 500 ml bacterial culture for 30 minutes for the bacteria to adhere in the setts.

Fertilizer application

One third of nitrogen and one half of potassium and total phosphorus, sulphur and zinc were applied as basal dose and thoroughly mixed with the soil before planting. Remaining potassium and one third nitrogen were applied as top dressing at tillering stage (120-150 days). The rest amount of nitrogen was top dressed after completion of tillering (about 180 days).

Inoculants application rate

40 L bacterial suspension was prepared with 500 ml bacterial culture for inoculating 1 acre of land. Inoculants were applied at the base of seedling at 120 and 180 DAP. Necessary intercultural operations were done throughout the cropping season for proper growth and development of the crop. Data were compiled and tabulated in proper form and were subjected to statistical analysis by using the computer package Statistix 10 proGram for Windows Version. Computation was done by the use of Microsoft Excel 2003 program.

11. Results and Discussion (with appropriate pictures):

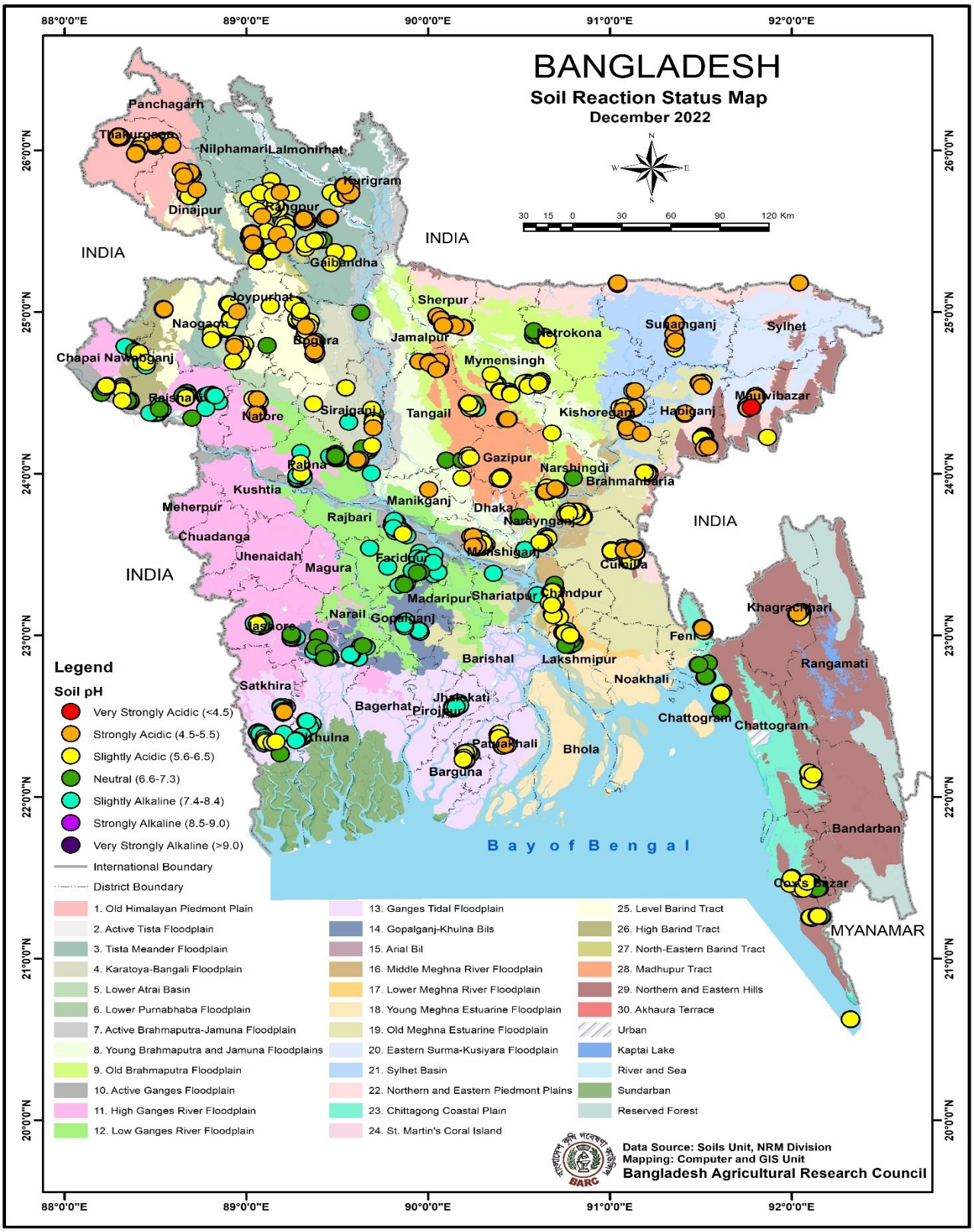


Fig. 29. pH status map of 30 AEZs of Bangladesh

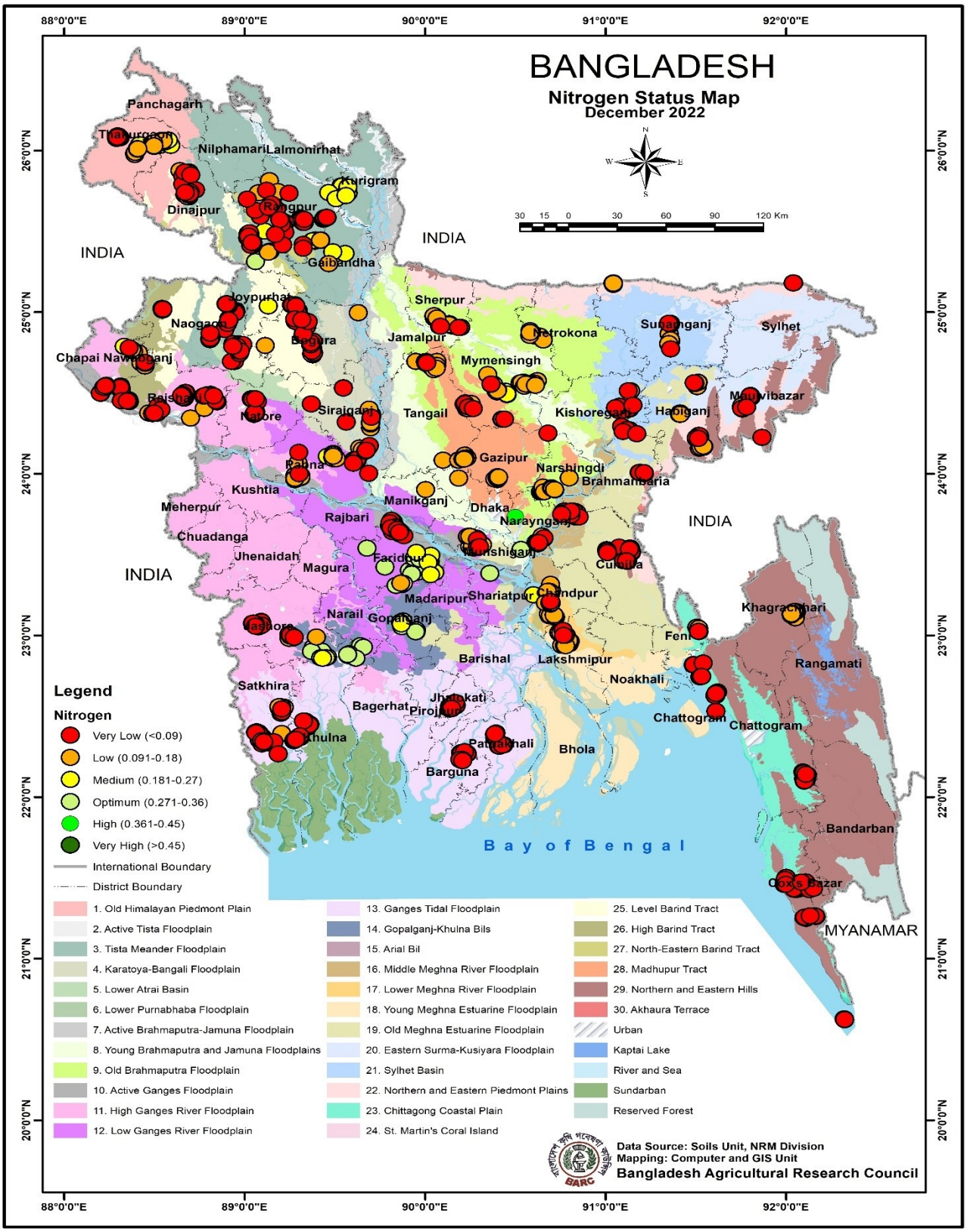


Fig. 30. Nitrogen status map of 30 AEZs of Bangladesh

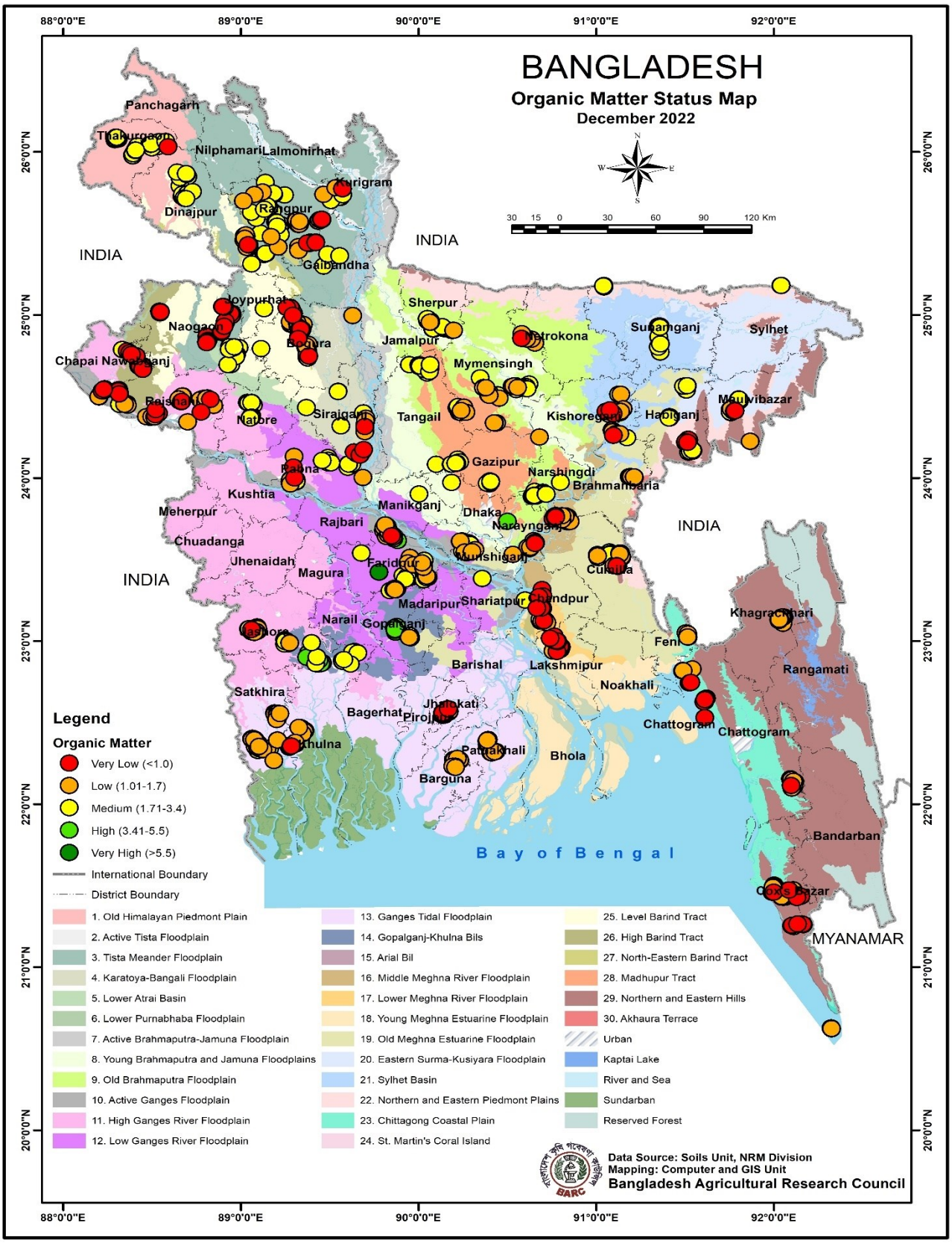


Fig. 31. Organic matter status map of 30 AEZs of Bangladesh

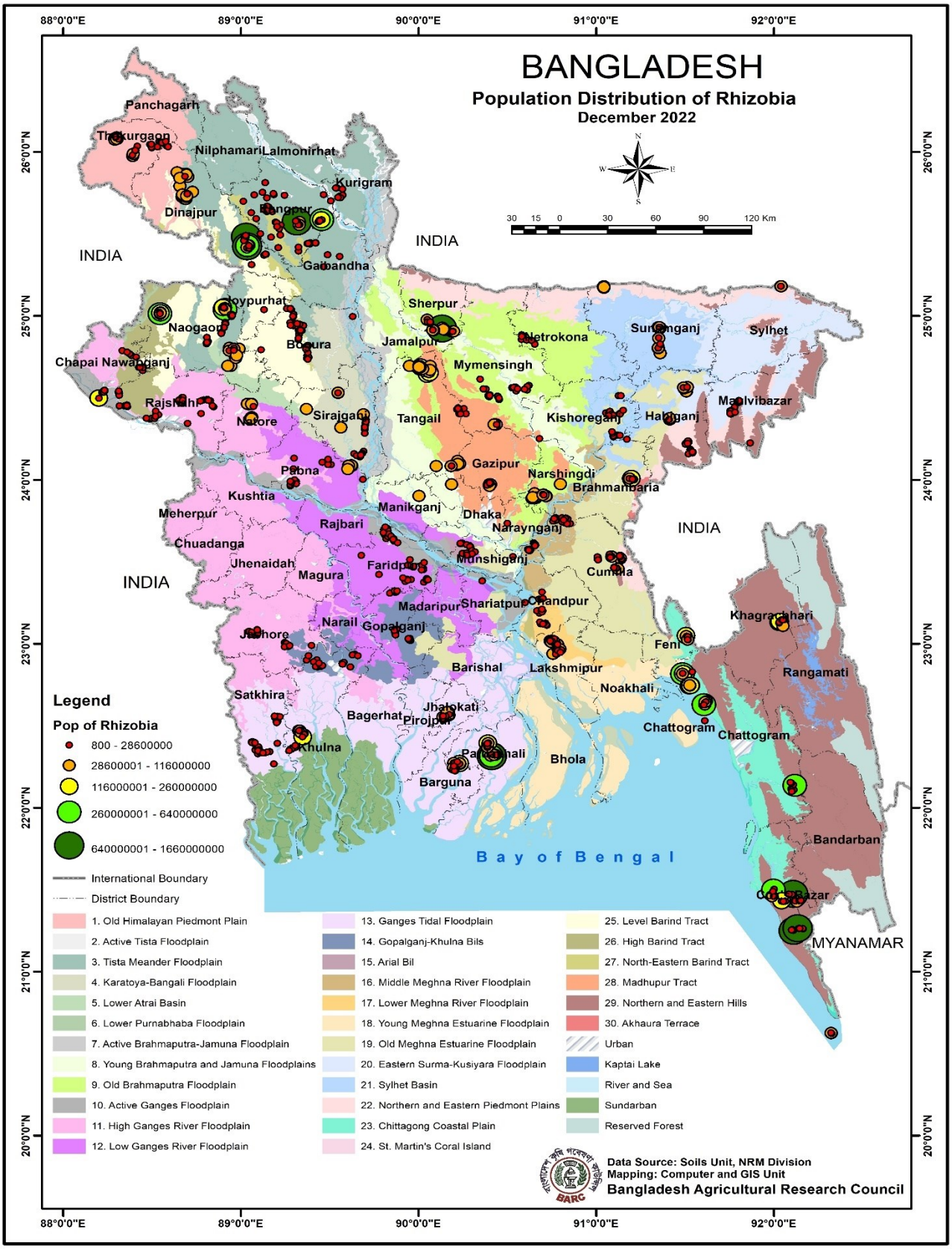


Fig. 32. Rhizobial population map of 30 AEZs of Bangladesh

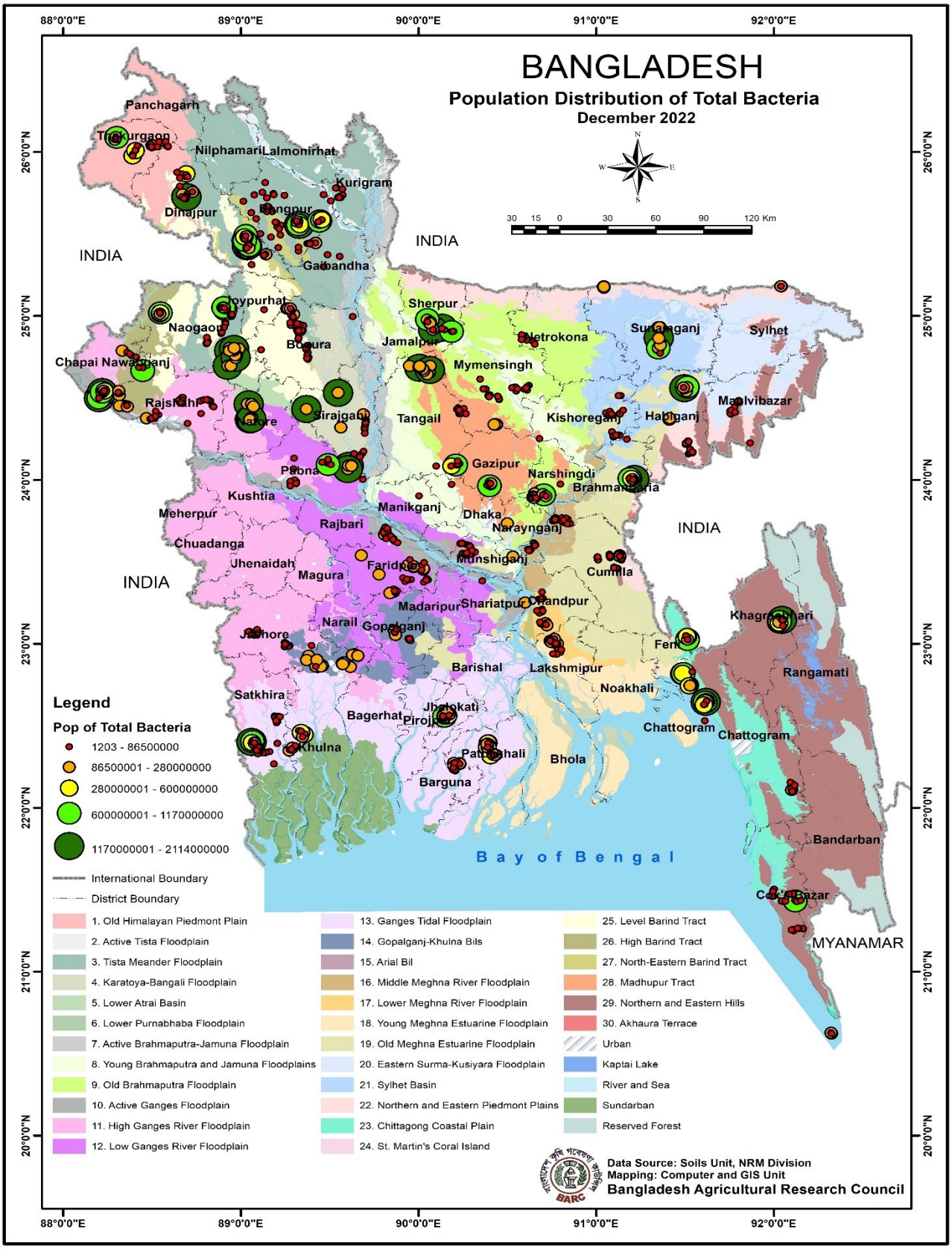


Fig. 33. Total bacterial population map of 30 AEZs of Bangladesh

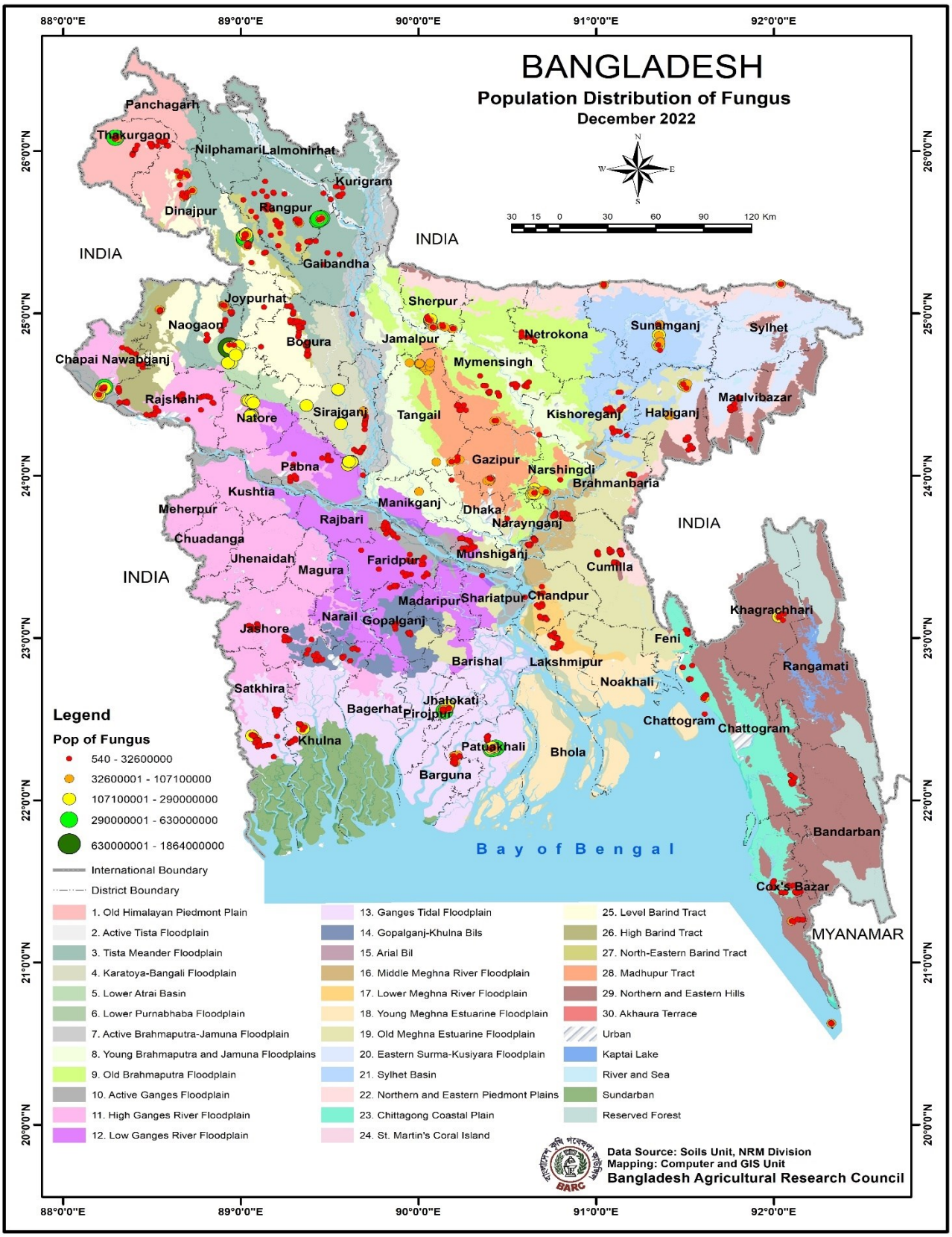


Fig. 34. Fungus population map of 30 AEZs of Bangladesh

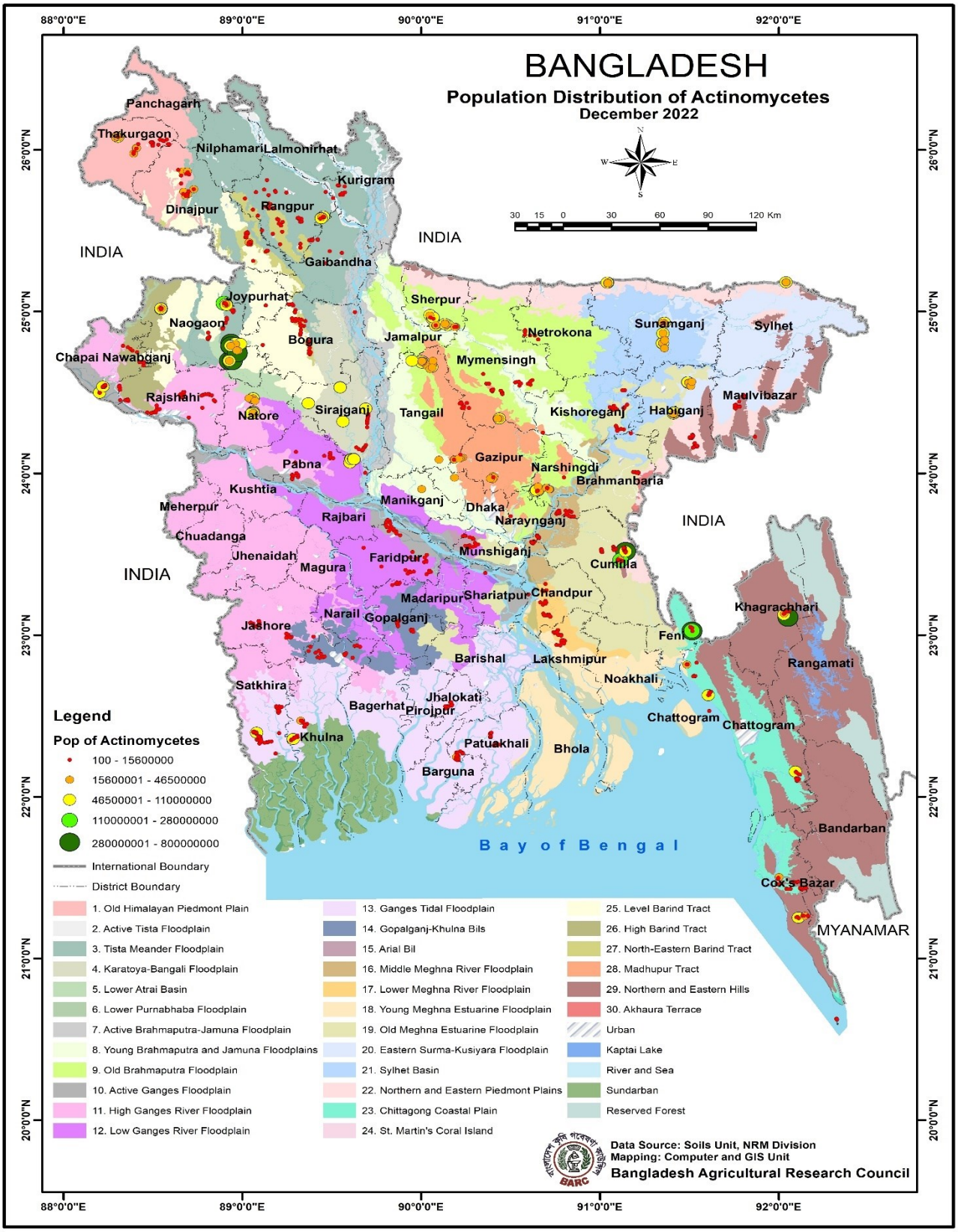


Fig. 35. Actinomycetes population map of 30 AEZs of Bangladesh

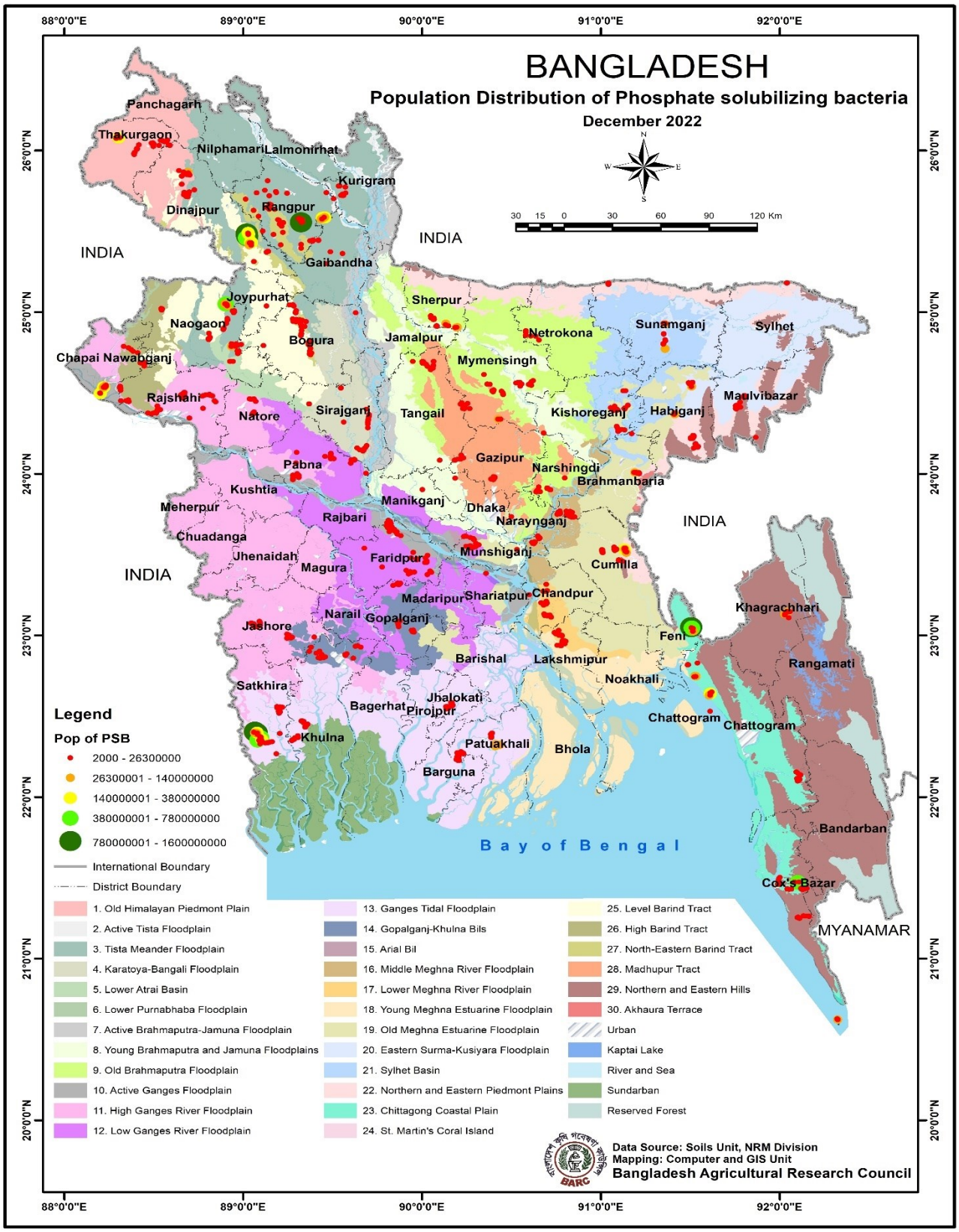


Fig. 36. Phosphate solubilizing bacteri (PSB) population map of 30 AEZs of Bangladesh

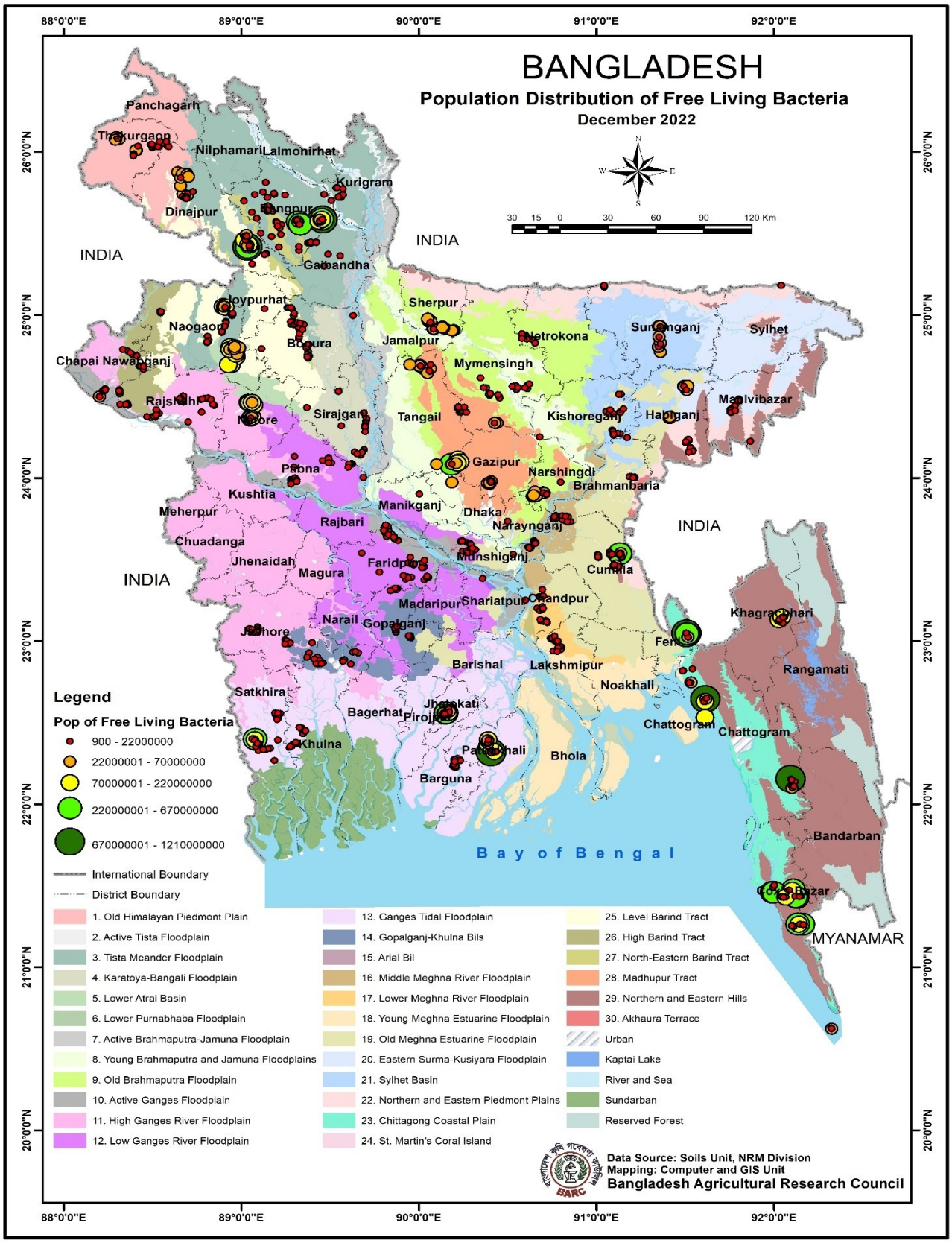


Fig. 37. Free living bacterial population map of 30 AEZs of Bangladesh

BARI Component

Soil chemical properties of different AEZs

Chemical properties of AEZ-02 (Active Tista Floodplain) soils of Kurigram and Rangpur

In AEZ 2 soil, the pH was ranged from 5.3 to 8.1, OC varied from 0.5 to 1.9 (%), TN ranged from 0.04 to 0.10 (%) at Kurigram district and pH ranged from 4.6 to 6, OC ranged from 0.5 to 1.2 (%), TN ranged 0.04 to 0.11 (%) at Rangpur district (Table 06, Fig. 29, Fig. 30, Fig. 31).

Considering AEZ-2 soil, the lowest pH was recorded 4.6 at Badarganj, Rangpur and the highest pH was recorded 8.1 at Fulbari, Kurigram, the lowest OC was recorded 0.5(%) at Nagessor, Kurigram and the highest OC was recorded 1.9 (%) at Nagessor, Kurigram, the lowest TN was recorded 0.04(%) at Nagessori, Kurigram and the highest TN was recorded 0.11 (%) at Badarganj, Rangpur (Table 06, Fig. 29, Fig. 30, Fig. 31).

Table 06. Soil chemical properties of AEZ- 2 soils of Kurigram and Rangpur

AEZ No.	District	Upazila	Chemical properties		
			Soil pH	Organic Carbon (%)	Total Nitrogen (%)
AEZ- 2	Kurigram	Fulbari	5.3-8.1	0.7-1.1	0.06-0.1
		Nagessor	5.3-7.9	0.5-1.9	0.04-0.09
	Rangpur	Taraganj	4.9-5.9	0.6-1	0.05-0.09
		Badarganj	4.6-6.0	0.5-1.2	0.04-0.11

Chemical properties of AEZ 06 (Lower Purnabhaba Floodplain) soils of Naogaon and Chapainawabganj

Soil pH of AEZ 06 ranged from 5.00 to 7.22, Organic Carbon (OC) ranged from 0.35 to 0.89 (%), Total Nitrogen (TN) ranged 0.03 to 0.08 (%) at Naogoan district and pH ranged from 6.08 to 8.10, OC ranged from 0.47 to 0.94 (%), TN ranged 0.04 to 0.09 (%) at Chapainawabganj district, respectively (Table 07, Fig. 29, Fig. 30, Fig. 31).

Considering AEZ-6 soil, the lowest pH (5.0) was recorded at Badalgachhi, Naogaon and the highest pH (8.1) was recorded at Gomastapur, Chapainawabganj, the lowest OC (0.35%) was recorded at Dhamoirhat, Naogaon and the highest OC (0.94%) was recorded at Gomastapur, Chapainawabganj, the lowest TN (0.03 %) was recorded at Dhamoirhat, Naogaon and the highest TN (0.09%) was recorded at Gomastapur, Chapainawabganj (Table 07, Fig. 29, Fig. 30, Fig. 31).

Table 07. Soil chemical properties of AEZ 06 (Lower Purnabhaba Floodplain) soils of Naogaon and Chapainawabganj

AEZ No.	District	Upazila	Chemical properties		
			Soil pH	Organic Carbon (%)	Total Nitrogen (%)
AEZ 06	Naogaon	Dhamoirhat Badalgachhi	5.54-6.47 5.00-7.22	0.35-0.89 0.47-0.75	0.03-0.08 0.04-0.07
	Chapainawabganj	Gomastapur	6.08-8.10	0.47-0.94	0.04-0.09

Chemical properties of AEZ 13 (Ganges Tidal Floodplain) soils of Khulna and Satkhira

In AEZ 13 soil, the pH was ranged from 7.34 to 8.40, OC ranged from 0.50 to1.03 (%), TN ranged 0.05-0.09 (%) at Khulna district and pH ranged from 8.27 to 8.48, OC ranged from 0.64-0.99 (%), TN ranged 0.06 to 0.09 (%) at Satkhira district, respectivel (Table 08, Fig. 29, Fig. 30, Fig. 31). Considering AEZ-13 soil, the lowest pH was recorded 7.34 at Dacope, Khulna and the highest pH was recorded 8.48 at Shyamnagar, Satkhira, the lowest OC was recorded 0.64(%) at Kaliganj, Satkhira and the highest OC was recorded 1.03(%) at Batiaghata, Khulna, the lowest TN was recorded 0.05(%) at Dacope, Khulna and the highest TN was recorded 0.09(%) at Batiaghata, Khulna and Kaliganj, Satkhira and Shyamnagar, Khulna (Table 08, Fig. 29, Fig. 30, Fig. 31)

Table 08. Soil chemical properties of AEZ 13 (Ganges Tidal Floodplain) soils of Khulna and Satkhira

AEZ No.	District	Upazila	Chemical properties		
			Soil pH	Organic Carbon (%)	Total Nitrogen (%)
AEZ 13	Khulna	Batiaghata,	7.75-8.40	0.75-1.03	0.07-0.09
		Dacope	7.34-7.96	0.50-0.92	0.05-0.08
	Satkhira	Kaliganj,	8.27-8.48	0.64-0.96	0.06-0.09
		Shyamnagar	8.16-8.45	0.69-0.99	0.06-0.09

Chemical properties of AEZ-18 (Young Meghna Estuarine Floodplain) soils of Patuakhali, Barishal and Bhola

In case of tested soils of AEZ 18, the pH varied from 5.56 to 8.65, OC ranged from 0.62 to 1.06 (%), TN ranged from 0.056 to 0.096 (%) at Patuakhali district and pH ranged from 8.14 to 8.44, OC ranged from 0.51 to 1.01 (%), TN ranged 0.05 to 0.155 (%) at Barishal district. and pH ranged from 5.3 to 7.8, OC ranged from 0.6 to 1 (%), TN ranged 0.05 to 0.09 (%) at Bhola district, respectively (Table 09, Fig. 29, Fig. 30, Fig. 31).

Considering AEZ-18 soil, the lowest pH was recorded 5.3 at Borhanuddin, Bhola and the highest pH was recorded 8.65 at Sadar, Patuakhali, the lowest OC was recorded 0.51 (%) at Gowronodi, Barishal and the highest OC was recorded 1.06 (%) at Dumki, Patuakhali, the lowest TN was recorded 0.05(%) at Gowronodi, Barishal and the highest TN was recorded 0.155 (%) at Gowronodi, Barishal (Table 09, Fig. 29, Fig. 30, Fig. 31).

Table 09. Soil chemical properties of AEZ- 18 soils of Patuakhali, Barishal and Bhola

AEZ No.	District	Upazila	Chemical properties		
			Soil pH	Organic Carbon (%)	Total Nitrogen (%)
AEZ- 18	Patuakhali	Dumki	5.96-7.76	0.82-1.06	0.075-0.096
		Sadar	5.56-8.65	0.62-1.05	0.056-0.095
	Barishal	Gowronodi	8.14-8.44	0.51-1.01	0.05-0.155
	Bhola	Sadar	5.7-7.5	0.6-1	0.05-0.09
		Borhanuddin	5.3-7.8	0.6-1	0.05-0.09

Chemical properties of AEZ 23 (Chattogram coastal plain) soils of Chattogram and Cox's Bazar

The pH was recorded ranged from 6.46 to 8.40, OC ranged from 0.42- 0.91(%), TN ranged 0.04-0.08 (%) at Chattogram district and pH ranged from 6.13 to 7.79, OC ranged from 0.33-1.01 (%), TN varied from 0.03-0.09 (%) at Cox's Bazar District, under the AEZ 23 (Table 10, Fig. 29, Fig. 30, Fig. 31).

For AEZ-23 soil, the lowest pH (5.97) was recorded at Ramu, Cox's Bazar and the highest (8.40) pH was recorded at Sitakunda, Chattogram. The lowest OC (0.33 %) was recorded at Ramu, Cox's

Bazar and the highest OC (1.01 %) was recorded at Cox's Bazar Sadar, Cox's Bazar. Again, the lowest (0.03%) TN was recorded at Ramu, Cox's Bazar and the highest TN (0.09%) was recorded at Cox's Bazar Sadar, Cox's Bazar (Table 10, Fig. 29, Fig. 30, Fig. 31).

Table 10. Soil chemical properties of AEZ 23 (Chattogram coastal plain) soils of Chattogram and Cox's Bazar

AEZ No.	District	Upazila	Chemical properties		
			Soil pH	Organic Carbon (%)	Total Nitrogen (%)
AEZ 23	Chattogram	Sitakunda, Mirsharai	6.46-8.40 6.68-8.20	0.45-0.73 0.42-0.91	0.04-0.07 0.04-0.08
	Cox's Bazar	Ramu, Cox's Bazar Sadar	5.97-7.79 6.13-7.40	0.33-0.89 0.46-1.01	0.03-0.08 0.04-0.09

Chemical properties of AEZ 24 (Saint Martin's Coral Island) soils, Saint Martin, Cox's Bazar

In case of AEZ 24, soil pH varied from 5.6 to 7.6, OC ranged from 0.88- 1.10 (%), TN ranged 0.08-0.10 (%) at Saint Martin, Teknaf upazila of Cox's Bazar. (Table 11, Fig. 29, Fig. 30, Fig. 31). Considering AEZ-24 soil, the lowest pH was recorded 5.6 at Saint Martin's, Cox's Bazar and the highest pH was recorded 7.6 at Saint Martin, Cox's Bazar, the lowest OC was recorded 0.88 (%) at Saint Martin, Cox's Bazar and the highest OC was recorded 1.10 (%) at Saint Martin, Cox's Bazar, the lowest TN was recorded 0.08 (%) at Saint Martin's, Cox's Bazar and the highest TN was recorded 0.10 (%) at Saint Martin, Cox's Bazar (Table 11, Fig. 29, Fig. 30, Fig. 31).

Table 11. Soil chemical properties of AEZ 24 (Saint Martin's Coral Island) soils, Saint Martin, Cox's Bazar

AEZ No.	District	Upazila	Chemical properties		
			Soil pH	Organic Carbon (%)	Total Nitrogen (%)
AEZ 24	Cox's Bazar	Saint Martin, Teknaf	5.6-7.6	0.88-1.10	0.08-0.10

Chemical properties of AEZ-29 (Northern and Eastern Hills)

For AEZ 29 soil, the pH varied from 5.91 to 7.99, OC ranged from 0.13 to 1.05 (%), TN ranged from 0.039 to 0.09 (%) at Bandarban district and pH ranged from 5.05 to 6.57, OC ranged from 0.62 to 1.02 (%), TN ranged from 0.09 to 0.16 (%) at Khagrachari district, respectively, (Table 12, Fig. 29, Fig. 30, Fig. 31).

In particular, lowest soil pH (5.05) was recorded at Matiranga, Khagrachari and the highest pH (7.99) was recorded at Sadar, Bandarban, the lowest OC (0.13 %) was recorded at Sadar, Bandarban and the highest OC (1.05 %) was recorded at Bandarban Sadar, Bandarban. The lowest TN (0.09%) was recorded at Matiranga, Khagrachari and the highest TN (0.16 %) was recorded at Matiranga upazila, Khagrachari (Table 12, Fig. 29, Fig. 30, Fig. 31).

Table 12. Soil chemical properties of AEZ- 29 soils of Bandarban and Khagrachsri

AEZ No.	District	Upazila	Chemical properties		
			Soil pH	Organic Carbon (%)	Total Nitrogen (%)
AEZ- 29	Bandarban	Naikhongchari	5.91-7.43	0.43-1.01	0.039-0.092
		Sadar	6.05-7.99	0.13-1.05	0.056-0.102
	Khagrachari	Dighinala	5.13-6.24	0.64-0.98	0.1-0.15
		Matiranga	5.05-6.57	0.62-1.02	0.09-0.16

Chemical properties of AEZ 30 (Akhaura Terrace) soils of Brahmanbaria and Hobiganj district

In case of AEZ 30, soil pH ranged from 5.46 to 7.75, OC varied from 0.47 to 1.13 (%) and TN ranged 0.04 to 0.11 (%) at Brahmanbaria district. On the other hand, at Hobigonj, pH ranged from 5.54 to 7.08, OC from 0.70-1.13 (%) while TN varied 0.06-0.11 (%) (Table 13, Fig. 29, Fig. 30, Fig. 31).

Specifically, lowest pH (5.46) of soil was recorded at Akhaura, Brahmanbaria and the highest pH (8.75) was recorded at Kasba, Brahmanbaria. The lowest OC (0.47%) was recorded at Akhaura, Kasba, Brahmanbaria, and the highest OC (1.13%) was recorded both at Akhaura, Brahmanbaria and Madhabpur, Hobiganj. The lowest TN (0.04%) was recorded at Akhaura, Kasba, Brahmanbaria and the highest TN (0.11%) was observed both at Akhaura, Brahmanbaria and Madhabpur, Hobiganj, (Table 13, Fig. 29, Fig. 30, Fig. 31).

Fig. 38. Soil pH determination by glass electrode pH meter method

Fig. 39. Determination of organic carbon by wet oxidation method

Table 13. Soil chemical properties of AEZ 30 (Akhaura Terrace) soils of Brahmanbaria and Hobiganj district

AEZ No.	District	Upazila	Chemical properties		
			Soil pH	Organic Carbon (%)	Total Nitrogen (%)
AEZ 30	Brahmanbaria	Akhaura, Kasba	5.46-7.75 5.78-8.75	0.47-1.13 0.47-1.12	0.04-0.11 0.04-0.10
	Hobiganj	Madhabpur	5.54-7.08	0.70-1.13	0.06-0.11

Plate culture

Plate culture

Fig. 40. Plate culture of different media

Soil Microbial Population of Different AEZs

Microbial Population in the soils of AEZ 02 (Active Tista Floodplain)

In AEZ 2, the microbial populations varied widely from 1.0×10^5 to 8.8×10^8 for Rhizobia (R) and 1.0×10^5 to 1.4×10^8 for Bradyrhizobia (BR) along with a total bacteria (TB) count 2.0×10^5 to 6.5×10^9. However, fungus (F) population varied from 1.0×10^7 to 6.3×10^8, actinomycetes (AMs) 8.0×10^5 to 6.6×10^9, phosphate solubilizing bacteria (PSB) 1.0×10^5 to 1.26×10^9, free living bacteria (FLB) 1.0×10^5 to 5.4×10^9 cfu g^{-1} soil at Kurigram district. While at Rangpur the vaiations in populations were R 1.0×10^5 to 9.2×10^8, BR 1.0×10^5 to 1.0×10^7, Total bacteria (TB) 1.4×10^7 to 1.09×10^9, Fungus (F) 1.0×10^5 to 5.6×10^8, Actinomycetes (AMs) 1.0×10^4 to 8.0×10^7, Phosphate solubilizing bacteria (PSB) 2.0×10^5 to 1.6×10^9, Free living bacteria (FLB) 1.0×10^5 to 8.3×10^8 cfu g^{-1} soil, respectively (Table 14, Fig. 32, Fig. 33, Fig. 34, Fig. 35, Fig. 36, Fig. 37).

In case of AEZ-2 soil, the lowest populations (1.0×10^5 cfu g^{-1} soil) of Rhizobia were recorded in Fulbari, Kurigram and the highest population (9.2×10^8 cfu g^{-1} soil) was observed in Taraganj, Rangpur. Similarly, the lowest population of Bradyrhizobia were recorded 1.0×10^5 cfu g^{-1} soil at Fulbari, Kurigram and the highest population were recorded 1.4×10^8 cfu g^{-1} soil at Nagessor, Kurigram. Likewise, the lowest population of total bacteria were recorded 2.0×10^5 cfu g^{-1} soil at Fulbari, Kurigram and the highest population were recorded 1.09×10^9 cfu g^{-1} soil at Taraganj, Rangpur. On the other hand, the lowest population of fungus were recorded 1.0×10^5 cfu g^{-1} soil at Badarganj, Rangpur and the highest population were recorded 5.6×10^8 cfu g^{-1} soil at Taraganj, Rangpur. In the sameway, the lowest population of actinomycetes were recorded 1.0×10^4 cfu g^{-1} soil at Taraganj, Rangpur and the highest population were recorded 6.6×10^9 cfu g^{-1} soil at Nagessor, Kurigram. On the contrary, the lowest population of Phosphate solubilizing bacteria were recorded 1.0×10^5 cfu g^{-1} soil at Fulbari, Kurigram and the highest population were recorded 1.6×10^9 cfu g^{-1} soil at Taraganj, Rangpur. On the contrary, the lowest population of free living bacteria were recorded 1.0×10^5 cfu g^{-1} soil at Fulbari, Kurigram and the highest population were recorded 5.4×10^9 cfu g^{-1} soil at Nagessori, Kurigram (Table 14, Fig. 32, Fig. 33, Fig. 34, Fig. 35, Fig. 36, Fig. 37).

Table 14. Soil Microbial population of AEZ-2 soils of Kurigram and Rangpur

AEZ No.	**District**	**Upazila**	**Microbial population ranged (cfu/g soil)**						
			(R)	**(BR)**	**(TB)**	**(F)**	**(AMs)**	**(PSB)**	**(FLB)**
AEZ-2	Kurigram	Fulbari	1.0×10^5-8.8×10^8	1.0×10^5-6.0×10^7	2.0×10^5-1.65×10^9	1.0×10^7-9.0×10^7	1.0×10^7-2.0×10^7	1.0×10^5-1.3×10^9	1.0×10^5-6.7×10^8
		Nagessori	6.0×10^5-4.2×10^8	8×10^5-1.4×10^8	5.7×10^6-6.5×10^9	1×10^7-6.3×10^8	8×10^5-6.6×10^9	7.0×10^5-3.7×10^8	5.0×10^5-5.4×10^9
	Rangpur	Taraganj	1×10^5-9.2×10^8	3×10^5-1×10^7	1.4×10^7-1.09×10^9	3.6×10^6-5.6×10^8	1.0×10^4 -1.0×10^5	4.0×10^5-1.6×10^9	1.0×10^5-1.7×10^8
		Badarganj	6.0×10^5-7.3×10^8	1.0×10^5-1.0×10^7	1.9×10^8-8.1×10^9	1.0×10^5-4.0×10^7	4.0×10^5-8.0×10^7	2.0×10^5-3.0×10^8	5.0×10^5-8.3×10^8

R=*Rhizobium*, BR= *Bradyrhizobium*, TB=total bacteria, AMs=Actinomycetes, PSB= Phosphate solubilizing bacteria, FLB= free living N_2 fixing bacteria

Microbial Population in the soils of AEZ 06 (Lower Purnabhaba Floodplain

In AEZ 06 soil, the populations of Rhizobia (R), Bradyrhizobia (BR), Total bacteria (TB), Fungus (F), Actinomycetes (AMs), Phosphate solubilizing bacteria (PSB), Free living bacteria (FLB) were found to ranged from $1.5x10^4$ to $5.2x10^8$, 1.6×10^4 to $7.0x10^7$, $2.9x10^6$ to $1.1x10^9$, $1.0x10^4$ to $1.0x10^8$, $1.0x10^5$ to $2.8x10^8$, $1.0x10^4$ to $6.2x10^8$, $1.0x10^5$ to $2.09x10^8$ cfu g^{-1} soil at Naogoan district. But in Chapainawabganj district such variations were recorded as Rhizobia (R) from $1.0x10^5$ to $2.5x10^8$, Bradyrhizobia (BR) $1.0x10^5$ to $1.0x10^7$, Total bacteria (TB) $1.0x10^6$ to $1.50\ x10^9$, Fungus (F) $9.0x10^5$ to $1.4x10^8$, Actinomycetes (AMs) 1.2 to $5x10^7$, Phosphate solubilizing bacteria (PSB) $5.0x10^5$ to $2.6x10^8$, Free living bacteria (FLB) $1.0x10^4$ to $4.2x10^7$ cfu g^{-1} soil (Table 15, Fig. 32, Fig. 33, Fig. 34, Fig. 35, Fig. 36, Fig. 37).

In particular, for AEZ 06 soil, the lowest population of Rhizobia was recorded as 1.5×10^4 cfu g^{-1} soil at Dhamoirhat, Naogaon and the highest population were recorded 5.2×10^8 cfu g^{-1} soil at Badalgachhi, Naogaon. Similarly, the lowest population of Bradyrhizobia were recorded 1.6×10^4 cfu g^{-1} soil at Dhamoirhat, Naogaon and the highest population were recorded 5.0×10^7 cfu g^{-1} soil at Dhamoirhat, Naogaon. Likewise, the lowest population of total bacteria were recorded 2.9×10^6 cfu g^{-1} soil at Dhamoirhat, Naogaon and the highest population were recorded 1.5×10^9 cfu g^{-1} soil at Gomastapur, Chapainawabganj. On the other hand, the lowest population of fungus were recorded 1.0×10^4 cfu g^{-1} soil at Dhamoirhat, Naogaon and the highest population were recorded 1.4×10^8 cfu g^{-1} soil at Gomastapur, Chapainawabganj. In the sameway, the lowest population of actinomycetes were recorded 1.0×10^5 cfu g^{-1} soil at Dhamoirhat, Naogaon and the highest population were recorded 2.8×10^8 cfu g^{-1} soil at Dhamoirhat, Badalgachhi, Naogaon. On the contrary, the lowest population of Phosphate Solubilizing Bacteria were recorded 1.0×10^4 cfu g^{-1} soil at Dhamoirhat, Naogaon and the highest population were recorded 6.2×10^8 cfu g^{-1} soil at Dhamoirhat, Badalgachhi, Naogaon. On the contrary, the lowest population of free living bacteria was recorded 1.0×10^4 cfu g^{-1} soil at Gomastapur, Chapainawabganj and the highest population was recorded as 2.09×10^8 cfu g^{-1} soil at Dhamoirhat, Naogaon (Table 15, Fig. 32, Fig. 33, Fig. 34, Fig. 35, Fig. 36, Fig. 37).

Table 15. Soil Microbial population of AEZ 06 (Lower Purnabhaba Floodplain) soils of Naogaon and Chapainawabganj

AEZ No.	District	Upazila	Microbial population ranged (cfu/g soil)						
			(R)	(BR)	(TB)	(F)	(AMs)	(PSB)	(FLB)
AEZ 06	Naogaon	Badalgachhi	1.3×10^5-5.2×10^8	2×10^5 -1×10^7	5.5×10^6-1.12×10^9	2×10^5-1.0×10^8	2×10^5-2.8×10^8	1.0×10^5-6.2×10^8	1.2×10^6-1.1×10^8
		Dhamoirhat	1.5×10^4-3.5×10^8	1.6×10^4-5×10^7	2.9×10^6-1.2×10^8	1×10^4-1.0×10^8	1×10^5-2.8×10^8	1.0×10^4-6.2×10^8	1.0×10^5-2.09×10^8
	Chapainawabganj	Gomastapur	1×10^5-2.5×10^8	1×10^5-1×10^7	1.0×10^6-1.5×10^9	9×10^5-1.4×10^8	1.2×10^5-5.0×10^7	5.0×10^5-2.6×10^8	1.0×10^4-4.2×10^7

R=*Rhizobium*, BR= *Bradyrhizobium*, TB=total bacteria, AMs=Actinomycetes, PSB= Phosphate solubilizing bacteria, FLB= free living N_2 fixing bacteria

Microbial population in the soils of AEZ 13 (Ganges Tidal Floodplain)

The population of Rhizobia (R) were found to ranged from $5.0x10^3$ to $1.8x10^8$, Bradyrhizobia (BR) $3.0x10^4$ to $5.0x10^7$, Total bacteria (TB) $2.0x10^4$ to $3.0x10^8$, Fungus (F) $1.2x10^3$ to $2.0x10^7$, Actinomycetes (AMs) $1.0x10^4$ to $1.0x10^8$, Phosphate solubilizing bacteria (PSB) $1.0x10^3$ to $1.1x10^7$, Free living bacteria (FLB) $1.0x10^5$ to $2.0x10^7$cfu g^{-1} soil at Khulna district. For Satkhira, Rhizobia (R) ranged from $4.0x10^3$ to $5.0x10^5$, Bradyrhizobia (BR) $1.0x10^5$ to $7.7x10^8$, Total bacteria (TB) $1.0x10^5$ to $3.74\ x10^9$, Fungus (F) $1.0x10^4$ to $1.3x10^8$, Actinomycetes (AMs) $1.3x10^4$ to $1.1x10^8$, Phosphate solubilizing bacteria (PSB) $1.0x10^3$ to $1.44x10^9$, Free living bacteria (FLB) $1.0x10^4$ to $3.8x10^8$ cfu g^{-1} soil (Table 16, Fig. 32, Fig. 33, Fig. 34, Fig. 35, Fig. 36, Fig. 37).

According to results of AEZ 13 soils, the lowest population of Rhizobia was recorded as $4.0\ x10^3$ cfu g^{-1} soil at Kaliganj, Satkhira and the highest population ($1.8x10^8$ cfu g^{-1} soil) was recorded at Batiaghata, Khulna. Similarly, the lowest population of Bradyrhizobia was recorded as $3.0x10^4$ cfu g^{-1} soil at Dacope, Khulna and the highest population was recorded $7.7x10^8$ cfu g^{-1} soil at Kaliganj, Satkhira. Likewise, the lowest population of total bacteria were recorded $2.0x10^4$ cfu g^{-1} soil at Batiaghata, Khulna and the highest population were recorded $3.74\ x10^9$ cfu g^{-1} soil at Kaliganj, Satkhira. On the other hand, the lowest population of fungus were recorded $1.2x10^3$ cfu g^{-1} soil at Batiaghata, Khulna and the highest population were recorded $1.3x10^8$ cfu g^{-1} soil at Kaliganj, Satkhira. In the sameway, the lowest population of actinomycetes were recorded $1x10^4$ cfu g^{-1} soil at Dacope, Khulna and the highest population were recorded $1.1x10^8$ cfu g^{-1} soil at Kaliganj, Satkhira. On the contrary, the lowest population of Phosphate Solubilizing Bacteria were recorded $1x10^3$ cfu g^{-1} soil at Shyamnagar, Satkhira and Batiaghata, Khulna and the highest population were recorded $1.44x10^9$ cfu g^{-1} soil at Shyamnagar, Satkhira. On the contrary, the lowest population of free-living bacteria were recorded $1.0x10^4$ cfu g^{-1} soil at Kaliganj, Satkhira and the highest population were recorded $3.8x10^8$ cfu g^{-1} soil at Kaliganj, Satkhira (Table 16, Fig. 32, Fig. 33, Fig. 34, Fig. 35, Fig. 36, Fig. 37).

Table 16. Soil Microbial population of AEZ 13 (Ganges Tidal Floodplain)

AEZ No.	District	Upazila	Microbial population ranged (cfu/g soil)						
			(R)	(BR)	(TB)	(F)	(AMs)	(PSB)	(FLB)
AEZ 13	Khulna	Dacope	5.0×10^3-2.0×10^7	3.0×10^4-5.0×10^7	1.0×10^5-1.7×10^8	2.0×10^4-2.0×10^7	1×10^4-1.0×10^8	1.0×10^5-1.0×10^6	1.0×10^5-2.0×10^7
		Batiaghata	2.0×10^5-1.8×10^8	2.0×10^5 – 5.0×10^7	2.0×10^4 - 3.0×10^8	1.2×10^3-1.0×10^7	1.4×10^5-1.0×10^8	1.0×10^3 - 1.1×10^7	2.0×10^5-2.0×10^7
	Satkhira	Kaliganj	4.0×10^3-3.0×10^5	3×10^5-7.7×10^8	1.0×10^7-3.7×10^9	2.0×10^5-1.3×10^8	1.0×10^5-1.1×10^8	6.0×10^5-1.1×10^9	1.0×10^4-3.8×10^8
		Shyamnagar	2.0×10^5-5.0×10^5	1.0×10^5-2.7×10^8	1.0×10^5-1.5×10^9	1.0×10^4-4.0×10^7	1.3×10^4-1.0×10^7	1.0×10^3-1.4×10^9	1.0×10^5-1.0×10^7

R=*Rhizobium*, BR= *Bradyrhizobium*, TB=total bacteria, AMs=Actinomycetes, PSB= Phosphate solubilizing bacteria, FLB= free living N_2 fixing bacteria

Microbial population in the soils of AEZ-18 (Young Meghna Estuarine Floodplain)

In AEZ 18, the microbial populations found to be ranged from Rhizobia (R) 6.0×10^3 to 2.4×10^8 , Bradyrhizobia (BR) 2×10^4 to 2×10^6 , Total bacteria (TB) 3×10^5 to 2.5×10^8, Fungus (F) 2.0×10^4 to 7.0×10^7, Actinomycetes (AMs) 4.0×10^3 to 3.0×10^7, Phosphate solubilizing bacteria (PSB) 1.0×10^5 to 1.0×10^7 , Free living bacteria (FLB) 1.0×10^5 to 5.0×10^6 cfu g^{-1} soil at Patuakhali district, and Rhizobia (R) 1.0×10^5 to 1.0×10^8, Bradyrhizobia (BR) 1.0×10^5 to 2.8×10^8, Total bacteria (TB) 6.0×10^5 to 3.85×10^9, Fungus (F) 1.0×10^5 to 5.1×10^8, Actinomycetes (AMs) 1.0×10^5 to 2.0×10^7, Phosphate solubilizing bacteria (PSB) 2.0×10^5 to 2.0×10^7 , FLB 1.0×10^5 to 3.9×10^8 cfu g^{-1} soil at Barishal district, and R 1.0×10^5 to 7.7×10^8, Bradyrhizobia (BR) 1.0×10^5 to 3.3×10^8, Total bacteria (TB) 4.2×10^6 to 6.0×10^9, Fungus (F) 1.0×10^5 to 4.7×10^8 , AMs 1.0×10^5 to 2.0×10^7, Phosphate solubilizing bacteria (PSB) 3.0×10^5 to 1.3×10^8 , Free living bacteria (FLB) 3.0×10^5 to 1.21×10^9 cfu g^{-1} soil at Bhola district, respectively, (Table 17, Fig. 32, Fig. 33, Fig. 34, Fig. 35, Fig. 36, Fig. 37).

As per laboratory results of the present study, the soils of AEZ-18 showed the lowest population of Rhizobia (6.0×10^3 cfu g^{-1} soil) at Sadar, Patuakhali and the highest population were recorded as7.7×10^8cfu g^{-1} soil at Borhanuddin, Bhola. Similarly, the lowest population of Bradyrhizobia were recorded 2.0×10^4 cfu g^{-1} soil at Sadar, Patuakhali and the highest population were recorded 3.3×10^8 cfu g^{-1} soil at Borhanuddin, Bhola Likewise, the lowest population of total bacteria were recorded 3.0×10^5 cfu g^{-1} soil at Dumki, Patuakhali and the highest population were recorded 6.0×10^9 cfu g^{-1} soil at Borhanuddin, Bhola. On the other hand, the lowest population of fungus were recorded 2.0×10^4 cfu g^{-1} soil at Sadar, Patuakhali and the highest population were recorded 4.7×10^8 cfu g^{-1} soil at Borhanuddin, Bhola. In the sameway, the lowest population of actinomycetes were recorded 4.0×10^3 cfu g^{-1} soil at Sadar, Patuakhali and the highest population were recorded 3.0×10^7 cfu g^{-1} soil at Sadar, Patuakhali. On the contrary, the lowest population of Phosphate Solubilizing Bacteria were recorded 1.0×10^5 cfu g^{-1} soil at Dumki, Patuakhali and the highest population were recorded 1.3×10^8 cfu g^{-1} soil at Borhanuddin, Bhola. On the contrary, the lowest population of free-living bacteria were recorded 1.0×10^5 cfu g^{-1} soil at Dumki, Patuakhali and the highest population were recorded 1.21×10^9 cfu g^{-1} soil at Borhanuddin, Bhola. (Table 17, Fig. 32, Fig. 33, Fig. 34, Fig. 35, Fig. 36, Fig. 37)

Table 17. Soil Microbial populations of AEZ-18 (Young Meghna Estuarine Floodplain) soils

AEZ No.	**District**	**Upazila**	**Microbial population ranged (cfu/g soil)**						
			(R)	**(BR)**	**(TB)**	**(F)**	**(AMs)**	**(PSB)**	**(FLB)**
AEZ-18	Patuakhali	Dumki	2.0×10^4-2.4×10^8	1.0×10^5-2.0×10^6	3.0×10^5-2.5×10^8	1.0×10^6-7.0×10^7	4.0×10^5-2.0×10^7	1.0×10^5-1.5×10^7	1.0×10^5-5.0×10^6
		Sadar	6.0×10^3-5.0×10^7	2.0×10^4-2.0×10^6	3.0×10^6–2.2×10^8	2.0×10^4 -5×10^7	4.0×10^3-3.0×10^7	3.0×10^5-1.0×10^7	5.0×10^5-1.0×10^6
	Barishal	Gowronodi	1.0×10^5-1.0×10^8	1.0×10^5-2.8×10^8	6.0×10^5-3.5×10^9	1.0×10^5-5.1×10^8	1.0×10^5-2.0×10^7	2.0×10^5-2.0×10^7	1.0×10^5-3.9×10^8
	Bhola	Sadar	1.0×10^5-2.3×10^8	5.0×10^5-2.8×10^8	6.4×10^6-4.8×10^8	1.0×10^5-2.0×10^7	1.0×10^5-2.0×10^7	3.0×10^5-1.0×10^7	8.0×10^5-2.2×10^8
		Borhanuddin	9.8×10^6-7.7×10^8	1.0×10^5-3.3×10^8	4.2×10^6-6.0×10^9	9.0×10^5-4.7×10^8	1.0×10^5 -1.0×10^7	3.0×10^7-1.3×10^8	3.0×10^5-1.2×10^9

R=*Rhizobium*, BR= *Bradyrhizobium*, TB=total bacteria, AMs=Actinomycetes, PSB= Phosphate solubilizing bacteria, FLB= free living N_2 fixing bacteria

Microbial population in the soils of AEZ 23 (Chattogram Coastal Plain)

In AEZ 23, the population of Rhizobia (R) ranged from $1.0x10^4$ to $4.4x10^8$, Bradyrhizobia (BR) $3.0x10^4$ to $2.0x10^7$, Total bacteria (TB) $3.0x10^4$ to $1.52x10^9$. Fungal (F) population of this AEZ specially in Chattogram district varied from $1.0x10^5$ to $3.0x10^7$ whereas Actinomycetes (AMs) $5.0x10^3$ to $5.0x10^7$, Phosphate solubilizing bacteria (PSB) $1.0x10^5$ to $3.6x10^8$, Free living bacteria (FLB) $3.0x10^4$ to $8.5x10^8$ cfu g^{-1} soil. Again at Cox's Bazar district, Rhizobia (R) were found to be ranged from $1.2\ x10^4$ to $9.3x10^8$, Bradyrhizobia (BR) $1.0x10^5$ to $1.05x10^9$, Total bacteria (TB) $1.0x10^5$ to $1.04\ x10^8$, Fungus (F) $1x10^4$ to $2.1x10^8$, Actinomycetes (AMs) $1.0x10^5$ to $1.8x10^7$, Phosphate solubilizing bacteria (PSB) $1.0x10^5$ to $7.4x10^8$, Free living bacteria (FLB) $1.0x10^5$ to $6.0x10^8$ cfu g^{-1} soil. As per the above results of AEZ 23 soils, the lowest population of Rhizobia were recorded as $1.0x10^4$ cfu g^{-1} soil at Mirsharai, Chattogram and the highest population were recorded $9.3x10^8$ cfu g^{-1} soil at Ramu, Cox's Bazar. Similarly, the lowest population of Bradyrhizobia were recorded $3.0x10^4$ cfu g^{-1} soil at Sitakunda, Chattogram and the highest population were recorded $1.05x10^9$ cfu g^{-1} soil at Ramu, Cox's Bazar. Likewise, the lowest population of total bacteria were recorded $3.0x10^4$ cfu g^{-1} soil at Mirsharai, Chattogram and the highest population were recorded $1.52x10^9$ cfu g^{-1} soil at Sitakunda, Chattogram. On the other hand, the lowest populations of fungus were recorded $1.0x10^4$ cfu g^{-1} soil at Ramu, Cox's Bazar and the highest populations ($2.1x10^8$ cfu g^{-1} soil) were also recorded at Ramu, Cox's Bazar. In the sameway, the lowest population of actinomycetes were recorded $5.0x10^3$ cfu g^{-1} soil at Mirsharai, Chattogram and the highest population were recorded $5.0x10^7$ cfu g^{-1} soil at Sitakunda, Chattogram. On the contrary, the lowest population of Phosphate Solubilizing Bacteria were recorded $1.0x10^5$ cfu g^{-1} soil at Mirsharai, Chattogram and Cox's Bazar Sadar, Cox's Bazar and the highest population were recorded $7.4x10^8$ cfu g^{-1} soil at Ramu, Cox's Bazar. However, the lowest populations of free-living bacteria were recorded as $3.0x10^4$ cfu g^{-1} soil at Sitakunda, Chattogram and the highest ($8.5x10^8$ cfu g^{-1} soil) populations were also found at Sitakunda, Chattogram (Table 18, Fig. 32, Fig. 33, Fig. 34, Fig. 35, Fig. 36, Fig. 37. Fig. 41).

Table **18.** Soil Microbial population of AEZ 23 (Chattogram Coastal Plain)

AEZ No.	**District**	**Upazila**	**Microbial population ranged (cfu/g soil)**						
			(R)	**(BR)**	**(TB)**	**(F)**	**(AMs)**	**(PSB)**	**(FLB)**
AEZ 23	Chattogram	Sitakunda	2.4×10^6-4.4×10^8	3.0×10^4-2.0×10^7	4.0×10^5-1.5×10^9	1.0×10^5-3.0×10^7	2.0×10^5-5.0×10^7	1.3×10^5-3.6×10^8	3.0×10^4-8.5×10^8
		Mirsharai	1.0×10^4-3.5×10^8	2.0×10^5-2×10^7	3.4×10^4-7.9×10^8	3.0×10^5-3.0×10^7	5.0×10^3-2.0×10^7	1.0×10^5-5.0×10^7	1.0×10^5-1.0×10^7
	Cox's Bazar	Ramu	3.0×10^5-9.3×10^8	1.3×10^5-1.1×10^9	1.4×10^5-1.4×10^9	1.0×10^4-2.1×10^8	3.0×10^5-6.0×10^6	1.5×10^5-7.4×10^8	3.0×10^5-6.0×10^8
		Cox's Bazar Sadar	1.2×10^4-4.6×10^8	1.0×10^5-1.0×10^7	3.0×10^5-5.0×10^6	1.0×10^5-5.0×10^6	1.0×10^5-1.8×10^7	1.0×10^5-2.0×10^7	1.0×10^5-5.3×10^8

R=*Rhizobium*, BR= *Bradyrhizobium*, TB=total bacteria, AMs=Actinomycetes, PSB= Phosphate solubilizing bacteria, FLB= free living N_2 fixing bacteria

Microbial population in the soils of AEZ 24 (Saint Martin's Coral Island)

Similarly, the populations of Rhizobia (R) were recorded to be ranged from $1.3x10^5$ to $9.0x10^7$, Bradyrhizobia (BR) $1.0x10^5$ to $4.0x10^6$, Total bacteria (TB) $1.0x10^6$ to $2.3x10^8$. The populations fungus (F) varied from $9.0x10^5$ to $2.0x10^7$, Actinomycetes (AMs) $1.0x10^5$ to $1.0x10^7$, Phosphate solubilizing bacteria (PSB) $5.0x10^3$ to $2.2x10^7$, Free living bacteria (FLB) $2.1x10^4$ to $4.0x10^6$ cfu g^{-1} soil in the collected samples of Saint Martin under AEZ 24 (Table 19, Fig. 32, Fig. 33, Fig. 34, Fig. 35, Fig. 36, Fig. 37).

Specifically, for the soils of AEZ 24, the lowest population of Rhizobia was observed as $1.3x10^5$ cfu g^{-1} soil and the highest population was recorded as $9.0x10^7$ cfu g^{-1} soil. Similarly, the lowest population of Bradyrhizobia was recorded as $1.0x10^5$ cfu g^{-1} soil and the highest population were recorded as $4.0x10^6$ cfu g^{-1} soil. Likewise, the lowest population of total bacteria were recorded $1.0x10^6$ cfu g^{-1} soil and the highest population were recorded $2.3x10^8$ cfu g^{-1} soil. On the other hand, the lowest population of fungus were recorded $9.0x10^5$ cfu g^{-1} soil and the highest population were recorded $2.0x10^7$ cfu g^{-1} soil. In case of actinomycetes, the lowest population of was recorded as $1.0x10^5$ cfu g^{-1} soil and the highest population was recorded $1.0x10^7$ cfu g^{-1} soil. Again, the lowest population of Phosphate Solubilizing Bacteria was recorded $5.0x10^3$ cfu g^{-1} soil and the highest population was recorded $2.2x10^7$ cfu g^{-1} soil. However, the lowest population of free-living bacteria was recorded as $2.1x10^4$ cfu g^{-1} soil and the highest population was $4.0x10^6$ cfu g^{-1} soil (Table 19, Fig. 32, Fig. 33, Fig. 34, Fig. 35, Fig. 36, Fig. 37).

Table 19. Soil Microbial population of AEZ 24 (Saint Martin's Coral Island)

AEZ No.	**District**	**Upazila**	**Microbial population ranged (cfu/g soil)**						
AEZ 24			(R)	**(BR)**	**(TB)**	**(F)**	**(AMs)**	**(PSB)**	**(FLB)**
	Cox's Bazar	Teknaf	1.3×10^5-2.5×10^8	1.0×10^5-1.0×10^7	1.0×10^6-1.5×10^9	9.0×10^5-1.4×10^8	1.0×10^5-5.0×10^7	5.0×10^3-2.6×10^8	2.1×10^4-4.2×10^7

R=*Rhizobium*, BR= *Bradyrhizobium*, TB=total bacteria, AMs=Actinomycetes, PSB= Phosphate solubilizing bacteria, FLB= free living N_2 fixing bacteria

Microbial population in the soils of AEZ-29 (Northern and Eastern Hills)

In case of AEZ 29, the microbial populations varied from Rhizobia (R) 1.0×10^5 to 1.66×10^9, Bradyrhizobia (BR) 1.0×10^5 to 8.0×10^6, Total bacteria (TB) 5.0×10^5 to 1.22×10^8, Fungus (F) 2.0×10^5 to 3.8×10^7, Actinomycetes (AMs) 1.0×10^5 to 8.9×10^7, Phosphate solubilizing bacteria (PSB) 1.0×10^5 to 2.2×10^7, Free living bacteria (FLB) 2.0×10^5 to 7.3×10^8 cfu g^{-1} soil at Bandarban district. But such variations for Khagrachari district observed as Rhizobia (R) 1.0×10^5 to 2.1×10^8 , Bradyrhizobia (BR) 1.0×10^5 to 3.0×10^7 , Total bacteria (TB) 6.0×10^5 to 2.22×10^9, Fungus (F) 1.0×10^5 to 1.4×10^8, Actinomycetes (AMs) 1.0×10^5 to 6.3×10^8, Phosphate solubilizing bacteria (PSB) 3.0×10^5 to 1.22×10^9 , Free living bacteria (FLB) 1.0×10^5 to 1.08×10^9 cfu g^{-1} soil (Table 20, Fig. 32, Fig. 33, Fig. 34, Fig. 35, Fig. 36, Fig. 37).

Specifically, the lowest population of Rhizobia was recorded to be 1.0×10^5 cfu g^{-1} soil at Naikhongchari, Bandarban and the highest population (1.66×10^9 cfu g^{-1} soil) was noticed at Naikhongsori, Bandarban. Similarly, the lowest (1.0×10^5 cfu g^{-1} soil) population of Bradyrhizobia was recorded at Naikhongchari, Bandarban and the highest (3.0×10^7 cfu g^{-1} soil) population was found at Matiranga, Khagrachari. Likewise, the lowest (5×10^5 cfu g^{-1} soil) population of total bacteria was recorded at Naikhongsori, Bandarban and the highest (2.22×10^9 cfu g^{-1} soil) population was recorded at Dighinala, Khagrachari. On the other hand, the lowest (1.0×10^5 cfu g^{-1} soil) population of fungus was recorded at Dighinala, Khagrachari and the highest (1.4×10^8 cfu g^{-1} soil) population was recorded at Dighinala, Khagrachari. In case of actinomycetes, the lowest (1.0×10^5 cfu g^{-1} soil) population was recorded at Naikhongchari, Bandarban and the highest (6.3×10^8 cfu g^{-1} soil) population was recorded at Matiranga, Khagrachari. Again, the lowest (1.0×10^5 cfu g^{-1} soil) population of Phosphate Solubilizing Bacteria was recorded at Naikhongsori, Bandarban and the highest (1.22×10^9 cfu g^{-1} soil) population was recorded at Matiranga, Khagrachari. But the lowest (1.0×10^5 cfu g^{-1} soil) population of free-living bacteria was recorded at Dighinala, Khagrachari while the highest (1.08×10^9 cfu g^{-1} soil) population was recorded at Matiranga, Khagrachari (Table 20, Fig. 32, Fig. 33, Fig. 34, Fig. 35, Fig. 36, Fig. 37).

Table 20. Soil Microbial population of AEZ-29 soils of Bandarban and Khagrachari

AEZ No.	**District**	**Upazila**	**Microbial population ranged (cfu/g soil)**						
			(R)	**(BR)**	**(TB)**	**(F)**	**(AMs)**	**(PSB)**	**(FLB)**
AEZ-29	Bandarban	Naikhongchari	1.0×10^5-1.6×10^9	1.0×10^5-3.0×10^6	5.0×10^5-3.9×10^7	5.0×10^5-3.8×10^7	1.0×10^5-8.9×10^7	1.0×10^5-4.0×10^6	6.0×10^5-6.3×10^8
		Sadar	8.0×10^5-6.4×10^8	1.0×10^5-8.0×10^6	4.1×10^5-1.2×10^8	2.0×10^5-2.5×10^7	2.0×10^5-5.0×10^7	1.0×10^5-2.2×10^7	2.0×10^5-7.3×10^8
	Khagrachari	Dighinala	1.0×10^5-2.1×10^8	2.0×10^5-1.0×10^7	6.0×10^7-2.2×10^9	1.0×10^5-1.4×10^8	1.0×10^5-3.2×10^8	3.0×10^5-9.0×10^7	1.0×10^5-1.4×10^8
		Matiranga	1.0×10^5-1.3×10^8	1.0×10^5-3.0×10^7	6.0×10^5-8.9×10^9	1.0×10^5-3.0×10^7	1.0×10^5-6.3×10^8	7.0×10^5-1.2×10^9	2.9×10^6-1.1×10^9

R=*Rhizobium*, BR= *Bradyrhizobium*, TB=total bacteria, AMs=Actinomycetes, PSB= Phosphatesolubilizing bacteria, FLB= free living N_2 fixing bacteria

Microbial population in the soils of AEZ 30 (Akhaura Terrace)

In AEZ 30, the population of Rhizobia (R) was found to be ranged from 1.5 $x10^4$ to $1.0x10^8$, Bradyrhizobia (BR) ranged from $1.0x10^5$ to $4.9x10^8$ cfu g^{-1} soil, Total bacteria (TB) ranged from $1.2x10^6$ to $1.72x10^8$ cfu g^{-1} soil, Fungus (F) $6.0x10^5$ to $1.1x10^7$, Actinomycetes (AMs) $1.0x10^4$ to $8.0x10^8$, Phosphate solubilizing bacteria (PSB) $2.0x10^3$ to $1.7x10^8$, Free living bacteria (FLB) $3.0x10^4$ to $6.7x10^8$ cfu g^{-1} soil at Brahmanbaria district. Such vaiations in Hobigonj district recorded to be varied from Rhizobia (R) 1.0 $x10^5$ to $2.1x10^8$, Bradyrhizobia (BR) $2.0x10^4$ to $6.8x10^8$, Total bacteria (TB) $2.0x10^6$ to 2.68 $x10^9$, Fungus (F) $1.0x10^5$ to $1.0x10^7$, Actinomycetes (AMs) $1.0x10^5$ to $2.0x10^7$, Phosphate solubilizing bacteria (PSB) $1.0x10^5$ to $3.0x10^7$, Free living bacteria (FLB) $4.0x10^5$ to $6.4x10^8$ cfu g^{-1} soil (Table 21, Fig. 32, Fig. 33, Fig. 34, Fig. 35, Fig. 36, Fig. 37. Fig. 41).

As per the results of AEZ 30, the lowest (1.5 $x10^4$ cfu g^{-1} soil) population of Rhizobia was recorded at Akhaura, Brahmanbaria while the highest ($2.1x10^8$ cfu g^{-1} soil) population was observed at Madhabpur, Hobiganj. Similarly, the lowest ($2.0x10^4$ cfu g^{-1} soil) population of Bradyrhizobia was recorded at Madhabpur, Hobiganj and the highest ($6.8x10^8$ cfu g^{-1} soil) population was recorded at Madhabpur, Hobiganj. Likewise, the lowest ($1.2x10^6$ cfu g^{-1} soil) population of total bacteria was observed at Akhaura, Kasba, Brahmanbaria and the highest (2.68 $x10^9$ cfu g^{-1} soil) population was recorded at Madhabpur, Hobiganj. On the other hand, the lowest ($1.0x10^5$ cfu g^{-1} soil) population of fungus was recorded at Madhabpur, Hobiganj and the highest ($1.1x10^7$ cfu g^{-1} soil) population was recorded at Kasba, Brahmanbaria. Similarly, the lowest ($1.0x10^4$ cfu g^{-1} soil) population of actinomycetes was recorded at Akhaura, Brahmanbaria and the highest (8.0×10^8 cfu g^{-1} soil) population was recorded at Akhaura, Brahmanbaria. Incase of Phosphate Solubilizing Bacteria, the lowest ($2.0x10^3$ cfu g^{-1} soil) population was recorded at Kasba, Brahmanbaria while the highest ($1.7x10^8$ cfu g^{-1} soil) population were recorded at Akhaura, Brahmanbaria. Again, the lowest ($3.0x10^4$ cfu g^{-1} soil) population of free living bacteria was recorded at Kasba, Brahmanbaria and the highest (6.7×10^8 cfu g^{-1} soil) population was recorded at Akhaura, Brahmanbaria (Table 21, Fig. 32, Fig. 33, Fig. 34, Fig. 35, Fig. 36, Fig. 37. Fig.41).

Table 21. Soil Microbial population of AEZ 30 (Akhaura Terrace) soils of Brahmanbaria and Hobiganj district

AEZ No.	**District**	**Upazila**	**Microbial population ranged (cfu/g soil)**						
			(R)	**(BR)**	**(TB)**	**(F)**	**(AMs)**	**(PSB)**	**(FLB)**
AEZ 30	Brahmanbaria	Akhaura	1.5×10^{4}-1.0×10^{8}	1.0×10^{5}-4.9×10^{8}	1.2×10^{6}-1.7×10^{8}	6.0×10^{5}-8.0×10^{6}	1.0×10^{4}-8.0×10^{8}	1.0×10^{4}-1.7×10^{8}	1.0×10^{5}-6.7×10^{8}
		Kasba	4.0×10^{5}-4.0×10^{7}	1.2×10^{5}-1.0×10^{8}	1.2×10^{6}-1.7×10^{7}	2.0×10^{6}-1.1×10^{7}	1.0×10^{5}-1.8×10^{8}	2.0×10^{3}-2.0×10^{6}	3.0×10^{4}-3.0×10^{7}
	Hobiganj	Madhabpur	1.0×10^{5}-2.1×10^{8}	2.0×10^{4}-6.8×10^{8}	2.0×10^{6}-2.7×10^{9}	1.0×10^{5}-1.0×10^{7}	1.0×10^{5}-2.0×10^{7}	1.0×10^{5}-3.0×10^{7}	4.0×10^{5}-6.4×10^{8}

R=*Rhizobium*, BR= *Bradyrhizobium*, TB=total bacteria, AMs=Actinomycetes, PSB= Phosphate solubilizing bacteria, FLB= free living N_2 fixing bacteria

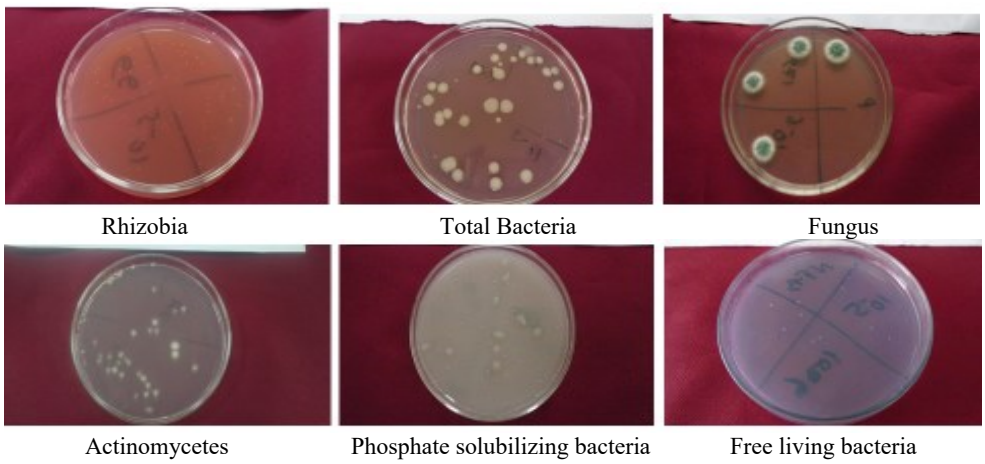


Fig. 41. Soil Microbial Population counting plate.

Table 22. Soil Textural class of different AEZs

AEZ No.	**Texture**
2 (Active Tista Floodplain) soils of Kurigram and Rangpur	Loam, Sandy Loam, Loamy Sand
6 (Lower Purnabhaba Floodplain) soils of Naogaon and Chapainawabganj	Sandy Loam, Loam, Loamy Sand, Sandy Clay Loam, Clay Loam
13 (Ganges Tidal Floodplain) soils of Khulna, Satkhira, Patuakhali and Barishal	Clay Loam, Loam, Sandy Loam, Sandy Clay Loam
18 (Young Meghna Estuarine Floodplain) soils of Patuakhali, Barishal and Bhola	Clay loam, Loam, Sandy Loam, Sandy Clay Loam
23 (Chattogram coastal plain) soils of Chattogram	Clay Loam, Loam, Sandy Loam, Sand, Loamy Sand
24 (Saint Martin's Coral Island) soils, Saint Martin, Cox's Bazar	Loamy Sand, Sand
29 (Northern and Eastern Hills) mostly hill districts	Sand, Sandy clay loam, Loam, Loamy Sand, Sandy Loam
30 (Akhaura Terrace) soils of Brahmanbaria and Hobiganj district of Bangladesh	Loamy Sand, Sandy Loam, Clay Loam, Loam, Sandy Clay Loam, Clay

Soil Textural Class:

Soil Texture was determined for the collected 310 samples. Soil Texture were determined by Hydrometer method and textural class of soil using Marshall's triangle.

Results of soil particle analysis revealed that major texture of the collected soils found to be Loam, Sandy Loam, Loamy Sand and Clay Loam (Table 22, Fig. 42, Fig. 43).

In particular, the soil texture of AEZ 06 appeared to be Sandy Loam, Loam, Loamy Sand, Sandy Clay Loam, and Clay Loam (Table 22). In case of AEZ 13, soil texture estimated to be Clay Loam, Loam, Sandy Loam and Sandy Clay Loam. Soil Texture of AEZ 18 found to be Clay loam, Loam, Sandy Loam, and Sandy Clay Loam. Collected soils of AEZ 23 represented Clay Loam, Loam, Sandy Loam, Sand and Loamy Sand texture while the Soil Texture of AEZ 24 calculated to be Loamy Sand and Sand. Incase of hill soils of AEZ 29, the major textural class was found to be Sand, Loam, Loamy Sand and Sandy Loam. However, soil textural classes of AEZ 30 were Loamy Sand, Sandy Loam, Clay Loam, Loam, Sandy Clay Loam and Clay (Table 22, Fig. 42, Fig. 43).

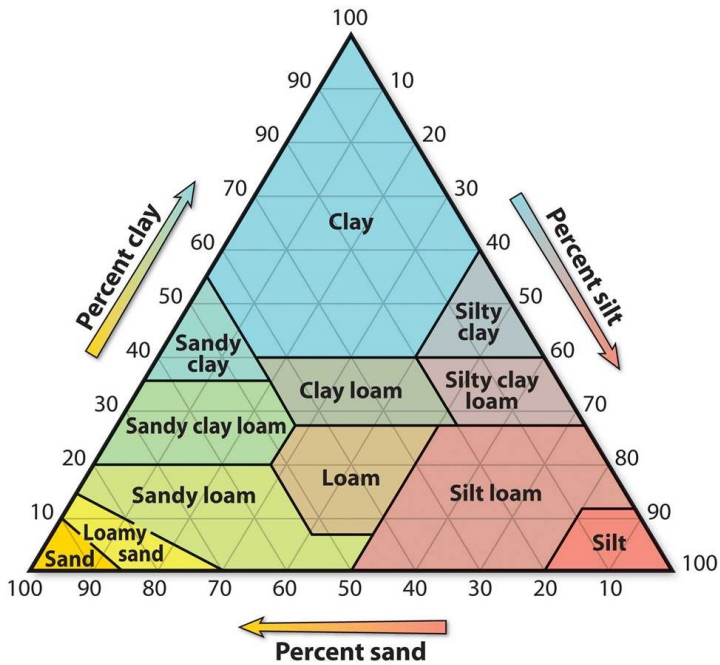
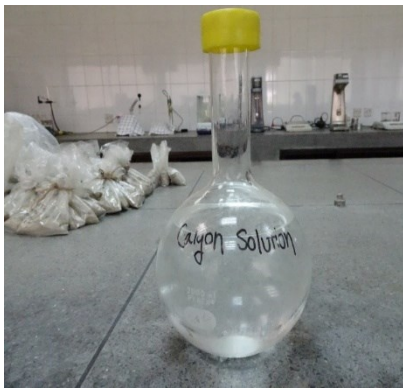


Fig. 42. Marshall's Texture Triangle.

Electric Stirrer

Stirring of soil water suspension



Calgon solution used as dispersing agents


Hydrometer reading was in progress


Blank hydrometer reading

Fig. 43. Determination of soil texture by hydrometer method

Characterization of N- fixing and Plant Growth Promoting Bacteria Isolated from Roots and Rhizosphere Soils

Morphology and biochemical traits of *Rhizobium* isolates

A total of 20 bacteria (isolates from groundnut and lentil root nodules) were collected from different AEZs of Bangladesh (Table 23, Table 24). The bacteria were characterized following the standard microbiological and biochemical methods. The morphology and gram staining of the bacteria were investigated. The biochemical characteristics such as congo red and gram staining were investigated. The cells of *Rhizobium* isolates were examined under stereo microscope and found that the cells were rod shape and motile. The isolates absorbed counter stain as they were gram negative bacteria. Aung., (2020) stated that *Rhizobium* was gram negative, rod shaped and motile which was in line with the present study. The isolates were observed as the lacking of the ability to absorb congo red from YEMA medium containing this dye where colonies were colorless white or very faintly pink colonies which is in agreement with the findings of Mondal *et al*., (2016). Congo red was thought to form colored colloidal complex with ions on the cell surface, the colonies absorbed little dye and remained colorless or became slightly pink after 2 days of incubation which proved all colonies belonged to *Rhizobium*. By determining bacterial plate growth activity and study of overall morphological characteristics, ten well-characterized bacteria were selected for further studies (Table 23, Table 24, Fig. 44, fig. 45).

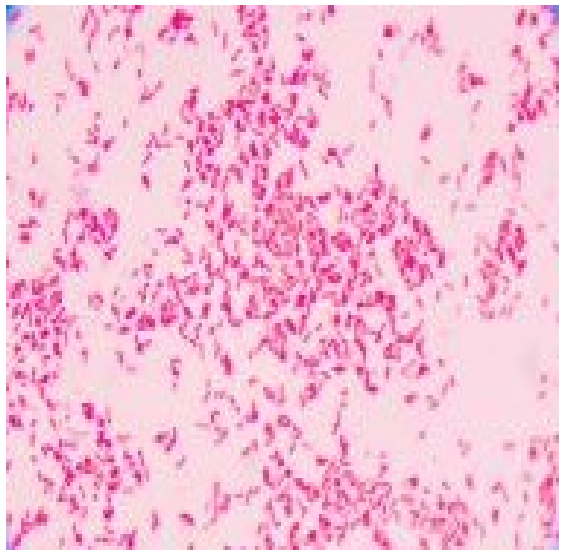
Findings of motility test

The motility test declared that all of the bacteria were gram-negative because they had flagella which were essentially required for their movement (Table 23, Table 24).

Gram staining test findings

In case of gram-negative bacteria, the cell wall also takes up the crystal violet-iodine complex but due to the thin layer of peptidoglycan and a thick outer layer which might have formed of lipids, crystal violet-iodine complex gets washed off. When they are exposed to alcohol, the decolorizer dissolves the lipids in the cell walls, which allows the crystal violet-iodine complex to leach out of the cells. Then when again stained with safranin, they take the stain and appear pink color. The bacteria in the sample were pink when the stain reacted with them. Isolated ten bacterial strains showed gram negative under stereo-microscope because of their pink in color (Table 23, Table 24, Fig. 44.).

a. Stereo-microscopic observation

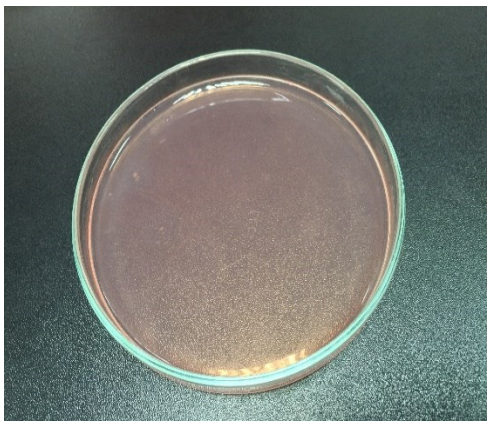


b. *Rhizobium* bacterial colony

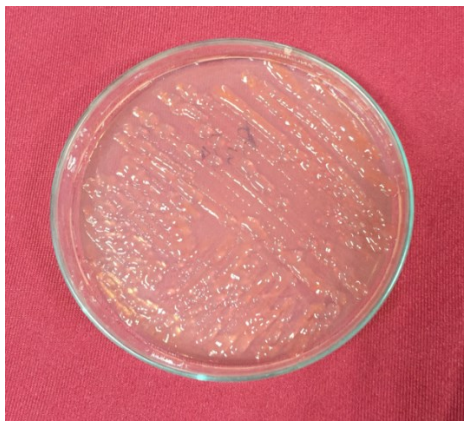
Fig. 44. Gram staining test (a) Stereo-microscopic observation; (b) Rhizobium bacterial colony

Congo red test findings

The purity of isolated *Rhizobium* sp. was tested using the congo red method since various strains of the bacteria varied in their capacity to hold onto the dye. Ten bacterial isolates were grown on yeast extract mannitol agar with congo red in the dark on YEMA medium did not hold onto the dye. All of these bacteria formed whitish color and didn't absorb congo red which indicates that they were gram negative. For Rhizobia, yeast extract was a good supply of easily available amino acids, vitamin B complex, and auxiliary growth agent (Aneja., 2007), **(**Fig. 45.).



a. Congo red containing media



b. Whitish bacteria didn't absorbe Congo red

Fig. 45. Congo red test: (a) Congo red containing media, (b) Whitish bacteria didn't absorbe Congo red.

Table 23. Morphological and Biochemical characterization of isolated *Rhizobium* from Groundnut

Sl no.	Name of isolate	Cell shape	Motility	Gram reaction	Congo red test	Culture growth 28±2°C, 48h	
						Plate	Broth
01	FAGR102	Rod	Motile	(-) ve	(-) ve	Quick	Quick, Mucilage
02	FAGR241	Rod	Motile	(-) ve	(-) ve	Quick	Quick, Mucilage
03	FAGR254	Rod	Motile	(-) ve	(-) ve	Slow	Slow, Mucilage
04	FAGR308	Rod	Motile	(-) ve	(-) ve	Slow	Slow, Mucilage
05	FAGR318	Rod	Motile	(-) ve	(-) ve	Medium	Medium, Mucilage
06	FAGR322	Rod	Motile	(-) ve	(-) ve	Quick	Quick, Mucilage
07	FAGR345	Rod	Motile	(-) ve	(-) ve	Quick	Quick, Mucilage
08	FAGR348	Rod	Motile	(-) ve	(-) ve	Slow	Slow, Mucilage
09	FAGR356	Rod	Motile	(-) ve	(-) ve	Slow	Slow, Mucilage
10	FAGR364	Rod	Motile	(-) ve	(-) ve	Medium	Medium, Mucilage

Table 24. Morphological and Biochemical characterization of isolated *Rhizobium* from Lentil

Sl no.	Name of isolate	Cell shape	Motility	Gram Reaction	Congo red test	Culture growth 28±2°C, 48h	
						Plate	Broth
01	FALR114	Rod	Motile	(-) ve	(-) ve	Quick	Slow, Mucilage
02	FALR315	Rod	Motile	(-) ve	(-) ve	Medium	Medium, Mucilage
03	FALR317	Rod	Motile	(-) ve	(-) ve	Quick	Quick, Mucilage
04	FALR319	Rod	Motile	(-) ve	(-) ve	Medium	Slow, Mucilage
05	FALR328	Rod	Motile	(-) ve	(-) ve	Slow	Medium, Mucilage
06	FALR329	Rod	Motile	(-) ve	(-) ve	Quick	Quick, Mucilage
07	FALR414	Rod	Motile	(-) ve	(-) ve	Slow	Quick, Mucilage
08	FALR421	Rod	Motile	(-) ve	(-) ve	Medium	Slow, Mucilage
09	FALR432	Rod	Motile	(-) ve	(-) ve	Medium	Slow, Mucilage
10	FALR445	Rod	Motile	(-) ve	(-) ve	Slow	Quick, Mucilage

Seedling infectivity test

Infection ability was checked in a test tube culture of groundnut and lentil. Ten isolates of effective *Rhizobium* of groundnut and lentil were used for the infection ability test and all bacteria successfully produced nodules in both groundnut and lentil roots grown in test tubes (Table 25, Fig. 46).
Olivares *et al*., (1980) found that the infectiveness of *Rhizobium meliloti* and *Medicago sativa* formed many nodules during the infectvity test using a method that involves mixing tetracycline or without tetracycline.

Table 25. Nodulation infectivity tests of *Rhizobium* on lentil and groundnut

Sl no.	Name of isolate from Lentil	Infectivity Test		Name of isolate from groundnut	Infectivity Test	
		Glass tube	Pot expt.		Glass tube	Pot expt.
01	FALR114	+	+	FAGR102	+	+
02	FALR315	+	+	FAGR241	+	+
03	FALR317	+	+	FAGR254	+	+
04	FALR319	+	+	FAGR308	+	+
05	FALR328	+	+	FAGR318	+	+
06	FALR329	+	+	FAGR322	+	+
07	FALR414	+	+	FAGR345	+	+
08	FALR421	+	+	FAGR348	+	+
09	FALR432	+	+	FAGR356	+	+
10	FALR445	+	+	FAGR364	+	+

Fig. 46. Nodulation infectivity tests

IAA production by bacterial isolates

Table 26. IAA determination of *Rhizobium* strains of lentil collected from ~~of~~ different regions

Isolates	IAA (µg / ml)
FALR114	8.59
FALR315	59.62
FALR317	15.14
FALR319	19.68
FALR328	48.68
FALR329	72.17
FALR414	8.18
FALR421	13.13
FALR432	84.99
FALR445	38.61

The IAA determination result showed that different bacterial isolate from lentil produced different amount of IAA (Table 26). The highest amount of IAA was produced by FALR432 (84.99 µg/ml) and lowest amount of IAA produced by FALR414 (8.18µg/ml).

Table 27. IAA determination of *Rhizobium* strains of groundnut collected from different regions

Isolates	IAA (µg / ml)
FAGR102	30.74
FAGR241	10.04
FAGR254	18.05
FAGR308	13.80
FAGR318	10.62
FAGR322	35.80
FAGR345	11.94
FAGR348	11.48
FAGR356	10.32
FAGR364	9.48

Bacterial isolates collected from groundnut produced different amount of IAA (Table 27). The highest amount of IAA was produced by FAGR322 (35.80 µg/ml) and lowest amount of IAA was produced by FAGR364 (9.48 µg/ml).

Cultivation of bacteria and DNA extraction

Selected effective *Rhizobium* sp. SR7, *Rhizobium* sp. SR15, *Rhizobium* sp. GR9 and *Rhizobium* sp. GR13 bacteria were cultured in test tubes containing 3 ml in YEM liquid broth by shaking in a rotary shaker at 180 rpm, 30°C, for 48 hours, and the cultures were centrifuged at 18,000 rpm for 5 minutes at 4°C. Genomic DNA was extracted from the pellet using DNA isolation kit (Promega, USA) and DNA yield was quantified using a spectrophotometer. The extracted bacterial DNA was used as a template for PCR amplification.

Olegonucleotide primers:

One pair of primers, which were specific for housekeeping gene (16S rRNA) of every morphologically and biochemically identified bacteria, were used to amply a fragment of 16S rRNA gene by PCR. The specific primers were designed from 16S rRNA gene sequences.

PCR amplification:

About 50 ng of template DNA was used to amply fragments of the 16S rRNA gene by PCR. The PCR test was carried out in a final volume of 25 µL containing 1 µL template DNA, 12.5 µL master mix (including polymerase, buffer, dNPT, Mg^{2+}, promega company), 1 µl forward primer, 1 µl reverse primer, 9.5 µL sterile water. PCR amplification was performed staring with 5 min denaturing step at 95°C, followed by 30 cycles of denaturation at 95°C for 30 sec, annealing at 48°C for 30 sec, extension at 72°C for 1.5 min, and final extension 72°C for 5 min. The PCR products were assessed by electrophoresis on 1% agarose gel (Fig. 47). DNA bands were visualized by UV illumination and photographed with gel documentation system. PCR products were purified using gel purification Kit and were kept for sequence.

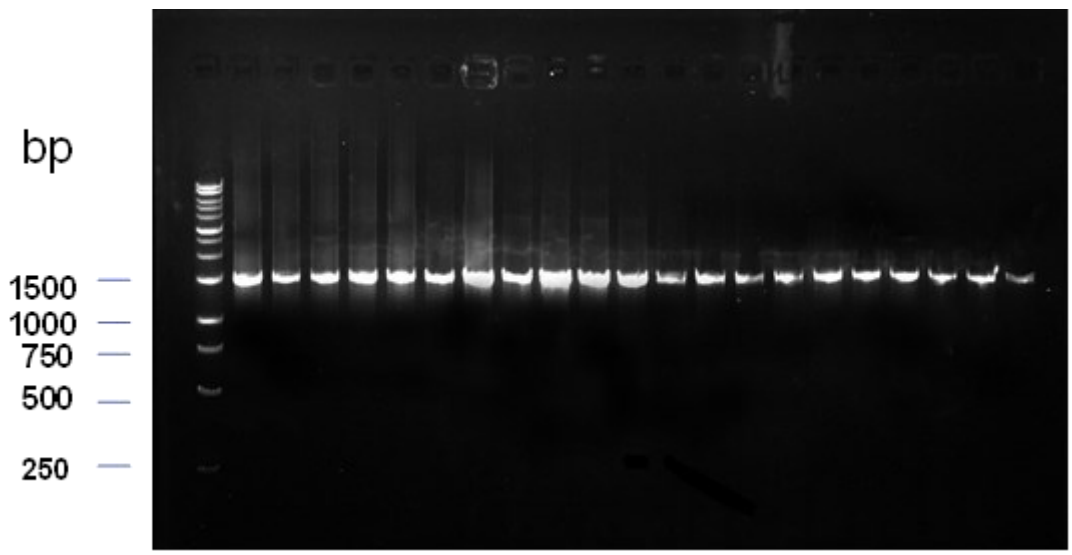


Fig. 47. PCR amplification of Rhizobial 16S rDNA for rhizobial strains

Sequencing and phylogenetic analysis

Selected effective *Rhizobium* sp. FAGR102, *Rhizobium* sp. FAGR241, *Rhizobium* sp. FAGR254, *Rhizobium* sp. FAGR308, *Rhizobium* sp. FAGR318, Reference strain *Rhizobium* sp. BARIRAh808 collected from groundnut root nodules; and *Rhizobium* sp. FALR114, *Rhizobium* sp. FALR315, *Rhizobium* sp. FALR317, *Rhizobium* sp. FALR319, *Rhizobium* sp. FALR328, Reference strain *Rhizobium* sp. BARIRLc107 collected from lentil root nodules were assessed for DNA sequencing (Fig. 48, Fig. 49). The bacterial DNA sequencing was performed using an Applied Biosystems 3730 automated sequencer with the M13 primer to obtain nearly full-length bacterial 16S rDNA sequences.

The bidirectional gene sequences were compiled using DNAMAN software (DNAMAN version 4.11, Lynnon Biosoft, San, Ramon, CA, USA), and the sequences were analyzed using MEGA 5.2 software. The consensus sequences were used in a BLAST search of the NCBI GenBank database. Phylogenetic analysis was conducted using MEGA version 11, and a neighbor-joining tree were constructed using Kimura 2-parameter distances with 1000 replicates to estimate bootstrap support. The compiled sequence of the *Rhizobium* strains was deposited in the GenBank database and assigned accession number. The the groundnut nodulated bacterial gene sequencing result showed that *Rhizobium* sp. FAGR308, *Rhizobium* sp. FAGR318, *Rhizobium* sp. FAGR322 were similar with *Rhizobium* miluonense CCBAU41251T(EF061096) bacterial sequence and *Rhizobium* sp. FAGR254, *Rhizobium* sp FAGR102, *Rhizobium* sp BARIRAh808 were similar to *Rhizobium* miluonense CCBAU41251T(EF061096) bacterial sequence which were belonging to bacteria kingdom, proteobacteria phylum, alpha proteobacteria class, rhizobiales order, rhizobiaceae family, and genus *Rhizobium* (Fig. 48).

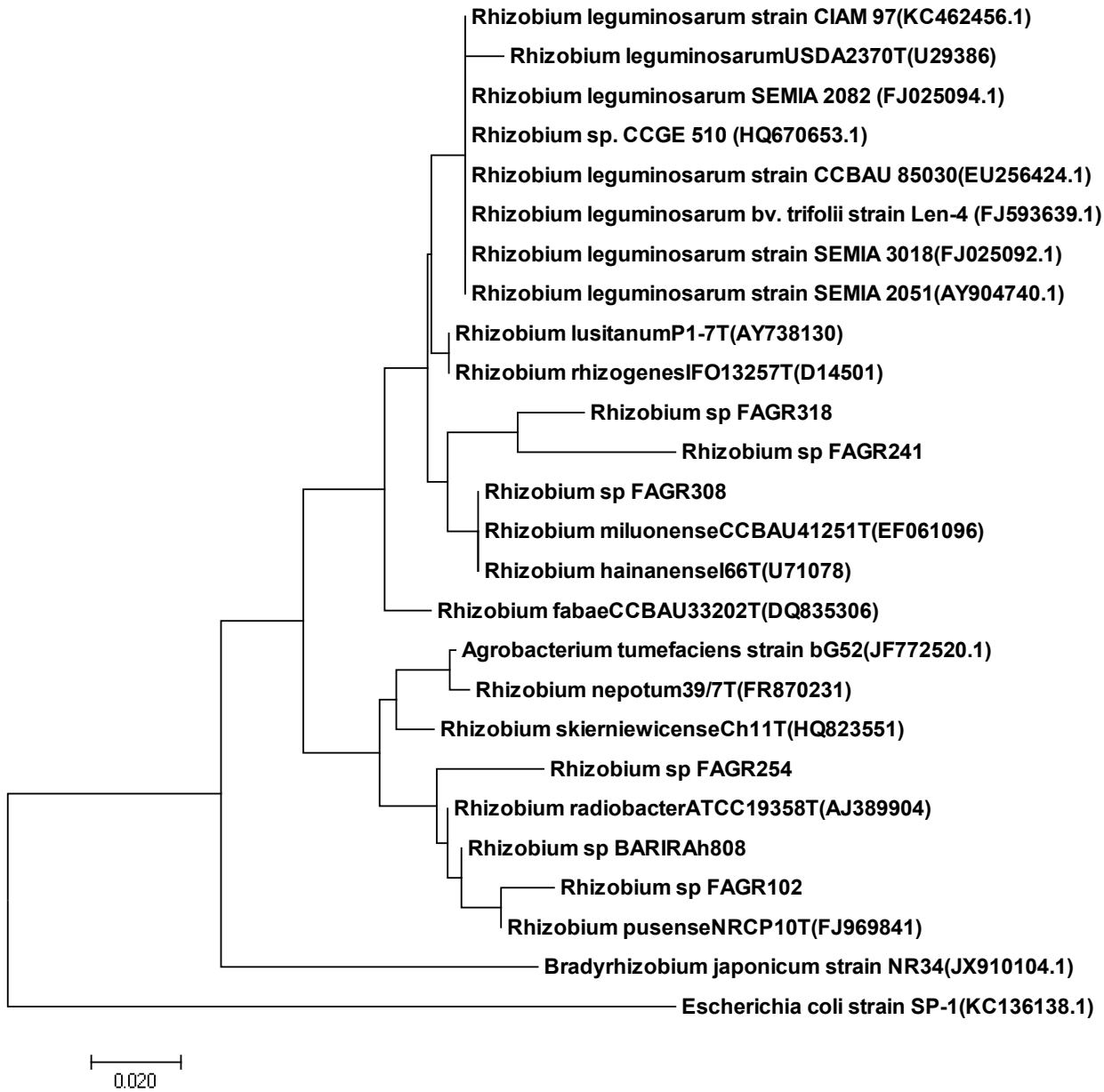


Fig. 48. Phylogenetic analysis of *Rhizobium* bacteria used for biofertilizer production of groundnut.

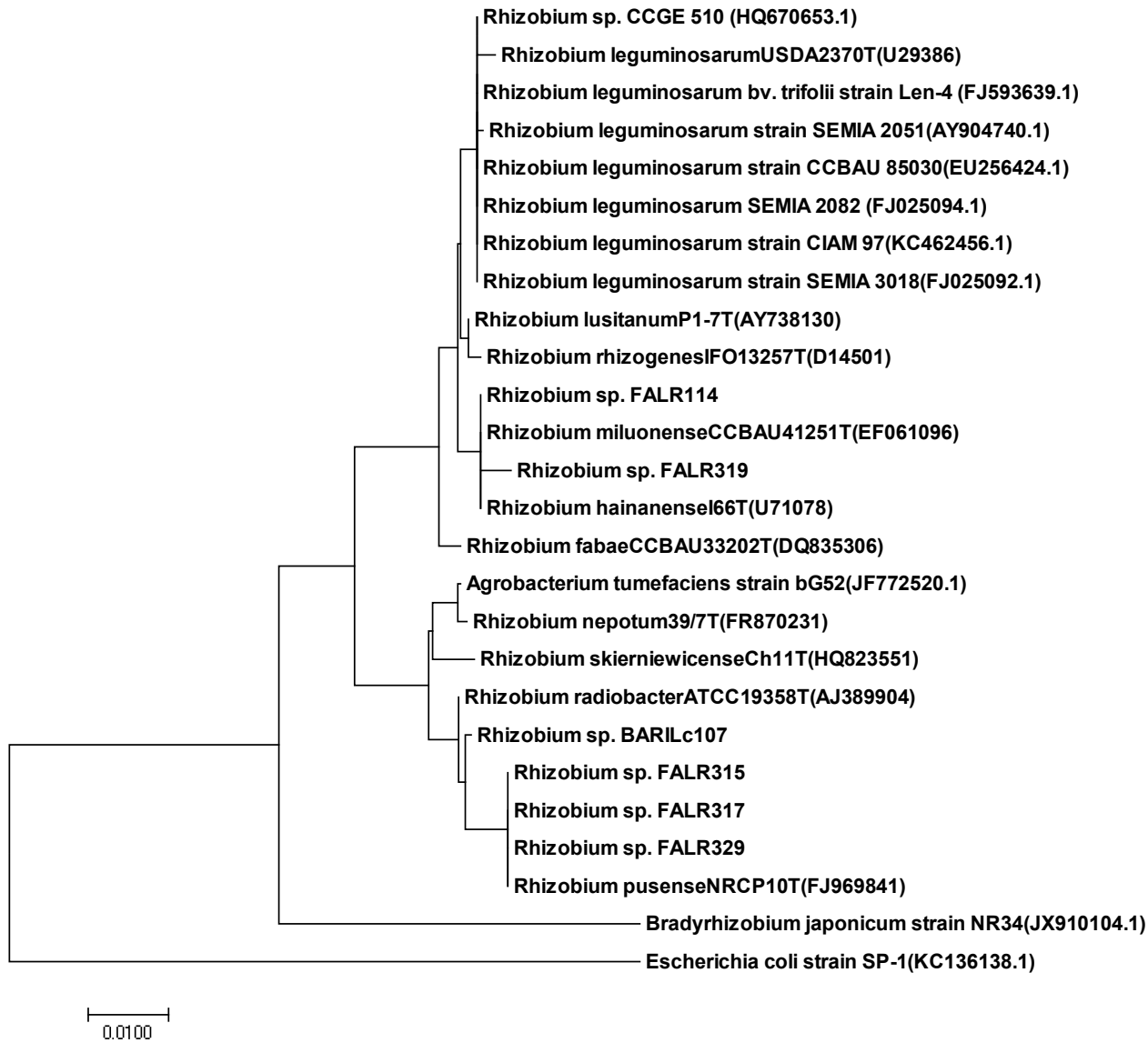


Fig. 49. Phylogenetic analysis of *Rhizobium* bacteria used for biofertilizer production of Lentil.

Similarly, the lentil nodulated bacterial gene sequencing results represented that *Rhizobium* sp. FALR114, *Rhizobium* sp. FALR319, *Rhizobium* sp. FALR328 were similar with *Rhizobium* hainanenseI66T(U71078) bacterial sequence and *Rhizobium* sp. FALR315, *Rhizobium* sp FALR317, *Rhizobium* sp. FALR317, *Rhizobium* sp. BARIRLc107 were similar to *Rhizobium* pusenseNRCP10T(FJ969841) bacterial sequence which were belonging to bacteria kingdom, proteobacteria phylum, alpha proteobacteria class, rhizobiales order, rhizobiaceae family, and genus *Rhizobium* (Fig. 49).

Evaluation of *Rhizobium* Biofertilizer on Groundnut

Results and Discussion

Pot trial

Pot trials for the evaluation of *Rhizobium* biofertilizer on groundnut were conducted in Gazipur during 2020-2021 and 2021-2022. However, results of this study are presented in Table 28 and 29 with subsequent discussion as below.

Table. 28. Yield contributing characters of Groundnut (BARI Chinabadam-8) as influenced by the application of *Rhizobium* biofertilizer in combination with recommended chemical fertilizers under pot sutdy at Joydebpur, Gazipur during 2020-2021.

Treatment	Plant height (cm)	Nodule No./ plant	Shoot weight (g/plant)	Root weight (g/plant)	Nodule Weight (g/plant)	No. of Nut/ plant	Nut yield (g/plant)
T_1	34.66ab	18.00c	14.04b	0.54ab	0.09ab	10.11ab	22.66ab
T_2	38.333a	20.00bc	13.30bc	0.68a	0.08ab	11.77a	23.50ab
T_3	37.33a	34.00a	15.80ab	0.77a	0.13ab	11.44ab	27.31a
T_4	39.16a	19.66bc	15.70ab	0.71a	0.08ab	11.88a	25.11ab
T_5	36.83ab	23.00b	21.20a	0.56ab	0.09ab	10.77ab	25.69ab
T_6	34.16ab	36.00a	13.42bc	0.56ab	0.21a	11.44ab	22.33ab
T_7	31.66b	16.00c	11.11c	0.40b	0.043b	9.55b	20.67b
CV%	8.42	10.84	10.28	22.26	67.31	11.04	12.23

In a column figures having similar letter (s) do not differ significantly whereas figures with dissimilar letter (s) differ significantly as per LSD at 5% level of significant.

Legends, CV= Co-efficient of Variation, T_1: *Rhizobium* sp. FAGR102, T_2: *Rhizobium* sp. FAGR241, T_3: *Rhizobium* sp. FAGR254, T_4: *Rhizobium* sp. FAGR308, T_5: *Rhizobium* sp. FAGR318, T_6: Reference strain *Rhizobium* sp. BARIRAh808, T_7: Control

Similarly, in case of first year (2020-20210), the tallest plant (39.16 cm) was also obtained with T_4 (*Rhizobium* sp. FAGR308), which was statistically identical toT_1, T_2, T_3 T_4, T_5 but significantly higher only over control. Nodule No. was recorded as the highest (34.00) with *Rhizobium* sp. FAGR254, which was identical to T_6 but significantly higher over other treatments. The highest shoot weight (21.20 gm) was obtained with *Rhizobium* sp. FAGR318, which was identical to T_3 and T_4 but significantly higher over other treatments. Root weight was recorded as the highest (0.77 gm) with Rhizobium sp. FAGR254, which was identical to other treatments except control. Again, the nodule weight was found the highest (0.21 gm) with *Reference* strain treatment, which was identical to T_2, T_3, T_4, T_5 but significantly differed with other treatments. Number of nut/plants was recorded as the highest (11.88) with Rhizobium sp. FAGR308 which was identical to T_1, T_2, T_4 but significantly higher over rest of the treatments. However, the highest (27.31g) nut yield/plant was recorded with Rhizobium sp. FAGR254, which was statistically identical to rest of the biofertilizer treatments except control (Table 28).

Table 29. Yield contributing characters of Groundnut (BARI Chinabadam-8) as influenced by the application of *Rhizobium* biofertilizer in combination with recommended chemical fertilizers under pot study at Joydebpur, Gazipur during 2021-2022

Treatment	Plant height (cm)	Nodule no./ plant	Nodule weight (g/plant)	Root dry weight (g/plant)	Shoot dry weight (g/plant)	No. of nut/ plant	Nut yield (g/plant)
T_1	29.44ab	45.33b	0.21ab	0.61ab	6.79b	17.66a	25.54ab
T_2	26.96ab	40.67cd	0.13cd	0.52bc	6.84b	15.67a	27.60a
T_3	30.14a	43.33bc	0.22a	0.53bc	7.52a	12.67b	21.84bc
T_4	31.18a	46.00a	0.18abc	0.55abc	6.67b	11.33b	18.31cd
T_5	28.81ab	37.00de	0.17abcd	0.65a	6.33b	11.67b	19.89c
T_6	28.08ab	35.00e	0.15bcd	0.51bc	6.52b	14.67a	25.78ab
T_7	25.61b	24.67f	0.09d	0.45c	5.46c	12.00b	14.99d
CV%	8.40	5.06	25.97	11.10	4.81	8.35	12.10

In a column figures having similar letter (s) do not differ significantly whereas figures with dissimilar letter (s) differ significantly as per LSD at 5% level of significant.

Legends, CV= Co-efficient of Variation, T1: Rhizobium sp. FAGR102, T2: Rhizobium sp. FAGR241, T3: Rhizobium sp. FAGR254, T4: Rhizobium sp. FAGR308, T5: Rhizobium sp. FAGR318, T6: Reference strain Rhizobium sp. BARIRAh808, T7: Control

The highest plant height (31.18 cm) was recorded with *Rhizobium* sp. FAGR308 treatment which was stastistically similar with all other treatments except control treatments. The maximum number of nodule (46.00) was recorded with *Rhizobium* sp. FAGR308 which was significantly higher overrest of the treatments. Nodule weight was recorded the highest (0.22gm) with *Rhizobium* sp. FAGR254 treatment which was identical with T_1, T_4, T_5 but significantly higher over rest of the treatments. The highest root dry weight (0.65gm) was recorded with *Rhizobium sp.* FAGR318, which was identical with T_1, T_4 but significantly higher over other treatments. Again, the maximum shoot dry weight (7.52gm) was recorded with Rhizobium sp. FAGR254, which was significantly higher over all other treatments. The highest nut yield (27.60 gm) was recorded with Rhizobium sp. FAGR241, which was identical with T_1 and T_6 but significantly higher over rest of the treatments. (Table 29).

Field Experiment

Field experiments for the evaluation of *Rhizobium* biofertilizer on groundnut were conducted in Gazipur and Cox's Bazar. However, results of this study are presented in Table 30 and 31 with following discussion.

Table 30. Growth parameter of Groundnut (BARI Chinabadam-8) as influenced by the application of *Rhizobium* biofertilizer in combination with chemical fertilizers at Gaziur during 2021-2022.

Treatment	Plant height (cm)	Root length (cm)	No. of Branch/plant	Nodule No./ plant	Nodule wt. (g /plant)
T_1	27.53b	14.40c	7.60b	90.00e	0.156b
T_2	31.30a	15.46b	6.66d	141.00a	0.143b
T_3	30.23ab	13.43d	6.90c	125.00b	0.153b
T_4	29.98ab	13.46d	8.10a	143.00a	0.136b
T_5	28.60ab	15.50b	6.23e	106.00d	0.30a
T_6	28.11ab	16.50a	6.20e	113.33c	0.16b
T_7	19.43c	7.33e	4.50f	81.67f	0.096b
CV%	6.65	2.47	1.91	1.31	14.19

In a column figures having similar letter (s) do not differ significantly whereas figures with dissimilar letter (s) differ significantly as per LSD at 5% level of significant.

Legends, CV= Co-efficient of Variation, T_1: *Rhizobium* sp. FAGR102, T_2: *Rhizobium* sp. FAGR241, T_3: *Rhizobium* sp. FAGR254, T_4: *Rhizobium* sp. FAGR308, T_5: *Rhizobium* sp. FAGR318, T_6: Reference strain *Rhizobium* sp. BARIRAh808, T_7: Control

The highest plant height (31.30 cm) was recorded with T_1 (Rhizobium sp. FAGR241) which was statistically similar to T_3, T_4, T_5, T_6 except T_7 (Table 30). Number of branch/plant was recorded as the highest (8.10) with T_4 (Rhizobium sp. FAGR308), which was significantly higher over rest of the treatments. The highest number (143.00) of nodule per plant was also recordrd with Rhizobium sp. FAGR308, which was identical to Rhizobium sp. FAGR241 treatment but significantly higher over other treatments. Again, nodule weight per plant was recorded as the highest (0.30 g) with T_5 (Rhizobium sp. FAGR318), which was significantly greaterover rest of the treatments. However, the tallest root length (16.50 cm) was recorded with T_6 (*Rhizobium* reference strain treatment) which was significantly longer than all other treatments (Table 30).

Table 31. Yield contributing characters of Groundnut (BARI Chinabadam-8) as influenced by the application of *Rhizobium* biofertilizer in combination with chemical fertilizers at Gaziur during 2021-2022.

Treatment	No. of filled pod/plant	No. of unfilled pod/plant	No. of kernel/plant	Shelling percentage	Nut yield (t ha^{-1})	Stover yield (t ha^{-1})
T_1	17.80b	4.50c	33.33a	63.70d	1.74bc	2.68b
T_2	18.36b	5.56b	28.53c	67.55b	1.74bc	1.81c
T_3	15.33c	7.40a	25.50d	65.60c	1.83b	2.60b
T_4	15.50c	7.56a	21.76e	65.60c	1.63c	2.60b
T_5	20.30a	4.41c	31.60b	72.66a	2.10a	1.73c
T_6	13.73d	4.96bc	21.66e	67.47b	1.76b	3.38a
T_7	7.60e	3.43d	13.60f	52.44e	1.06d	1.19d
CV%	2.66	6.74	1.10	0.30	3.89	5.26

In a column figures having similar letter (s) do not differ significantly whereas figures with dissimilar letter (s) differ significantly as per LSD at 5% level of significant.

Legends, CV= Co-efficient of Variation, T_1: *Rhizobium* sp. FAGR102, T_2: *Rhizobium* sp. FAGR241, T_3: *Rhizobium* sp. FAGR254, T_4: *Rhizobium* sp. FAGR308, T_5: *Rhizobium* sp. FAGR318, T_6: Reference strain *Rhizobium* sp. BARIRAh808, T_7: Control

The highest number of filled pod (20.30/plant) was recorded with *Rhizobium* sp. FAGR318, which was significantly higher over rest of the treatments. However, the highest number of unfilled pod (7.56/plant) was recorded with *Rhizobium* sp. FAGR308, which was identical to *Rhizobium* sp. FAGR254 but significantly higher over other treatments. Again, the number of kernel was recorded as the highest (33.33/plant) with Rhizobium sp. FAGR102, which was significantly greater over all treatments. Shelling percentage was recorded as the highest (72.66%) with *Rhizobium* sp. FAGR318 , which was statistically differed with all treatments. The nut yield was recorded as the highest (2.10 t/ ha) with T_5 (*Rhizobium* sp. FAGR318) treatment, which was significantly higher over all other treatments. Again, the stover yield was recorded as the highest (3.38 t/ha) with T_6 (Reference strain Rhizobium sp. BARIRAh808), which was statistically greater over rest of the strains and control treatment (Table 31).

Table 32. Growth parameter of Groundnut (BARI Chinabadam-8) as influenced by the application of *Rhizobium* biofertilizer in combination with chemical fertilizers at Cox's Bazar during 2021-2022.

Treatment	Nodule /plant (number)	Nodule weight (g/ plant)	Root wt. (g/plant)	Shoot wt. (g/plant)	Plant height (cm)	Root length (cm)	Branch/plant (number)
T_1	65.33c	0.163a	1.693b	46.23e	59.31d	13.63c	6.11ab
T_2	84.67b	0.15ab	1.45d	51.30d	63.98a	14.50bc	5.13bc
T_3	61.00d	0.166a	2.28a	55.72c	62.14bc	16.26a	6.14ab
T_4	83.33b	0.14b	1.42d	43.54f	63.15ab	15.23ab	7.026a
T_5	106.33a	0.116c	1.68b	61.24a	58.03d	15.73ab	6.50a
T_6	83.00b	0.136bc	1.63c	59.88b	60.95c	13.70c	6.30ab
T_7	45.00e	0.08d	1.31e	33.85g	44.54e	9.63d	4.166c
CV%	2.47	8.48	1.79	1.48	1.36	6.10	11.33

In a column figures having similar letter (s) do not differ significantly whereas figures with dissimilar letter (s) differ significantly as per LSD at 5% level of significant.

Legends, CV= Co-efficient of Variation, T_1: *Rhizobium* sp. FAGR102, T_2: *Rhizobium* sp. FAGR241, T_3: *Rhizobium* sp. FAGR254, T_4: *Rhizobium* sp. FAGR308, T_5: *Rhizobium* sp. FAGR318, T_6: Reference strain *Rhizobium* sp. BARIRAh808, T_7: Control

In case of Cox's Bazer, the nodule number per plant was recorded as the highest (106.33) with *Rhizobium* sp. FAGR318, which was significantly higher over all other treatments. But nodule weight was recorded highest (0.166 g/plant) with Rhizobium sp. FAGR254, which was identical to T_1, and T_2 although differed significantly with other treatments. Root weight was recorded as the highest (2.28 g/plant) also with the same strain (Rhizobium sp. FAGR254), which was statistically greater than the rest of the treatments. However, shoot weight was recorded as the highest (61.24 g/plant) with *Rhizobium* sp. FAGR318, which was statistically differed with rest of the treatments. Plant height weight was recorded as the highest (63.98 cm) with Rhizobium sp. FAGR241, which was statistically similar to T_4 but differed with other treatments. Root length was recorded as the highest (16.26 cm) with Rhizobium sp. FAGR254, which was identical with T_4 and T_5 but differed significantly with other treatments. The highest number (7.026) of branch/plant was recorded with Rhizobium sp. FAGR308, which was statistically identical to T_1, T_3, T_5 and T_6 but significantly higher over other treatments (Table 32).

Table 33. Yield contributing characters of Groundnut (BARI Chinabadam-8) as influenced by the application of *Rhizobium* biofertilizer in combination with chemical fertilizers at Cox's Bazar during 2021-2022.

Treatment	No. of filled pod/plant	No. of unfilled pod/plant	No. of kernel/plant	Shelling percentage	Stover yield ton/ha	Average Nut wt./plant (g)	Nut Yield (t/ha)	1000 Seed wt. (g)
T_1	41.33a	7.16bc	51.00a	71.74d	6.77b	27.23a	2.19a	540.8d
T_2	37.23c	7.16bc	26.33cd	73.41cd	7.22ab	26.54ab	2.013a	541.50d
T_3	31.96d	6.30c	26.83cd	73.54cd	7.00b	23.87cd	2.173a	592.98b
T_4	40.36ab	7.51b	37.51b	77.43a	7.11b	25.17bc	2.156a	585.67c
T_5	36.60c	7.50b	24.33d	75.08bc	7.15b	23.48d	2.22a	584.01c
T_6	38.93b	7.33b	27.90c	76.05ab	7.80a	26.30ab	2.28a	619.80a
T_7	15.70e	10.43a	18.33e	52.01e	4.25c	12.88e	0.686b	210.66e
CV%	2.49	6.40	4.96	1.45	4.95	3.46	9.77	0.49

In a column figures having similar letter (s) do not differ significantly whereas figures with dissimilar letter (s) differ significantly as per LSD at 5% level of significant.

Legends, CV= Co-efficient of Variation, T_1: *Rhizobium* sp. FAGR102, T_2: *Rhizobium* sp. FAGR241, T_3: *Rhizobium* sp. FAGR254, T_4: *Rhizobium* sp. FAGR308, T_5: *Rhizobium* sp. FAGR318, T_6: Reference strain *Rhizobium* sp. BARIRAh808, T_7: Control

The highest number of filled pod (41.33/plant) was recorded with Rhizobium sp. FAGR102 treatment, which was identical to T_4 but significantly higher over rest of the treatments. In contrary, the number of unfilled pod was recorded as the highest (10.43/plant) with T_7 (control), which was statistically differed with other treatments. Again, the highest number of kernel (51/plant) was recorded with Rhizobium sp. FAGR102, which was significantly higher over rest of the treatments. Shelling percentage was recorded as the highest (77.43%) with Rhizobium sp. FAGR308, which was statistically similar to T_6 but differed with other treatments. The stover yield was recorded as the highest (7.80 t/ha) with T_6 (Reference strain, Rhizobium sp. BARIRAh808), which was identical to T_2 but differed significantly with other treatments. Mean nut weight was recorded as the highest (27.23 g/plant) with Rhizobium sp. FAGR102, which was statistically similar to T_2 and T_6 but differed with other treatments. The highest weight of 1000 seed (619.80 g) was obtained with T_6, which was significantly higher over rest of the treatments. However, the highest nut yield (2.28 t/ha) was also recorded in T_6, which was statistically at par with rest of of the biofertilizer based treatments and all of them were significantly higher over control where biofertilizer was not applied **(**Table 33). This result implied that application of biofertilizer augmented the seed yield of grountnut showing better performance over control treatment.

Table 34. Growth parameter of Groundnut (BARI Chinabadam-8) as influenced by the application of *Rhizobium* biofertilizer in combination with chemical fertilizers at Gazipur during 2020-2021.

Treatment	Plant height (cm)	Nodule No./ plant	Shoot dry weight (g/plant)	Root dry weight (g/plant)	Nodule weight (g/plant)	Root length (cm)
T_1	54.26a	110.00a	45.53ab	1.17a	0.21b	12.20a
T_2	55.30a	84.00b	45.25ab	1.066a	0.26ab	11.73ab
T_3	54.60a	111.00a	42.78b	1.04ab	0.25ab	10.66abc
T_4	52.93a	114.30a	50.02a	1.17a	0.25ab	11.13abc
T_5	54.43a	104.00a	43.55b	0.86bc	0.25ab	10.13bcd
T_6	55.26a	77.33bc	47.71ab	0.98ab	0.28a	9.60cd
T_7	47.66b	70.33c	36.05c	0.69c	0.15c	8.53d
CV%	4.09	7.25	6.78	11.07	12.80	8.81

In a column figures having similar letter (s) do not differ significantly whereas figures with dissimilar letter (s) differ significantly as per LSD at 5% level of significant.

Legends, CV= Co-efficient of Variation, T_1: *Rhizobium* sp. FAGR102, T_2: *Rhizobium* sp. FAGR241, T_3: *Rhizobium* sp. FAGR254, T_4: *Rhizobium* sp. FAGR308, T_5: *Rhizobium* sp. FAGR318, T_6: Reference strain *Rhizobium* sp. BARIRAh808, T_7: Control

Table 35. Yield contributing characters of Groundnut (BARI Chinabadam-8) as influenced by the application of *Rhizobium* biofertilizer in combination with chemical fertilizers at Gazipur during 2020-2021.

Treatment	No. of Nut/Plant	Kernel/Nut	100 nut weight (gm)	100 Kernel weight (gm)	Nut yield (t/ha)
T_1	20.70ab	2.93b	111.51a	63.68a	1.78b
T_2	21.00 ab	3.00ab	77.04b	66.23a	1.51c
T_3	22.00 a	3.00ab	53.41d	63.01a	1.50c
T_4	20.36ab	3.20ab	68.84c	56.21b	1.39c
T_5	18.73b	2.93b	47.77e	68.30a	1.98a
T_6	18.70b	3.33a	52.71d	67.11a	1.53c
T_7	14.36c	2.53c	43.06f	53.47b	1.19d
CV%	7.21	7.10	4.06	4.80	5.89

In a column figures having similar letter (s) do not differ significantly whereas figures with dissimilar letter (s) differ significantly as per LSD at 5% level of significant.

Legends, CV= Co-efficient of Variation, T_1: *Rhizobium* sp. FAGR102, T_2: *Rhizobium* sp. FAGR241, T_3: *Rhizobium* sp. FAGR254, T_4: *Rhizobium* sp. FAGR308, T_5: *Rhizobium* sp. FAGR318, T_6: Reference strain *Rhizobium* sp. BARIRAh808, T_7: Control

In case of first year (2020-2021) at Gazipur, the longest (55.26 cm) plant of groundnut was recorded with T_6 (Reference strain *Rhizobium* sp. BARIRAh808), which was statistically identical to rest of the treatments but higher only over control. The highest number (114.3) of nodule per plant was recorded with Rhizobium sp. FAGR308, which was statistically identical to T_1, T_3, and T_5 but significantly higher over rest of the treatments. The highest shoot weight (50.02 gm/plant) was recorded with Rhizobium sp. FAGR308, which was statistically similar to T_1, T_2, and T_6 but differed with other treatments. Root dry weight (gm) was recorded as the highest (1.17 gm/plant) with both T_1 and T_4 and they were statistically similar to T_2 and T_3, but differed with rest of the treatments. Root length was recorded as the highest (12.20 cm) with Rhizobium sp. FAGR102, which was identical to T_2, T_3, and T_4 but differed with other treatments. Nodule weight was recorded as the highest (0.28 gm/plant) with *Reference* strain treatment, which was statistically similar to T_2, T_3, T_4, and T_5 but differed significantly with other treatments (Table 34). The highest number (22) of nut/plant was recorded with Rhizobium sp. FAGR254, which was statistically identical to T_1, T_2, and T_4 but differed with other treatments. However, kernel/nut was recorded as the highest (3.33) with T6 (Reference strain), which was identical to T_2, T_3, and T_4 but differed with other treatments. The weight of 100 nuts was recorded as the highest (111.51gm) with Rhizobium sp. FAGR102, which differed significantly with rest of the treatments. Kernel weight of 100 nuts was recorded as the highest (68.30 gm) with *Rhizobium* sp. FAGR318, which was identical to T_1, T_2, T_3 and T_6, but differed with T_4 (*Rhizobium* sp. FAGR308) and T_7 (control). However, the highest nut yield (1.98 t/ha) was obtained with T_5 (*Rhizobium* sp. FAGR318), which was significantly higher over all other treatments. The second highest pod yield (1.78 t/ha) was found with T_1 (*Rhizobium* sp. FAGR102), which was significantly higher over rest of the treatments except control (Table 35).

Evaluation of *Rhizobium* Biofertilizer on Lentil

Pot trial

Pot trials were also conducted for the evaluation of *Rhizobium* biofertilizer on lentil in Gazipur during 2020-2021 and 2021-2022. However, results of this study are presented in Table 36 and Table 37 with subsequent discussion as below.

Table 36. Yield contributing characters of Lentil (BARI Masur-8) as influenced by the application of *Rhizobium* biofertilizer in combination with chemical fertilizers at Gazipur under pot study during 2020- 2021

Treatment	Plant height (cm)	Nodule no./ plant	Shoot dry weight (g/ plant)	Root dry weight (g/ plant)	Nodule weight (g/plant)	No. of pod/ plant	Seed yield (g/plant)	Stover yield (g/plant)
T_1	30.70b	45.66e	1.13b	0.06	0.04b	20.06a	0.67a	0.57a
T_2	29.05bc	45.00ef	1.00bc	0.047	0.04b	10.93c	0.40bc	0.35b
T_3	29.18bc	65.30c	0.88bc	0.043	0.04b	11.40c	0.42bc	0.30b
T_4	30.30bc	76.00b	1.20b	0.05	0.09a	12.80c	0.41bc	0.32b
T_5	32.42ab	91.33a	0.89bc	0.047	0.04b	14.00bc	0.45abc	0.34b
T_6	35.04a	52.66d	1.97a	0.06	0.03b	17.66b	0.62ab	0.55a
T_7	26.56c	40.00f	0.75c	0.04	0.03b	9.66c	0.35c	0.26b
CV%	7.23	5.02	19.13	26.45	43.99	17.33	29.12	23.45

In a column figures having similar letter (s) do not differ significantly whereas figures with dissimilar letter (s) differ significantly as per LSD at 5% level of significant.

Legends, CV= Co-efficient of Variation, T_1: *Rhizobium* sp. FALR114, T_2: *Rhizobium* sp. FALR315, T_3: *Rhizobium* sp. FALR317, T_4: *Rhizobium* sp. FALR319, T_5: *Rhizobium* sp. FALR328, T_6: Reference strain *Rhizobium* sp. BARIRLc107, T_7: Control

For the first year (2020-2021), the highest plant height (35.04 cm) was recorded from T6 (Reference strain *Rhizobium* sp. BARIRLc107), which was statistically identical to T_5, but differed significantly with rest of the treatments. Nodule no. was recorded as the highest (91.33) with T_5 (Rhizobium sp. FALR328), which was significantly higher over all other treatments. Shoot dry weight was recorded as the highest (1.97gm/plant) with T_6 (Reference strain *Rhizobium* sp. BARIRLc107), which was significantly superior to rest of the treatments. Root dry weight was recorded as the highest (0.06gm/plant) with both T1 and T6 followed by T4 and T5 and the lowest from the T7 (control). However, the highest number (20.06) of pods/plant was recorded from T1 (*Rhizobium* sp. FALR114) , which was significantly higher over all other treatments. The highest seed yield (0.67 g/plant) was observed in T1, which was statistically similar to T6 but significantly higher over rest of the treatments. The stover yield was found highest (0.57 g /plant) also with T1, which was similar to T6 and both of them were significantly higher over rest of the treatments (Table 36).

Table 37. Yield contributing characters of Lentil (BARI Masur-8) as influenced by the application of *Rhizobium* biofertilizer in combination with chemical fertilizers at Gazipur under pot study during 2021- 2022

Treatment	Plant height (cm)	Nodule no./plant	Shoot dry wt. (g/plant)	Root dry wt. (g/plant)	No. of pod/ plant	Seed yield (g/plant)	Stover yield (g/plant)
T_1	25.78bc	36.30a	0.61abc	0.05b	45.33a	1.76a	1.42ab
T_2	26.63ab	25.66c	0.89a	0.05b	46.33a	1.67a	1.66a
T_3	26.98ab	29.43b	0.78abc	0.07a	32.06bc	1.62a	1.49ab
T_4	28.43a	18.93e	0.80ab	0.05ab	43.93a	1.36ab	1.41ab
T_5	24.04cd	21.10d	0.56bc	0.05b	27.26cd	1.47ab	1.07bc
T_6	24.98bc	10.83f	0.49c	0.04bc	35.00b	0.97bc	1.07bc
T_7	22.34d	7.20g	0.71abc	0.03c	22.33d	0.47c	0.70c
CV%	4.66	3.87	24.31	14.44	10.56	21.60	22.20

In a column figures having similar letter (s) do not differ significantly whereas figures with dissimilar letter (s) differ significantly as per LSD at 5% level of significant.

Legends, CV= Co-efficient of Variation, T_1: *Rhizobium* sp. FALR114, T_2: *Rhizobium* sp. FALR315, T_3: *Rhizobium* sp. FALR317, T_4: *Rhizobium* sp. FALR319, T_5: *Rhizobium* sp. FALR328, T_6: Reference strain *Rhizobium* sp. BARIRLc107, T_7: Control

Different strains of Rhizobium biofertilizer showed significant effect on the yield components and yield of lentil under pot culture (Table 36 and 37).

In case of second year (2021-2022), the highest plant height (28.43 cm) was obtained with Rhizobium sp. FALR319, which was statistically identical to T_2 and T_3 but differed significantly with other treatments. Nodule no. was recorded as the highest (36.30) with Rhizobium sp. FALR114, which was stastistically superior to all other treatments. Shoot dry wt. was recorded as the highest (0.89gm) with Rhizobium sp. FALR315, which was statistically similar to T_1, T_3, T_4, and T_7 and but significantly differed with rest of the treatments. Root dry wt. was recorded as the highest (0.07 gm) with Rhizobium sp. FALR317, which was identical to T_4 but differed with other treatments. No. of pods/ plant was recorded as the highest (46.33) with Rhizobium sp. FALR315, which was identical to T_1, and T_4 but differed with other treatments. The highest seed yiled (1.76 gm/plant) was obtained with Rhizobium sp. FALR114, which was identical to T_2, T_3, T_4, and T_5 but significantly higher over T_6 (Reference strain *Rhizobium* sp. BARIRLc107) and T_7 (control) differed with other treatments. Stover yield was recorded as the highest (1.66 gm/plant) with T_2 (Rhizobium sp. FALR315), which was identical to T_1, T_3, and T_4 but differed with rest of the treatments (Table 37).

Although application of Rhizobium biofertilizer resulted in higher performance on the yield and yield attributes of lentil under pot trial at Gazipur but year to year variations were inconsistent especially for nodule number, dry weight of shoot and root and also seed yield and stover yield.

Field study

Field experiments were conducted at Pabna and Joydebpur and results of Joydebpur and Pabna experiment of lentil field has been presented in Table 38, 39, 40 and 41.

Field experiments for the evaluation of *Rhizobium* biofertilizer on lentil were conducted in Gazipur and Pabna. However, results of this study are presented in Table 38, 39, 40 and 41 with following discussion.

Table 38. Yield contributing characters of Lentil (BARI Masur-8) as influenced by biofertilzer application in combination with chemical fertilizers at Pabna during 2020-2021.

Treatment	Plant Height (cm)	No. of Nodule plant	Shoot weight (g)	Root weight (g)	No. of pod/plant	No. of grain/pod	1000 seed weight (g)	Grain yield (t/ha)	Straw yield (t/ha)
T_1	28.56a	9.33b	2.93ab	0.82ab	28.36a	1.83a	21.66a	0.68a	0.20a
T_2	29.33a	8.08bc	3.14ab	0.85a	28.43a	1.70ab	21.43a	0.74a	0.28a
T_3	29.93a	10.11ab	2.46b	0.88a	22.26c	1.64ab	21.63a	0.58a	0.21a
T_4	29.26a	8.44bc	2.46b	0.87a	27.43a	1.60b	21.53a	0.69a	0.26a
T_5	28.36ab	9.33b	2.31b	0.71ab	24.26b	1.63ab	21.06ab	0.61a	0.26a
T_6	29.30a	11.99a	4.15a	0.81ab	23.93b	1.63ab	21.63a	0.73a	0.26a
T_7	26.56b	6.44c	2.05b	0.52b	17.43d	1.36c	19.50b	0.48a	0.18a
CV%	3.90	13.28	33.49	23.82	2.81	7.83	4.56	18.97	20.63

a column figures having similar letter (s) do not differ significantly whereas figures with dissimilar letter (s) differ significantly as per LSD at 5% level of significant.

Legends, CV= Co-efficient of Variation, T_1: *Rhizobium* sp. FALR114, T_2: *Rhizobium* sp. FALR315, T_3: *Rhizobium* sp. FALR317, T_4: *Rhizobium* sp. FALR319, T_5: *Rhizobium* sp. FALR328, T_6: Reference strain *Rhizobium* sp. BARIRLc107, T_7: Control

For the first-year trial at Pabna, the longest plant height (29.93 cm) of lentil was recorded in T3 (Rhizobium sp. FALR317), which was significantly higher only over control but statistically at par with rest of the treatments. The the highest number of nodule (11.99/plant) was recorded with T6, which was statistically identical to T_3 but differed significantly with other treatments. The dry weight of shoot was recorded as the highest (4.15 gm/plant) with T6, which was statistically identical to T_1, T_2 but differed significantly with other treatments. However, the root dry weight was highest (0.88 gm/plant) with Rhizobium sp. FALR317, which was significantly higher only over control and statistically at par with other treatments. The number of pods was recorded as the highest (28.43/plant) with Rhizobium sp. FALR315, which was statistically identical to T_1, and T_4 but differed significantly with other treatments. The number of seeds/pods were recorded as the highest (1.83) with Rhizobium sp. FALR114, which significantly higher only over control but statistically at par with all other treatments. Similarly, the 1000 seed weight was recorded as the highest (21.66 gm) with Rhizobium sp. FALR114, which was significantly higher only over control but statistically identical to all other treatments. However, no significant yiled variation in lentil was observed due to application of different biofertilizer strains under this trial. Nonetheless, the seed yield varied from 0.48-0.74 t/ha, where the numerically highest yield was obtained with T2 followed by T6 and the lowest in control. Similarly, the stover yield varied from 0.18 to 0.28 t/ha where numerically the highest result was obtained with T2, which was closely followed by T4, T5 and T6 and the lowest stover yield was recorded in biofertilizer control treatment (Table 38).

Table 39. Growth parameter of Lentil (BARI Masur-8) as influenced by biofertilizer application in combination with chemical fertilizers at Gazipur during 2020-2021

Treatment	Plant height (cm)	Nodule No /plant	Shoot dry wt. (g/plant)	Root dry wt. (g/plant)	No. of pod/ plant	Seed yield (t/ha)
T_1	24.6a	4.00a	1.63ab	0.08b	4.93bc	1.02cd
T_2	24.65a	2.66b	1.88a	0.08b	5.44b	1.07ab
T_3	24.33a	3.00b	1.41ab	0.08b	2.73d	1.05bcd
T_4	25.27a	7.00a	1.67a	0.13a	7.23a	1.09a
T_5	26.55a	5.00ab	1.48ab	0.09ab	3.56cd	1.06abc
T_6	27.05a	2.66b	2.05a	0.13a	2.20de	1.02cd
T_7	22.69a	2.33b	0.74b	0.06b	1.26e	1.01d
CV%	11.29	14.24	23.86	28.12	20.39	16.31

In a column figures having similar letter (s) do not differ significantly whereas figures with dissimilar letter (s) differ significantly as per LSD at 5% level of significant.

Legends, CV= Co-efficient of Variation, T_1: *Rhizobium* sp. FALR114, T_2: *Rhizobium* sp. FALR315, T_3: *Rhizobium* sp. FALR317, T_4: *Rhizobium* sp. FALR319, T_5: *Rhizobium* sp. FALR328, T_6: Reference strain *Rhizobium* sp. BARIRLc107, T_7: Control

Incase of first year (2020-2021), at Gazipur, the highest plant height (27.05 cm) was recorded with T6 (reference strain), which was identical to other treatments. The number of nodule was recorded as the highest (7/plant) with T4 (Rhizobium sp. FALR319), which was statistically identical to T_1 and T5 but significantly differed with other treatments. The maximum dry weight of shoot (2.05 g/plant) was recorded with T6 (Reference strain), which was significantly higher only over control but statistically similar to all other biofertilizer based treatments. Again, the highest dry weigt of root (0.13 g/plant) was recorded with both T4 and T6 and they were identical to T5 but significantly higher over rest of the treatments. The maximum number of pods (7.23/plant) was recorded with Rhizobium sp. FALR319, which differed significantly with all other treatments. In fact the highest seed yield (1.09 t/ha) was recorded with Rhizobium sp. FALR319, which was identical to T_1 and T_5 but significantly higher over rest of the treatments (Table 39).

Table 40. Yield contributing characters of Lentil (BARI Masur-8) as influenced by biofertilizerapplication in combination with chemical fertilizers at Gazipur during 2021-2022.

Treatment	Plant height (cm)	Root length (cm)	No. of branch/ plant	No. of pod/plant	No. of unfilled pod/plant	1000 Seed weight (g)	Grain Yield (t/ha)
T_1	26.36a	8.33b	7.53a	30.80b	3.66d	24.50ab	0.99b
T_2	26.40a	8.76ab	6.43b	27.93c	4.33c	25.16a	0.97d
T_3	27.30a	9.40a	5.46c	27.13c	8.33b	24.50ab	0.96d
T_4	26.56a	8.56b	5.76c	26.60c	3.23e	24.50ab	0.96d
T_5	27.36a	8.76ab	6.33b	26.60c	1.96f	24.66a	1.34a
T_6	26.66a	8.70ab	6.60b	40.46a	1.63f	25.66a	0.98c
T_7	18.70b	7.20c	5.43c	18.66d	11.76a	22.80b	0.42e
CV%	4.39	4.85	4.12	3.34	4.77	4.21	8.55

In a column figures having similar letter (s) do not differ significantly whereas figures with dissimilar letter (s) differ significantly as per LSD at 5% level of significant.

Legends, CV= Co-efficient of Variation, T_1: *Rhizobium* sp. FALR114, T_2: *Rhizobium* sp. FALR315, T_3: *Rhizobium* sp. FALR317, T_4: *Rhizobium* sp. FALR319, T_5: *Rhizobium* sp. FALR328, T_6: Reference strain *Rhizobium* sp. BARIRLc107, T_7: Control

During second year (2021-2022), at Gazipur, the highest plant height (27.36 cm) was recorded with T5 (Rhizobium sp. FALR328), which was statistically identical to all other treatments except T_7 (control). The highest root length was recorded (9.40 cm) with Rhizobium sp. FALR317, which was identical to T_2, T_5, and T_6 but differed significantly with the remaining treatments. The maxium number of branch (7.53) per plant was recorded with T1(Rhizobium sp. FALR114), which was significantly higher over rest of the treatments. No. of pods per plant (40.46) was recorded as the highest with T6 (Reference strain), which was statistically differed with other treatments. Number of unfilled pods (11.76/plant) was recorded as the highest with T_7 (control), which differed significantly with other treatments. Again, 1000 seed weight was recorded as the highest (25.66 g) with Reference strain treatment, which was statistically identical to rest of the biofertilizer strains except control. However, the seed yield of lentil was recorded as the highest (1.34 t/ha) from T_5 (*Rhizobium* sp. FALR328), which was significantly higher over rest of the treatments. The second highest seed yield (0.994 t/ha) was found with T1 (*Rhizobium* sp. FALR114), which was significantly higher over all other treatments except T_5 (Table 40).

Table 41. Yield contributing characters of Lentil (BARI Masur-8) as influenced by biofertilizer application in combination with chemical fertilizers at Pabna during 2021-2022.

Treatment	Plant height (cm)	No. of pods/plant	No. of seeds/pod	1000 seed weight (gm)	Seed yield (t/ha)	Stover yield (t/ha)	Root weight (gm)	Shoot weight (gm)	No. of Nodule/Plant
T_1	37.53ab	76.73a	1.80a	21.26a	1.81a	0.70c	0.99abc	6.22c	23.99b
T_2	37.60ab	72.06bc	1.70a	21.13a	1.29b	0.75abc	1.16ab	6.05c	18.06c
T_3	38.30a	73b	1.76a	20.60a	1.81a	0.83a	0.96bc	8.71a	16.53d
T_4	36.20b	77.10a	1.63a	21.56a	1.30b	0.73bc	1.14abc	7.28b	29.44a
T_5	36.83ab	72.03bc	1.66a	21.00a	1.41b	0.81ab	1.25a	6.22c	18.46c
T_6	37.46ab	71.40c	1.66a	21.60a	1.70a	0.82a	0.86c	6.24c	16.44d
T_7	31.10c	64.76d	1.13b	16.60b	1.13c	0.54d	0.42d	4.28d	11.95e
CV%	3.02	0.98	8.98	2.93	5.01	6.18	16.33	2.72	2.48

In a column figures having similar letter (s) do not differ significantly whereas figures with dissimilar letter (s) differ significantly as per LSD at 5% level of significant.

Legends, CV= Co-efficient of Variation, T_1: *Rhizobium* sp. FALR114, T_2: *Rhizobium* sp. FALR315, T_3: *Rhizobium* sp. FALR317, T_4: *Rhizobium* sp. FALR319, T_5: *Rhizobium* sp. FALR328, T_6: Reference strain *Rhizobium* sp. BARIRLc107, T_7: Control

At Pabna, in the second year, the highest plant height (38.30 cm) was recorded in T3 (Rhizobium sp. FALR317), which was statistically identical to T_1, T_2, T_5, T_6 but differed significantly with T4 and T7. Number of pods/plants was recorded as the highest (77.10) with T4, followed by T1 and both of them were significantly higher over rest of the treatments. Again, the number of seeds/pods was recorded as the highest (1.80) in T1, which was significantly higher only over T7 (control) but statistically similar to all other treatments. Similarly, 1000 seed weight was recorded as the highest (21.60 g) in T6 (Reference strain treatment), which was statistically at par with all other treatments except T7 (control). The dry weight of root (?) was recorded as the highest (1.25 g/plant) with T5 (Rhizobium sp. FALR328), which was statistically at par with T_1, T_2, and T_4 but differed significantly with T6 and T7. The mean dry weight of shoot (?) was recorded as the highest (8.71 g/plant) with T3 (Rhizobium sp. FALR317) which was significantly higher over all other treatments. The highest number of nodule (29.44/plant) was obtained with T4 (Rhizobium sp. FALR319), which differed significantly with other treatments. The seed yield of lentil was recorded as the highest (1.81 t/ha) with both T1 and T3 followed by T6 and they were significantly higher over rest of the treatments. However, the straw yield was recorded as the highest (0.83 t/ha) with T_3 (Rhizobium sp. FALR317), which was statistically identical toT_2, T_5, and T_6 but differed with orest of the treatments **(**Table 41).

The performance of biofertilizers in terms of yield and its attributes of lentil was much pronounced in the second year at both the locations. In case of Gazipur the effect of biofertilizer stains was non significant for the yield. However, the biofertilizers were better performed at Pabna than Gazipur irrespective of strains used might be due to the congenial soil and agro-climatic conditions at Pabna.

BRRI Component

Soil bio-physico-chemical properties of different AEZ's of Bangladesh and characterization of potential plant growth promoting bacteria (PGPB):

Soil bio-physico-chemical properties of AEZ-10 (Faridpur Sadar)

The soil samples were collected from Decreerchar, Char Madhobdia and North Channel union of Faridpur Sadar upazila in Faridpur district (Fig. 50)**.** A number of 15 soil samples from 0 to 15 cm depth (composite of 150 soils) were analysed to determine bio-physicochemical properties (details

in methothology section). The field history such as existing crop, cropping pattern and farmers details were recorded.

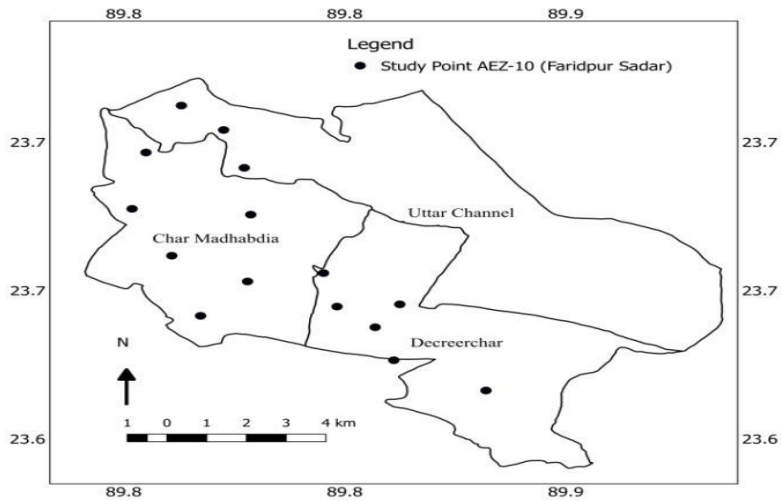


Fig. 50. Location map of AEZ-10 originates from GPS information: **S**tudy points of AEZ-10 (Uttar channel, Char Madhobdia and Deceerchar).

Soil biology: The soil biological properties of AEZ-10 were described in Table 42**.** In the AEZ-10, higher total bacteria population range was found in the Decreechar (2×10^6 to 2×10^9 cfu/g soil) and North Channel union (2×10^6 to 3×10^9 cfu/g soil) compared to Char Madhobdia (2×10^6 to 4×10^7 cfu/g soil). The average total bacteria population was high in North Channel (7×10^9 cfu/g soil). The population range of free-living N_2 fixing bacteria (1×10^5 to 8×10^5 cfu/g soil), Actinomycetes (2×10^3 to 2×10^4 cfu/g soil), and Fungus (5×10^3 to 2×10^4 cfu/g soil), were higher in the Char Madhobdia, however, almost similar average populations values were recorded in the three studied union. Phosphate solubilizing bacteria (2×10^5 to 5×10^5 cfu/g soil) and *Rhizobium* population (8×10^4 to 1×10^6 cfu/g soil) range was high in the Decreechar and average population values were almost similar in the three unions.

Soil physico-chemical properties: The soils of AEZ-10 (Faridpur Sadar) were Silty loam to Silty clay loam in nature (Table 42). The major crops in the cropping patterns were rice, Sarisha, Blakhk gram, Khesari, Garlic, Onion, Sweetgourd, Jute, Teel and Maize. Groundnut was cultivated in the Decreerchar. Soil pH was ranged from 7.5 to 7.9 in Decreerchar with an average value of 7.51. The soils of Char Madhobdia and North Channel were Silty Loam and average pH value was 7.8. In the Decreerchar, percent organic matter (OM) ranged from 0.6 to 1.60 with an average value of 1.68. The percent organic matter ranged from 1.34 to 1.8 in the Char Madhobdia, while in North Channel it was ranged from 1.15 to 1.5 percent. The average soil total nitrogen (TN) was very low and it was ranged from 0.04 to 0.15 percent with an average value of 0.08 percent in the AEZ-10 (Table 42).

Table 42. Soil biology of AEZ-10 (Faridpur Sadar)

District	Upazila	Union	Microbial population (cfu/g soil)					
			TB	NFB	PSB	Act	Fungus	Rhizobium
Faridpur	Faridpur Sadar	Decreerchar	2×10^6 - 2×10^9 (4×10^8)	1×10^4 - 3×10^5 (2×10^5)	2×10^5 - 5×10^5 (4×10^5)	3×10^3- 9×10^3 (6×10^3)	1×10^3- 6×10^3 (6×10^3)	8×10^4 - 1×10^6 (3×10^4)
		Char Madhobdia	3×10^6-4×10^7 (2×10^7)	1×10^5 - 8×10^5 (3×10^5)	7×10^4- 3×10^5 (2×10^5)	2×10^3- 2×10^4 (8×10^3)	5×10^3 - 2×10^4 (8×10^3)	1×10^5 - 6×10^5 (3×10^5)
		North Channel	2×10^6 - 3×10^9 (7×10^9)	7×10^4 - 3×10^5 (3×10^5)	2×10^4- 2×10^5 (2×10^5)	1×10^3- 2×10^3 (6×10^3)	4×10^3- 1×10^3 (7×10^3)	8×10^4- 3×10^5 (3×10^5)

Here, TB: total bacteria, NFB: Free-living N_2 fixing bacteria, PSB: phosphate solubilizing bacteria and Act: Actinimycetes. Value in the parenthesis is average value of the respective population in each column.

Table 43. Soil physico-chemical properties of AEZ-10 (Faridpur Sadar)

District	Upazila	Union	Cropping patterns of the sample collecting point	Physical property	Chemical properties		
				Texture	Soil pH	OM (%)	TN (%)
Faridpur	Faridpur Sadar	Decreerchar	• Boro/ **Mustard** -Fallow-Fallow • **Mustard**-Onion-Corn-Fallow • Boro/ **Mustard**-Blakhkgram/Kheshari-Fallow • Boro-/**Mustard** Kheshari-Fallow • **Groundnut**-Fallow-Fallow	Silty clay loam	7.5-7.9 (7.51)	0.6-1.60 (1.68)	0.04-0.14 (0.08)
		Char Madhobdia	• Boro/**Mustard-** Fallow-Kheshari • Boro/Mustard -Fallow-Garlic-**Onion** • **Sweetgourd**-Jute-Fallow-Garlic • Boro/**Mustard**-Onion/Garlic-Jute Fallow • **Onion**-Garlic-Jute-Fallow	Silty Loam	7.8-7.9 (7.84)	1.34-1.8 (1.53)	0.06-0.15 (0.08)
		North Channel	• Boro/**Maize**-Jute-Fallow • **Onion**-Teel-Aus-Fallow • **Boro**/Onion- Garlic- Jute-Fallow • Mustard/**Maize**-Aus/Jute/Teel-Fallow • Mustard/**Maize**-Aus/Jute/Teel-Fallow	Silty Loam	7.7-7.9 (7.82)	1.15-1.5 (1.30)	0.04-0.08 (0.06)

Value in the parenthesis is average value of the respective column. Bolded word represents existing crop during sampling.

Biochemical and molecular characterization of potential bacteria: Potential bacteria from AEZ-10 were identified and characterized for nitrogen fixation, phosphate solubilizing and indoleacetic acid production (Table 44). Among the selected nine bacteria, the higher concentration of N_2 (14 ppm) fixed by the strains (B41, B42, B43, B44, and B45) isolated from Char Madhobdia. The highest concentration of P solubilized from tri-calcium phosphate by the strain B38 (1730 ppm) followed by B41 (1698 ppm), B43 (1459 ppm) and B37 (1286 ppm). The highest concentration of IAA (28 ppm) was produced by the strain B38 isolated from Decreerchar. The potential bacteria identified from Decreerchar were *Bacillus cereus. Bacillus* sp. and *Acromobactor* sp. was identified from Char Madhobdia.

Table 44. Biochemical and molecular characteristics of the potential bacteria isolated from AEZ-10

District	Upazila	Union	Bacteria ID	Strain	Probability (%)	Population (Cfu/g soil)	Biochemical properties		
							N (ppm)	P (ppm)	IAA (ppm)
Faridpur	Faridpur Sadar	Decreer Char	B37	-		1×10^5	7	1286	3
			B38	*Bacillus cereus*	98	3×10^6	7	1730	28
			B39	*Brevundimonas naejangsanensis*	-	7×10^5	7	280	13
		Char Madhobdia	B40	-	-	7×10^6	14	1141	15
			B41	*Bacillus albus*	98	3×10^6	14	1698	3
			B42	-	-	2×10^6	14	141	2
			B43	-	-	2×10^6	14	1459	16
			B44	-	-	6×10^5	14	193	16
			B45	*Acromobactor sp*	93	4×10^6	14	146	6

Soil bio-physico-chemical properties of AEZ-11 (Jashore and Rajshahi)

The soil samples were collected from Jashore and Rajshahi district. (Fig. 51). A number of 40 soil samples from 0 to 15 cm depth (composite of 400 soils) were analysed to determine bio-physicochemical properties of AEZ-11(details in methothology section). The field history such as existing crop, cropping pattern and farmers details were recorded**.** In the Jashore district, soil samples were collected form Jhikorgacha (Panisara union and Gadkhali union) and Monirumpur (Monirumpur union) upazila. In the Rajshahi district soil samples were collected from Durgapur (Pananagar union and Kismotgonkoir union) and Poba upazela (Boroigachi union).

Soil biology: Soil biological properties were described in the Table 45. Among the tested three unions, the higher total bacteria range was found in Panisara union (2×10^7 to 2×10^9 cfu/g soil) followed by Gadkhali (2×10^7 to 3×10^7 cfu/g soil) and Monirampur (3×10^6 to 4×10^7 cfu/g soil). The average total bacteria population was found Panisara (2×10^8 cfu/g soil). The higher population of free-living N_2 fixing bacteria (1×10^6 to 2×10^7 cfu/g soil) was found in Panisara compared to Monirampur (3×10^5 to 3×10^6 cfu/g soil) and Gadkhali (6×10^5 to 2×10^6 cfu/g soil). However, the population of average free-living N_2 fixing bacteria was higher in Monirampur (2×10^6 cfu/g soil). The highest range (2×10^5 to 3×10^5 cfu/g soil) and average (3×10^5 cfu/g soil) population of phosphate solubilizing bacteria was in Gadkhali followed by Monirampur (1×10^4 to 3×10^5 cfu/g soil) and Panisara (2×10^4 to 4×10^4 cfu/g soil). There was no variation in Actinomycetes population range among the three unions. The range of fungus population was high in Panisara (4×10^4 to 7×10^7 cfu/g soil) compared to Monirampur (4×10^4 to 2×10^5 cfu/g soil) and Gadkhali (1×10^4 to 8×10^4 cfu/g soil). The average population was similar in Panisara and Gadkhali. The highest population range of Rhizobium was found in Panisara (5×10^5 to 1×10^8 cfu/g soil) followed by Monirampur (9×10^4 to 2×10^6 cfu/g soil) and Gadkhali (5×10^5 to 8×10^5 cfu/g soil). The average values of Rhizobium population were similar in three unions.

The total bacteria population of Rajshahi district was lower than Jashore district. Among the Three unions total bacteria population was high in Pananagar (1×10^7 to 2×10^7 cfu/g soil) compared to Kismotgonkoir (7×10^6 to 3×10^7 cfu/g soil) and Borogachi (4×10^6 to 2×10^7 cfu/g soil). However, average total bacteria population was similar. The range and average values of free-living N_2 fixing bacteria population was similar in these three unions. The average and range of population of phosphate solubilizing bacteria was lower in Pananagar (4×10^4 to 5×10^4 cfu/g soil) compared to Kismotgonkoi (2×10^5 to 4×10^5 cfu/g soil) and Borogachi (9×10^5 to 5×10^5 cfu/g soil). Actinomycetes population range was high in Borogachi (3×10^2 to 1×10^3 cfu/g soil) compared to other two unions of Rajshahi. However, average actinomycetes population

was similar. The range of fungus and Rhizobium populations were lower in the Pananagar compared to Kismotgonkoir and Borogachi.

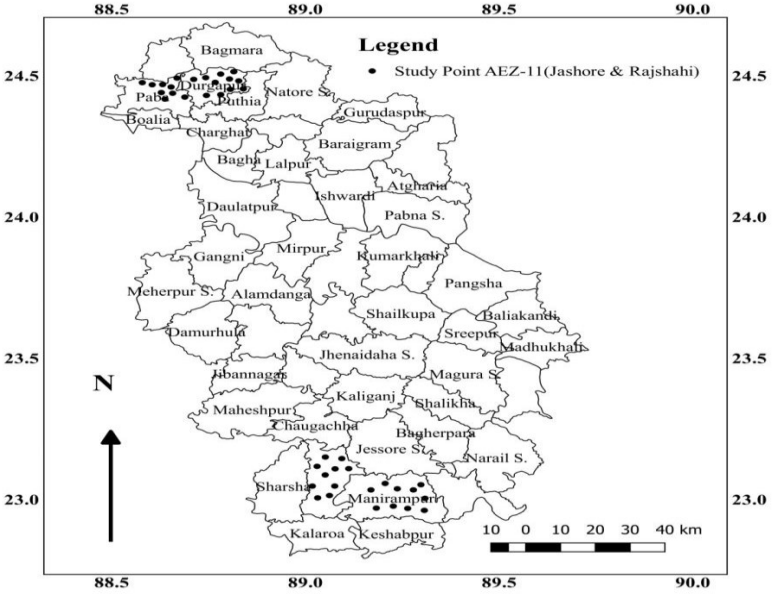


Fig. 51. Location map of AEZ-11 (Jashore and Rajshahi) originates from GPS information

Soil physico-chemical properties: Soil physicochemical properties of AEZ-11 were described in **Table 46a & 46b**. In Jashore, soil of the tested area were Silty clay loam (average 6.928% sand, 64.72% silt, 28.352% clay) to Silty loam (55.40% sand, 32.72% silt, 11.87% clay) in nature, and in Rajshahi, the texture of the soils were Silty loam where average sand 20.928%, silt 54.72%, and 24.352% clay. In Jashore soils of Panisara and Monirumpur were Silty clay loam whereas Gadkhali soil is Silty loam. The soil organic matter was ranged from 0.72 % to 2.3% in Jashore district, whereas it was 0.7% to 2.9% in Rajshahi district. On an average, the tested soils of Jashore and Rajshahi contained 0.09% and 0.08% total nitrogen (TN), respectively. Soils of Jashore were neutral average pH 7.37 and ranging from 6.11 to 7.98. Rajshahi soil was neutral to alkali, in nature, average pH 7.81and ranging from 6.13 to 8.5, respectively. The major crops in cropping pattern of Jashore were rice, mustard, jute lentil, vegetables and wheat. Rice, jute, mustard, chili, potato, onion, maize, cauliflower, and bitter gourd were main crops in the cropping pattern of Rajshahi.

Table 45. Soil biology of AEZ-11 (Jashore and Rajshahi)

District	Upazila	Union	Microbial populationranges (cfu/g soil)					
			TB	NFB	PSB	Act	Fungus	Rhizobium
Jashore	Jikorgacha	Panisara	2×10^{7}- 2×10^{9} (2×10^{8})	1×10^{6}- 2×10^{7} (7×10^{5})	2×10^{4}-4×10^{4} (1×10^{5})	1×10^{4} -8×10^{4} (4×10^{4})	4×10^{4} -7×10^{7} (2×10^{5})	5×10^{5} -1×10^{8} (7×10^{5})
		Gadkhali	2×10^{7}-3×10^{7} (3×10^{7})	6×10^{5}-2×10^{6} (1×10^{6})	2×10^{5}-3×10^{5} (3×10^{5})	1×10^{4}-6×10^{4} (4×10^{4})	1×10^{4}-8×10^{4} (4×10^{4})	5×10^{5}-8×10^{5} (6×10^{5})
	Monirumpur	Monirumpur	3×10^{6}-4×10^{7} (3×10^{7})	3×10^{5} -3×10^{6} (2×10^{6})	1×10^{4} -3×10^{5} (1×10^{5})	1×10^{4} -9×10^{4} (5×10^{4})	4×10^{4} -2×10^{5} (1×10^{5})	9×10^{4} -2×10^{6} (8×10^{5})
Rajshahi	Durgapur	Pananagar	1×10^{7} -2×10^{7} (1×10^{7})	5×10^{5} -1×10^{6} (8×10^{5})	4×10^{4}- 5×10^{4} (4×10^{4})	1×10^{2} -4×10^{2} (3×10^{2})	2.5×10^{3}-3×10^{3} (3×10^{3})	4×10^{4}-5×10^{4} (4×10^{4})
		Kismotgonkoir	7×10^{6} -3×10^{7} (2×10^{7})	6×10^{5} -2×10^{6} (1×10^{6})	2×10^{5} -4×10^{5} (2×10^{5})	1×10^{2} -6×10^{2} (3×10^{2})	4×10^{3} -1×10^{4} (7×10^{3})	2×10^{5} -4×10^{5} (2×10^{5})
	Poba	Boroigachi	4×10^{6} -2×10^{7} (1×10^{7})	4×10^{5} -1×10^{6} (7×10^{5})	9×10^{5}-5×10^{5} (2×10^{5})	3×10^{2} -1×10^{3} (5×10^{2})	3×10^{3} -1×10^{4} (6×10^{3})	9×10^{5} -8×10^{5} (2×10^{5})

Here, TB: total bacteria, NFB: Free-living N_2 fixing bacteria, PSB: phosphate solubilizing bacteria and Act: Actinimycetes. Value in the parenthesis is average value of the respective population in each column.

Table 46a. Soil physico-chemical properties of AEZ-11 (Jashore)

District	Upazila	Union	Cropping patterns of the sample collecting point	Physical property	Ranges of Chemical properties		
				Texture	Soil pH	OM (%)	TN (%)
Jashore	Jhikargacha	Panisara	• Boro/ **Mustard**-Fallow-Aman • **Mustard**/Lentil - Jute- Aman • Boro/ **Mustard** – Fallow-Aman • Boro-Aus- **Tomato** • **Boro-**Aus-Vegetable • **Boro-**Aus-Vegetable • **Boro**-Fallow-Aman	Silty clay loam	7.2-7.8 (7.52)	1.5-2.3 (1.79)	0.09-0.11 (0.09)
		Gadkhali	• **Boro**-Aus-Aman • **Boro**/ Mustard-Fallow-Aman • Boro/**Pea-**Fallow T.Aman	Silty loam	6.1-7.7 (7.06)	0.07-1.9 (1.46)	0.07-0.11 (0.08)
	Monirumpur	Monirumpur	• Boro-**Fallow**-T.Aman • **Mustard**-Mugbean-Vegetable • Boro/ **Mustard**-Fallow-Aman • **Tomato**-Vegetable-Fallow- Fallow • Boro-**Fallow**-T.Aman • **Lentil**-Jute-Aman • **Wheat**-Jute-Aman • **Vegetable**-Jute-Aman • **Boro**-Fallow-T. Aman • **Vegetable**-Jute-Aman	Silty clay loam	7.0-8.0 (7.55)	1.4-2.3 (1.87)	0.04-0.08 (0.10)

Value in the parenthesis is average value of the respective column. Bolded word represents existing crop during sampling.

Biochemical and molecular characterization of potential bacteria: Potential bacteria from AEZ-11 were identified and characterized for nitrogen fixation, phosphate solubilizing and indoleacetic acid production **(Table 47).** Among the selected twelve bacteria, the highest concentration of N_2 (21 ppm) was fixed by the strain B70 isolated from Pananagar union of Rajshahi. The highest concentration of P was solubilized from tri-calcium phosphate by the strain B64 (3582 ppm) of Panisara union of Jashore district followed by B75 (2408 ppm) Boroigachi union of Rajshahi, B67 (2009 ppm) Monirampur union of Jashore and B70 (1448 ppm) Pananagar union of Rajshahi. The highest concentration of IAA (34 ppm) was produced by the strain B64 isolated from Panisara union of Jashore. The potential bacteria identified from Panagar, Rajshahi was *Pseudomonas* sp. *Stenotrophomonas maltophilia* from Panisara Jashore and *Bacillus cereus* was identified from Monirampur, Jashore.

Table 46b. Soil physico-chemical properties of AEZ-11 (Rajshahi)

District	Upazila	Union	Cropping patterns of the sample collecting point	Physical property	Chemical properties		
				Texture	Soil pH	OM (%)	TN (%)
Rajshahi	Durgapur	Pananagar	• Boro/**Mustard**-Jute-Aman • Boro/ **Mustard**-Jute-Aman	Silty loam	8.4-8.5 (8.43)	1-1.2 (1.09)	0.08 (0.08)
		Kismotgonkoir	• **Chilli**-Potato-Onion • **Onion**-Jute-Fallow • Boro/**Mustard** -Fallow-Fallow • Boro/ **Mustard**-Fallow-Aman • Boro/ **Mustard**-Fallow-Aman • Boro/ **Mustard**-Fallow-Aman • Boro/ **Mustard**-Fallow-Aman • **Onion**-Jute-T.Aman	Silty loam	7.4-8.1 (7.71)	0.7-2.9 (1.28)	0.06-0.11 (0.09)
	Poba	Boroigachi	• **Potato**-Cauliflower-Bittergourd • Late Boro-Fallow-T.Aman **- Potato** • **Potato**/Maize-FallowT.Aman • Late Boro-Vegetable- **Potato** • Late Boro-Vegetable **-Potato** • Boro/ **Mustard** –Fallow-T.Aman • Boro/ **Mustard** –Fallow-T.Aman • Late Boro-T.Aman- **Potato** • Late Boro-T.Aman- **Potato** • Late Boro-T.Aman- **Potato**	Silty loam	6.1-7.7 (7.29)	0.8-2.1 (1.38)	0.06-0.13 (0.08)

Value in the parenthesis is average value of the respective column. Bolded word represents existing crop during sampling.

Table 47. Biochemical and molecular characteristics of the potential bacteria isolated from AEZ-11

District	Upazila	Union	Bacteria ID	Strain	Probability (%)	Population (Cfu/g soil)	Biochemical properties		
							N (ppm)	P (ppm)	IAA (ppm)
Jashore	Jhikargacha	Panisara	B64	*Pseudomonas* sp.	96	2×10^6	7	3582	34
			B65	-		1×10^6	14	142	5
			B66	-		5×10^6	7	623	30
		Gadkhali	-	-					
	Monirampur	Monirampur	B67	-		2×10^7	14	2009	6
			B68	-		6×10^5	7	204	4
			B69	*Stenotrophomonas maltophilia*	99	4×10^6	14	1403	26
Rajshahi	Durgapur	Pananagar	B70	*Bacillus cereus*	96	1×10^7	21	1448	11
			B71	-		3×10^5	14	88	4
			B72	-		1×10^6	14	1315	4
		Kismotgonkoir	-	-					
	Poba	Boroigachi	B73	-		5×10^6	14	34	11
			B74	-		2×10^6	14	37	24
			B75	*Bacillus sp.*		7×10^5	14	2408	8

Here, IAA represents indoleacetic acid

Soil bio-physico-chemical properties of AEZ-13 (Satkhira)

The soil samples were collected from Satkhira district. (Fig.52). A number of 20 soil samples from 0 to 15 cm depth (composite of 200 soils) were analysed to determine bio-physicochemical properties of AEZ-13(details in methothology section). The field history such as existing crop, cropping pattern and farmers' details were recorded. In the Satkhira district, soil samples were collected form Ashasuni (Borodol union) and Shyamnagar (Shyamnagar union) upazila.

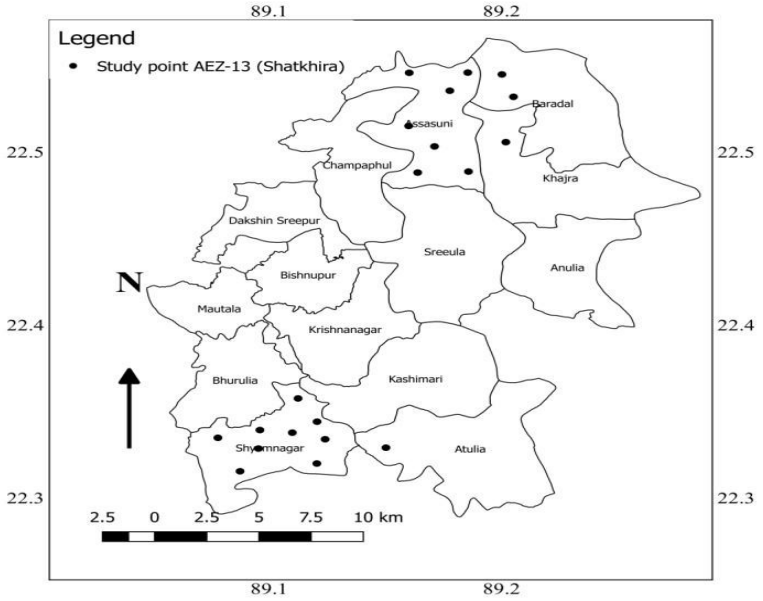


Fig. 52: Location map ofAEZ-13 (Satkhira) originates from GPS information

Soil biology: Soil biological properties were described in the **Table 48**. Total bacteria range was found in Borodol union (9×10^5 to 1×10^7 cfu/g soil) and Shyamnagar union (1×10^6 to 3×10^7 cfu/g soil). The average total bacteria population was found almost similar in Borodol (6×10^6 cfu/g soil) and Shyamnagar union (9×10^6 cfu/g soil). The population range of free-living N_2 fixing bacteria was 6×10^4 to 2×10^6 cfu/g soil in Borodol union and 8×10^4 to 3×10^5 cfu/g soil in Shyamnagar union. The population of phosphate solubilizing bacteria ranged from 8×10^4 to 3×10^5 cfu/g soil and 1×10^4 to 5×10^5 cfu/g soil in Borodol and Shymnagar, respectively. The average (1×10^5 cfu/g soil) population of phosphate solubilizing bacteria was higher in Borodol compared to Shyamnagar (9×10^4 cfu/g soil). Actinomycetes population range was higher in Borodol union (1×10^2 to 1×10^3 cfu/g soil) compared to Shyamnagar (1×10^2 to 8×10^2 cfu/g soil). However average actinomycetes population was similar in the both unions. The range and average p**op**ulation of fungus and Rhizobium were similarin the both unions.

Table 48. Soil biology of AEZ-13 (Satkhira)

District	Upazila	Union	Microbial population ranges (cfu/g soil)					
			TB	NFB	PSB	Act	Fungus	Rhizobium
Satkhira	Ashashuni	Borodol	9×10^5 – 1×10^7 (6×10^6)	6×10^4 – 2×10^6 (4×10^5)	8×10^4- 3×10^5 (1×10^5)	1×10^2 - 1×10^3 (4×10^2)	3×10^3- 1×10^4 (6×10^3)	5×10^4 – 3×10^5 (1×10^5)
	Shyamnagar	Shyamnagar	1×10^6 – 3×10^7 (9×10^6)	8×10^4 - 2×10^6 (5×10^5)	1×10^4 - 5×10^5 (9×10^4)	1×10^2 - 8×10^2 (3×10^2)	1×10^3 - 2×10^4 (7×10^3)	1×10^4 -7×10^5 (2×10^5)

Here, TB: total bacteria, NFB: Free-living N_2 fixing bacteria, PSB: phosphate solubilizing bacteria and Act: Actinomycetes. Value in the parenthesis is average value of the respective population in each column.

Soil physico-chemical properties: Soil physico-chemical properties were given in Table 49. The soils of Borodol, Satkhira was Silty Clay Loam with average pH 7.11 and ranged from 5.1 to 7.9. The soils of Shyamnagar were Silty Loam and pH ranged from 5.7 to 7.2 with an average value of 6.27. Soil organic matter ranged from 1.1 to 3.1% and 1.31 to 2.1% in Borodol and Shyamnagar, respectively. The average organic matter (1.69%) was similar for both of the union. Average total nitrogen was higher in the Borodol (0.11%) compared to Shyamnagar (0.07%). The major crop in the cropping patterns was only T. Aman rice in this area.

Biochemical and molecular characterization of potential bacteria: Potential bacteria from AEZ-13 were identified and characterized for nitrogen fixation, phosphate solubilizing and indoleacetic acid production (Table 50). Among the selected six bacteria, there was no difference found for N_2 (14 ppm) fixation, however the highest concentration of P solubilized from tri-calcium phosphate by the strain B77 (2394 ppm) of Borodol union followed by B81 (2353ppm) Shyamnagar union. The highest concentration of IAA (69 ppm) was produced by the strain B77 isolated from Borodol union. The potential bacteria was identified from Shyamnagar was *Bacillus amyloliquefaciens.*

Table 49. Soil physico-chemical properties of AEZ-13 (Satkhira)

District	Upazila	Union	Cropping patterns of the sample collecting point	Physical property	Chemical properties		
				Texture	Soil pH	OM (%)	TN (%)
Satkhira AEZ13	Ashasuni	Borodol	• **Fallow**-Fallow-T.Aman • **Fallow**-Fallow-T.Aman • **Fallow**-Fallow-T.Aman • **Fallow**-Fallow-T.Aman • **Fallow**-Fallow-T.Aman • **Fallow**-Fallow-T.Aman • **Fallow**-Fallow-T.Aman • **Fallow**-Fallow-T.Aman • **Fallow**-Fallow-T.Aman • **Fallow**-Fallow-T.Aman • **Fallow**-Fallow-T.Aman	Silty clay loam	5.1-7.9 (7.11)	1.1-3.1 (1.69)	0.07-0.19 (0.11)
	Shyamnagar	Shyamnagar	• **Fallow**-Fallow-T.Aman • **Fallow**-Fallow-T.Aman • **Fallow**-Fallow-T.Aman • **Fallow**-Fallow-T.Aman • **Fallow**-Fallow-T.Aman • **Fallow**-Fallow-T.Aman • **Fallow**-Fallow-T.Aman • **Fallow**-Fallow-T.Aman • **Fallow**-Fallow-T.Aman	Silty Loam	5.7-7.2 (6.27)	1.31-2.1 (1.69)	0.05-0.11 (0.07)

Value in the parenthesis is average value of the respective column. Bolded word represents existing crop during sampling.

Table 50. Biochemical and molecular characteristics of the potential bacteria isolated from AEZ-13

District	Upazila	Union	Bacteria ID	Strain	Probability (%)	Population (Cfu/g soil)	Biochemical properties		
							N (ppm)	P (ppm)	IAA (ppm)
Satkhira	Ashasuni	Borodol	B76	-	-	1×10^7	14	74	22
			B77	-	-	1×10^3	14	2394	69
			B78	Bacellius cereus	98	6×10^6	14	1621	27
	Shyamnagar	Shyamnagar	B79	-	-	2×10^7	14	43	28
			B80	*Sporosarcina pasteurii*	-	4×10^6	14	920	2
			B81	*Bacillus amyloliquefaciens*	98	3×10^6	14	2353	13

Here, IAA represents indoleacetic acid

Bio-physico-chemical properties of AEZ-15

The soil samples were collected from Munshiganj district. (Fig.53). A number of 20 soil samples from 0 to 15 cm depth (composite of 200 soils) were analysed to determine bio-physicochemical properties of AEZ-15(details in methothology section). The field history such as existing crop, cropping pattern and farmers details were recorded. In the Munshiganj district, soil samples were collected form Shymshiddhi union, Shologhar union and Hashara union of Srinagar upazila.

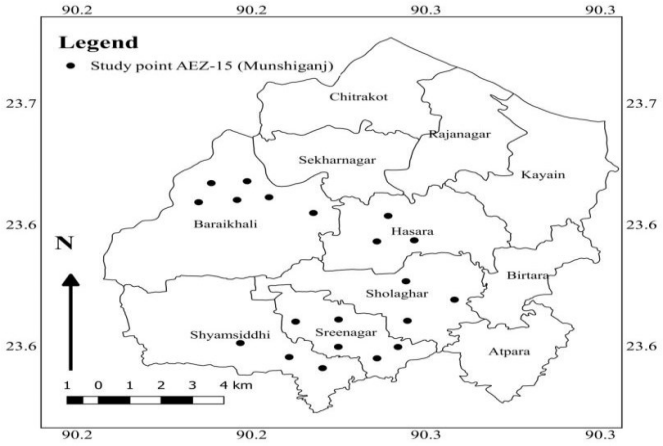


Fig. 53. Location map ofAEZ-15 (Munshiganj) originates from GPS information

Soil biology: Soil biological properties were described in the Table 51. Total bacteria range was higher in Shyamshiddhi (2×10^6 to 3×10^8 cfu/g soil) and Hashara union (1×10^6 to 3×10^8 cfu/g soil) compared to Shologhar (4×10^6 to 2×10^7 cfu/g soil). The average total bacteria population was found almost similar in Shyamshiddhi (8×10^7 cfu/g soil) and Hashara union (7×10^7 cfu/g soil), however it was 9×10^6 cfu/g soil in Shologhar union. The population range of free-living N_2 fixing bacteria were 3×10^5 to 1×10^6 cfu/g soil in Shyamshiddhi union, 9×10^5 to 1×10^6 cfu/g soil in Shologhar union and 2×10^5 to 2×10^6 cfu/g soil in Hashara union. The population of phosphate solubilizing bacteria ranged from 1×10^5 to 4×10^5 cfu/g soil and 1×10^5 to 2×10^5 cfu/g soil in Shyamshiddhi and Shologhar union, respectively. The population range

of phosphate solubilizing bacteria was lower in Hasahra union. Nevertheless, the average population of phosphate solubilizing bacteria was similar in all unions. Actinomycetes population range and average were similar in all three unions of Sreenagar Upazela. Fungus population range was high in the Hashara union (2×10^3 to 1×10^4 cfu/g soil) compared to other two unions. However, average fungus population were almost similar. The range of Rhizobium population was lower in Shyamshiddhi (9×10^4 to 4×10^5 cfu/g soil) compared to Shologhar (1×10^5 to 5×10^5 cfu/g soil) and Hashara (1×10^5 to 7×10^5 cfu/g soil). The average population of Rhizobium were similar in all three unions.

Soil physico-chemical properties: Soil physico-chemical properties were given in Table 52. The soils of Shyamshiddhi and Hashara were Clay with average pH 5.68 and 6.34 respectively. Soil pH ranged from 5.0 to 6.2 in Shyamshiddhi and 5.5 to 6.8 in Hashara union. The soils of Shologhar were Silty Clay Loam and pH ranged from 6.1 to 6.4 with an average value of 6.18. Soil organic matter ranged from 1.4 to 3.6%, 1.4 to 2.4% and 1.6 to 3.5% in Shyamshiddhi, Shologhar and Hashara union, respectively. The average organic matter was lower (1.67%) in Shologhar compared to other two unions. Average total nitrogen was higher in the Shyamshiddhi (0.15%) and Hashara (0.14%) compared to Shologhar (0.10%) union. The major crops in the cropping patterns were Boro rice, Sweetgourd, Bittergourd, Mustard, Potato, and Gourd this area.

Table 51. Soil biology of AEZ-15 (Munshiganj)

District	Upazila	Union	Microbial population ranges (cfu/g soil)					
			TB	NFB	PSB	Act	Fungus	Rhizobium
Munshiganj	Sreenagar	Shyamshiddhi	2×10^6 -3×10^8 (8×10^7)	3×10^5-1×10^6 (7×10^5)	1×10^5 -4×10^5 (3×10^5)	1×10^3 -4×10^3 (2×10^3)	1×10^3 -9×10^3 (4×10^3)	9×10^4 -4×10^5 (3×10^5)
		Shologhar	4×10^6 -2×10^7 (9×10^6)	9×10^5 -1×10^6 (9×10^5)	1×10^5 -2×10^5 (2×10^5)	1×10^3 -4×10^3 (3×10^3)	2×10^3 -7×10^3 (4×10^3)	1×10^5 -5×10^5 (3×10^5)
		Hashara	1×10^6 -6×10^8 (7×10^7)	2×10^5 -2×10^6 (7×10^5)	4×10^4 -3×10^5 (1×10^5)	2×10^3 -7×10^3 (4×10^3)	2×10^3 -1×10^4 (5×10^3)	1×10^5 -7×10^5 (3×10^5)

Here, TB: total bacteria, NFB: Free-living N_2 fixing bacteria, PSB: phosphate solubilizing bacteria and Act: Actinomycetes. Value in the parenthesis is average value of the respective population in each column.

Table 52. Soil physico-chemical properties of AEZ-15, Munshiganj

District	Upazila	Union	Cropping patterns of the sample collecting point	Physical property	Chemical properties		
				Texture	Soil pH	OM (%)	TN (%)
Munshiganj	Sreenagar	Shyamshiddhi	• **Boro**-Sweetgourd-Bittergourd • **Boro**-Fallow-Fallow • **Boro**-Fallow-Fallow • **Boro**-Fallow-Fallow • **Fallow**- Bittergourd Fallow • **Boro**-Fallow-Fallow • **Boro** / Mustard - Fallow- Fallow	Clay	5.0-6.2 (5.68)	1.4-3.6 (2.27)	0.09-0.2 (0.15)
		Shologhar	• **Boro**-Fallow-Potato • **Boro**-Fallow-Potato • **Boro**-Mustard-Potato	Silty clay loam	6.1-6.4 (6.18)	1.4-2.4 (1.67)	0.09-0.13 (0.10)
		Hashara	• **Boro**-Fallow-Fallow • **Boro**-Fallow-Fallow • **Boro**-Fallow-Fallow • **Vegetable**-Vegetable-Vegetable • **Boro**/Mustard-Fallow-Fallow • **Tomato**-Gourd-Bittergourd • **Boro**/Mustard-Fallow-Fallow • Boro/**Mustard**-Fallow-Fallow • Boro/**Mustard**-Fallow-Fallow • Boro/**Mustard**-Fallow-Fallow	Clay	5.5-6.8 (6.34)	1.6-3.5 (2.48)	0.09-0.18 (0.14)

Value in the parenthesis is average value of the respective column. Bolded word represents existing crop during sampling.

Biochemical and molecular characterization of potential bacteria: Potential bacteria from AEZ-15 were identified and characterized for nitrogen fixation, phosphate solubilizing and indoleacetic acid production (Table 53). Among the selected six bacteria, the highest N_2 fixation (28 ppm) was recorded in B61 followed by B62, these two bacteria were isolated from Hashara union. The highest concentration of P solubilized from tri-calcium phosphate by the strain B58 (2361 ppm) followed by B59 (1604 ppm) from the Shyamshiddhi union. The highest concentration of IAA (144 ppm) was produced by the strain B59 isolated from same union. The potential bacteria *Pseudomonas geniculata* (B61) was identified from Shyamshiddhi.

Table 53. Biochemical and molecular characteristics of the potential bacteria isolated from AEZ-15

District	Upazila	Union	Bacteria ID	Strain	Probability (%)	Population (cfu/g soil)	Biochemical properties		
							N (ppm)	P (ppm)	IAA (ppm)
Munshiganj	Sreenagar	Shyamshiddhi	B58	-	-	8×10^6	14	1604	11
			B59	*Stenotrophomonas pavanii*	-	4×10^6	14	2961	144
			B60	-	-	1×10^6	14	122	4
		Shologhar	-	-	-	-	-	-	-
		Hashara	B61	*Pseudomonas geniculata*	98	3×10^6	28	1403	12
			B62	-	-	3×10^5	21	13	6
			B63	-	-	3×10^5	14	129	9

Here, IAA represents indoleacetic acid

Bio-physico-chemical properties of AEZ-16

The soil samples were collected from Munshiganj and Brahmanbaria district (Fig. 54)**.** A number of 40 soil samples from 0 to 15 cm depth (composite of 400 soils) were analysed to determine bio-physicochemical properties of AEZ-16 (details in methothology section). The field history such as existing crop, cropping pattern and farmers' details were recorded. In the Munshiganj district, soil samples were collected form Baluakandi and Tengarchar union of Gajaria upazila. While, in Brahmanbaria district, soil sampling was done in Bancharampur and Salimabad union of Bancharampur upazila.

Soil biology: Soil biological properties were described in the Table 54. Among the tested two unions of Gajaria, the higher total bacteria range was found in Baluakandi union (9×10^5 to 1×10^7 cfu/g soil). In the Tengarchar union total bacteria ranged from 6×10^5 to 7×10^6 cfu/g soil. The higher population of free-living N_2 fixing bacteria (1×10^4 to 4×10^6 cfu/g soil) was found in Baluakandi compared to Tengarchar union (3×10^4 to 6×10^5 cfu/g soil). However, the average population of total bacteria and free-living N_2 fixing bacteria was almost similar in both unions. The higher population range (1×10^4 to 4×10^5 cfu/g soil) of phosphate solubilizing bacteria was recorded in Baluakandi compared to Tengarchar (1×10^4 to 4×10^4 cfu/g soil). The Actinomycetes population was also high in Baluakandi union however the average actinomycetes populations were similar. The range of fungus and *Rhizobium* population was similar in two unions.

The total bacteria population of Brahmanbaria district was higher than Munshiganj district. Total bacteria population ranged from 7×10^6 to 3×10^7cfu/g soil in Bancharampur and 2×10^6 to 3×10^7 cfu/g soil in Salimabad union. However, average total bacteria population was high (2×10^7) in Bancharampur. The range and average values of free-living N_2 fixing bacteria, phosphate solubilizing bacteria and actinomycetes population was similar in these two unions. Fungus population range was high in Salimabad

(2×10^3 to 2×10^4 cfu/g soil) compared to Bancharampur union (1×10^3 to 8×10^3 cfu/g soil) of Brahmanbaria. The range of Rhizobium populations was lower in Salimabad (1×10^5 to 2×10^6 cfu/g soil) compared to Bancharampur union (5×10^4 to 3×10^5 cfu/g soil).

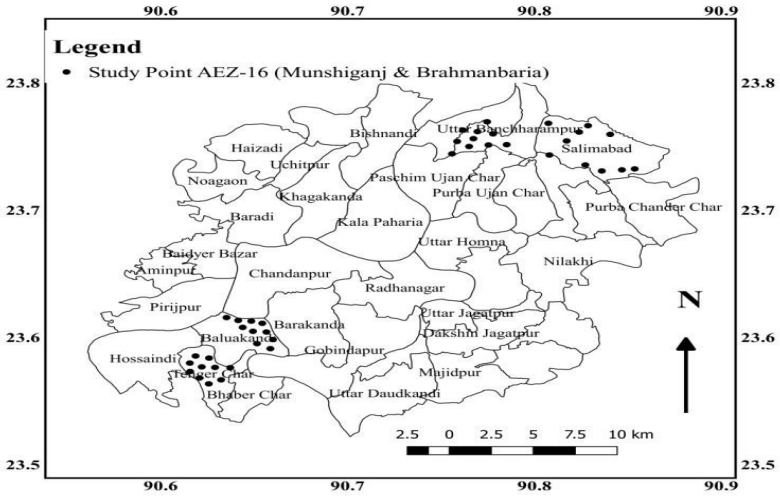


Fig. 54. Location map ofAEZ-16 (Munshiganj and Brahmanbaria) originates from GPS information

Table 54. Soil biology of AEZ-16 (Munshiganj and Brahmanbaria)

District	Upazila	Union	Microbial populationranges (cfu/g soil)					
			TB	NFB	PSB	Act	Fungus	Rhizobium
Munshiganj	Gajaria	Baluakandi	9×10^5 -1×10^7 (1×10^6)	1×10^4 -4×10^6 (7×10^5)	1×10^4 -4×10^5 (2×10^5)	1×10^3 -1×10^4 (5×10^3)	1×10^3 -1×10^4 (7×10^3)	5×10^4 -5×10^5 (3×10^5)
		Tengarchar	6×10^5-7×10^6 (3×10^6)	3×10^4-6×10^5 (2×10^5)	1×10^4-4×10^5 (1×10^5)	1×10^3 -8×10^3 (4×10^3)	1×10^3 -1×10^4 (9×10^3)	3×10^4 -2×10^5 (1×10^5)
Brahmanbaria	Bancharampur	Bancharampur	7×10^6 -3×10^7 (2×10^7)	3×10^5 -3×10^6 (1×10^6)	1×10^5 – 4×10^5 (3×10^5)	1×10^3 -5×10^3 (3×10^3)	1×10^3-8×10^3 (3×10^3)	1×10^5 -2×10^6 (5×10^5)
		Salimabad	2×10^6 -3×10^7 (9×10^6)	4×10^5 -10×10^6 (6×10^5)	2×10^5 – 4×10^5 (3×10^5)	1×10^3 -5×10^3 (2×10^3)	2×10^3-2×10^4 (1×10^4)	5×10^4-3×10^5 (3×10^5)

Here, TB: total bacteria, NFB: Free-living N_2 fixing bacteria, PSB: phosphate solubilizing bacteria and Act: Actinomycetes. Value in the parenthesis is average value of the respective population in each column.

Soil physico-chemical properties: Soil physicochemical properties of AEZ-16 were described in Table 55a & 55b. The soil texture of the Baluakandi and Tengarchar union of Munshiganj was Silty clay and Silty clay loam in nature. Soil pH ranged from 5.8 to 7.3 in Baluakandi and 5.6 to 6.1 in Tengarchar of Munshiganj. The range of soil organic matter and total nitrogen in Baluakandi were 1.0 to 2.8 %, and 0.09 to 0.18%, while, in Tengarchar it was 1.2 to 2.1% and 0.07 to 0.15%. The average pH value (6.41), soil organic matter (1.78%) and total nitrogen (0.12%) was higher in Baluakandi compared to Tengarchar (Table 55a). Soil samples were collected from Boro, Mustard, T. Aman, Potao and Chili containing cropping pattern.

In the Brahmanbaria, soil texture of Bancharampur was Silty clay loam and in Salimabad it was Silty loam. Soil pH of Bancharampur ranged from 5.9 to 6.7 with an average value of 6.34. Whereas, the range of soil pH was 6.0 to 6.8 and average pH was 6.41. The value in the range of soil organic matter and total nitrogen were higher in Bancharampur compared to Salimabad. The crops in the cropping pattern of Salimabad were almost similar to the Bancharampur union (Table 55b)

Table 55a. Physico-chemical properties of AEZ-16

District	Upazila	Union	Cropping patterns of the sample collecting point	Physical property	Chemical properties		
				Texture	Soil pH	OM (%)	TN (%)
Munshiganj	Gajaria	Baluakandi	• **Boro**-fallow-fallow • **Vegetable**- Dhaincha-Aman • **Cucumber/**Chilli - Dhaincha-Aman • **Boro**-Fallow-Fallow-water hayacinth • **Tomato**-Patshak-Data-Aman • **Sharisha**/Rabicrop- Jute-Fallow-Fallow • **Boro**-Dhaincha-Aman-Sweetpotato • **Boro**-Fallow-Fallow • **Boro**-Fallow-Fallow	Silty clay	5.8-7.3 (6.41)	1.0-2.8 (1.78)	0.09-0.18 (0.12)
		Tengarchar	• **Boro**-Fallow-Fallow • **Potato**-Fallow-Aman • **Vegetable** - Fallow -Aman • **Boro**-Fallow-Fallow • **Boro**-Fallow-Fallow • **Boro**-Fallow-Fallow • **Boro**-Fallow-Fallow • **Boro**-Fallow-Fallow • **Boro**-Fallow-Fallow • **Mustard**- Fallow -Aman	Silty clay loam	5.6-6.1 (5.86)	1.2-2.1 (1.55)	0.07-0.15 (0.10)

Value in the parenthesis is average value of the respective column. Bolded word represents existing crop during sampling.

Table 55b. Physico-chemical properties of AEZ-16

District	Upazila	Union	Cropping patterns of the sample collecting point	Physical property	Chemical properties		
				Texture	Soil pH	OM (%)	TN (%)
Brahmanbaria	Bancharampur	Bancharampur	• **Boro**-T.aman-Sweet potato • Boro/**Mustard** -Fallow-T.Aman • Wheat/**Mustard** – Jute/Teel-T.aman • **Boro** -Jute-T.aman • Boro-T.aman-Jute • Boro/Potato/**Chilli**-Jute-T.aman • Boro/**Mustard** -Fallow-T.Aman • **Boro**-Fallow-Fallow • **Boro**-Fallow-Fallow • **Chilli+Coriender**/Boro-Fallow-Fallow	Silty clay loam	5.9-6.7 (6.34)	0.5-1.7 (1.07)	0.04-0.11 (0.08)
		Salimabad	• **Mustard** - Til T.aman • **Boro**-Fallow-Fallow • **Boro**-Fallow-Fallow • Boro/**Mustard** –Fallow-T.aman • **Tomato**/Chilli-Fallow-Vegetable • **Potato**- Til -T.aman/Blakhkgram • **Boro**- Til -Cucumber • **Chilli**/ Mustard -T.aman- • **Boro**-Fallow-Fallow • **Boro**-Fallow-Fallow	Silty loam	6.0-6.8 (6.41)	1.1-2.1 (1.51)	0.06-0.14 (0.09)

Value in the parenthesis is average value of the respective column. Bolded word represents existing crop during sampling.

Biochemical and molecular characterization of potential bacteria: Potential bacteria from AEZ-16 were identified and characterized for nitrogen fixation, phosphate solubilizing and indoleacetic acid production (Table 56). Among the selected twelve bacteria, the highest N_2 fixation (21 ppm) was recorded in B14 and B23, and these two strains were isolated from Baliakandi and Salimabad union, respectively. The highest concentration of P solubilized from tri-calcium phosphate was recorded by the strain B20 (1947 ppm) followed by B14 (1791 ppm) and these two strains were isolated from Bancharampur and Baliakandi union, respectively. The highest concentration of IAA (17 ppm) was produced by the strain B16, that isolated from Tengarchar union. The potential bacteria *Bacillus tropicus* (B14 isolate) was identified from Tengarchar and *Bacillus pumilis* (B20 isolate) from Bancharampur union.

Table 56. Biochemical and molecular characteristics of the potential bacteria isolated from AEZ-16

District	Upazila	Union	Bacteria ID	Strain	Probability (%)	Population (cfu/g soil)	Biochemical properties		
							N (ppm)	P (ppm)	IAA (ppm)
Munshiganj	Gajaria	Baluakandi	B13			3×10^5	14	264	12
			B14	*Bacillus tropicus*	99	6×10^5	21	1791	2
			B15			4×10^6	14	88	7
		Tengarchar	B16			2×10^5	7	295	17
			B17			6×10^5	4	1347	2
			B18			2×10^6	14	1	5
Brahman Baria	Bancharampur	Bancharampur	B19			1×10^7	7	67	6
			B20	*Bacillus pumilis*	98	3×10^5	14	1947	4
			B21			3×10^6	7	45	14
		Salimabad	B22			4×10^6	14	746	4
			B23			2×10^6	21	45	5
			B24			2×10^6	14	239	12

Here, IAA represents indoleacetic acid

Bio-physico-chemical properties of AEZ-19

The soil samples were collected from Cumilla and Kishoreganj district. (Fig.55). A number of 40 soil samples from 0 to 15 cm depth (composite of 400 soils) were analysed to determine bio-physicochemical properties of AEZ-19 (details in methothology section). The field history such as existing crop, cropping pattern and farmers' details were recorded**.** In the Cumilla district, soil samples were collected form Burichang and Deviddar upazela. While, in Kishoreganj district, soil sampling was done in Mithamoin, Itna and Austogram upazila.

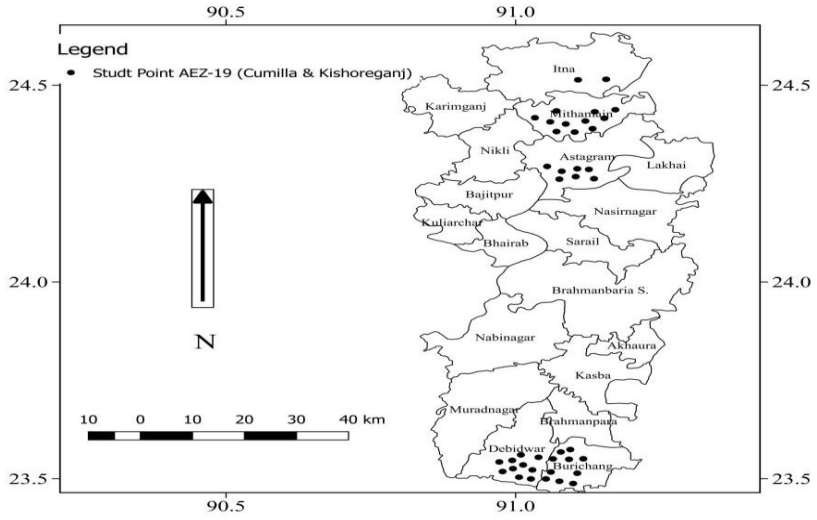


Fig. 55. Location map ofAEZ-19 (Cumilla and Kishoreganj) originates from GPS information

Soil biology: Soil biological properties were described in the Table 57. In the Cumilla district, soil sample were collected from Dokkhin Verala union of Burichang upazila and Uttor Barkanda union of Deviddar upazila. Among the tested two unions, the population range and average population was higher in the Uttor Barkanda. The higher average population of free-living N_2 fixing bacteria (4×10^6 cfu/g soil) was found in Uttor Barkanda union compared to Dokkhin Verala (5×10^5 cfu/g soil). However, value of population range was almost similar in the both unions. Moreover, the average population and range were similar for phosphate solubilizing bacteria in the both unions. Higher Actinomycetes population range (1×10^3 to 1×10^4 cfu/g soil) was noticed in the Uttor Barkanda on the other hand, Fungus and Rhizobium population were higher in the Dokkhin Verala.

A total seven unions of Kishoreganj were studied, among them Kaeorjor, Ghagra and Mithamoin union were under Mithamoin upazela. In this upazela the highest range and average bacteria were recorded in the Mithamoin union (1×10^7 to 2×10^7 cfu/g soil) followed by Kaeorjor (1×10^6 to 1×10^7 cfu/g soil) and Ghagra (4×10^6 to 8×10^6 cfu/g soil). The highest range of free-living N_2 fixing bacteria and phosphate solubilizing bacteria were found in the Ghagra (1×10^6 to 3×10^6 cfu/g soil) and Mithamoin (1×10^5 to 2×10^5 cfu/g soil), respectively. Among three unions, the lower Actinomycetes population (5×10^2 to 9×10^2 cfu/g soil) was recorded in the Ghagra union, while; the fungus population range was higher (2×10^4 to 3×10^4 cfu/g soil) in the Kaeorjor union. The highest range of Rhizobium population was recorded in the Mithamoin (2×10^5 to 2×10^6 cfu/g soil), followed by Ghajra (1×10^5 to 4×10^5 cfu/g soil) and Kaeorjor (4×10^4 to 1×10^5 cfu/g soil).

Joyshiddi union was under Itna upazela of Kishoregonj, while, Kastail, Deoghar and Austogram unions were under Austogram upazela. There were no variations in the range of total population among the four unions. Free- living N_2 fixing bacteria population was almost similar in the Kastail, Joyshiddi and Austogram union. The range of phosphate solubilizing bacteria was lower in the (4×10^4 to 7×10^7 cfu/g soil) Joyshiddi union, however average population is similar in all of the four unions. The range and average population was similar in the Kastail, Deoghar and Austogram and Joyshiddi union. In comparison with the four unions fungus population range was higher in the Deoghar and Austogram comared to Joyshiddi and Kastail. The highest Rhizobium population was recorded in Joyshiddi.

Table 57. Soil biology of AEZ-19 (Cumilla and Kishoreganj)

District	Upazila	Union	Microbial population ranges (cfu/g soil)					
			TB	NFB	PSB	Act	Fungus	Rhizobium
Cumilla	Burichang	Dokkhin Verala	2×10^5 -8×10^7 (3×10^6)	3×10^4-8×10^6 (4×10^6)	4×10^4-1×10^5 (8×10^4)	1×10^3-6×10^3 (4×10^3)	4×10^3-1×10^5 (3×10^4)	8×10^4-4×10^7 (5×10^6)
	Deviddar	Uttor Barkanda	2×10^6-4×10^7 (1×10^7)	8×10^4-1×10^6 (5×10^5)	6×10^4-2×10^5 (1×10^5)	1×10^3-1×10^4 (4×10^3)	1×10^3-3×10^4 (2×10^4)	3×10^3-1×10^6 (5×10^5)
Kishoreganj	Mithamoin	Keorjore	1×10^6 -1×10^7 (6×10^6)	2×10^5 -2×10^6 (1×10^6)	1×10^4 -2×10^5 (3×10^5)	5×10^2-1×10^3 (8×10^2)	2×10^4 -3×10^4 (2×10^4)	4×10^4 -1×10^5 (9×10^4)
		Ghagra	4×10^6 -8×10^6 (4×10^6)	1×10^6 -3×10^6 (2×10^6)	8×10^4 -8×10^5 (3×10^5)	5×10^2-9×10^2 (7×10^2)	6×10^3-2×10^4 (1×10^4)	1×10^5 -4×10^5 (3×10^5)
		Mithamoin	1×10^7 -2×10^7 (2×10^7)	5×10^5 -3×10^6 (2×10^6)	1×10^5 -1×10^5 (1×10^5)	1×10^2-1×10^3 (5×10^2)	3×10^3-1×10^4 (6×10^3)	2×10^5 -2×10^6 (9×10^5)
	Itna	Joyshiddi	1×10^7 -3×10^7 (2×10^7)	2×10^6 -2×10^6 (2×10^6)	4×10^4-3×10^5 (2×10^5)	6×10^2-9×10^3 (8×10^2)	4×10^3 -6×10^3 (6×10^3)	1×10^6-2×10^6 (2×10^6)
	Austogram	Kastail	2×10^7 -3×10^7 (2×10^7)	1×10^6 -2×10^6 (2×10^6)	2×10^5 -3×10^5 (2×10^5)	8×10^2 -2×10^3 (1×10^3)	5×10^3 -8×10^3 (6×10^3)	3×10^5-6×10^5 (4×10^5)
		Deoghar	1×10^7 -3×10^7 (2×10^7)	5×10^5 -1×10^6 (9×10^5)	1×10^5 -3×10^5 (1×10^5)	5×10^2-2×10^3 (1×10^3)	3×10^3 -1×10^5 (6×10^3)	7×10^5-1×10^6 (8×10^5)
		Austogram	2×10^7 -3×10^7 (2×10^7)	1.2×10^6 -4×10^6 (1×10^6)	1×10^5-2×10^5 (1×10^5)	8×10^2 -2×10^3 (1×10^3)	1×10^3 -3×10^5 (2×10^3)	7×10^5-1×10^6 (8×10^5)

Here, TB: total bacteria, NFB: Free-living N_2 fixing bacteria, PSB: phosphate solubilizing bacteria and Act: Actinomycetes.
Value in the parenthesis is average value of the respective population in each column.

Soil physico-chemical properties

Soil physicochemical properties of AEZ-19 were described in Table 58 a & 58b. The soil texture of the Dokkhin Verala union of Burichang upazila was Silty clay loam and Uttor Barkanda union of Deviddar was Silty loam in nature. Soil pH ranged from 5.5 to 7.9 in Dokkhin Verala and 5.7 to 6.1 in Uttor Barkanda union of Cumilla. The range of soil organic matter and total nitrogen in Dokkhin Verala were 1.9 to 3.5 %, and 0.08 to 0.2%, while, in Uttor Barkanda it were 1.6 to 3.1% and 0.04 to 0.12%. The average pH value (6. 1), soil organic matter (2.63%) and total nitrogen (0.13%) was higher in Dokkhin Verala compared to Uttor Barkanda union (Table 58a). Soil samples were collected mostly from Boro rice, and only two from Potato containing cropping pattern.

In the Kishoreganj, soil texture of Joyshiddi and Keorjor were Silty clay loam and rest of the five union were (Kastail, Deoghar, Ghagra, Mithamoin and Austogram) Silty loam. Soil pH of Mithamoin upazila ranged from 5 to 7 with an average value of 6.0. Whereas, the range of soil pH was 5.3 to 6.0 and average pH was 5.60 recorded in the Itna and Austogram upazila. The highest average value of soil organic matter (2.1%) was found in Austogram followed by Joyshiddi (1.69%) and Mithamoin (1.60%). The value of total nitrogen was ranged from 0.05 to 0.17%. The crop in the cropping pattern of Kishoreganj was rice (Table 58b).

Table 58a. Physico-chemical properties of AEZ 19

District	Upazila	Union	Cropping patterns of the sample collecting point	Physical property	Chemical properties		
				Texture	Soil pH	OM (%)	TN (%)
Cumilla	Buric hang	Dokkhin Verala	• **Boro**-Aus-T.Aman • **Boro**-Aus-T.Aman • **Boro**-Aus-T.Aman • **Boro**-Aus-T.Aman • Boro-Aus-T.Aman-**Potato** • Boro-Aus-T.Aman-**Potato** • **Boro**-Aus-T.Aman • **Boro**-Aus-T.Aman • **Boro**-Aus-T.Aman • **Boro**-Aus-T.Aman	Silty clay loam	5.5-7.9 (6.10)	1.9-3.5 (2.63)	0.08-0.2 (0.13)
	Devi ddar	Uttor Barkanda	• **Boro**-Aus-T.Aman • **Boro**-Aus-T.Aman • **Boro**-Aus-T.Aman • **Boro**-Aus-T.Aman • **Boro**-Aus-T.Aman • **Boro**-Aus-T.Aman • **Boro**-Aus-T.Aman • **Boro**-Aus-T.Aman • **Boro**-Aus-T.Aman • **Boro**-Aus-T.Aman	Silty loam	5.7-6.1 (5.94)	1.6-3.1 (2.42)	0.04-0.12 (0.09)

Value in the parenthesis is average value of the respective column. Bolded word represents existing crop during sampling.

Table 58b. Physico-chemical properties of AEZ-19

District	Upazila	Union	Cropping patterns of the sample collecting point	Physical property	Chemical properties		
				Texture	Soil pH	OM (%)	TN (%)
Kishoreganj	Mithamoin	Keorjore	• **Boro**-Fallow-Fallow • Boro-Fallow-Fallow-Mustard • **Boro**-Fallow-Fallow	Silty clay loam	6.0 (6.0)	0.6-1.0 (0.06)	0.08 (0.08)
		Ghagra	• **Boro**-Fallow-Fallow-**Mustard** • **Boro**-Fallow-Fallow • **Boro**-Fallow-Fallow • **Boro**-Fallow-Fallow	Silty loam	5.0-7.0 (6.00)	1.1-1.3 (1.21)	0.05-0.15 (0.08)
		Mithamoin	• **Boro**-Fallow-Fallow • **Maize**-Fallow-Fallow • **Boro**-Fallow-Fallow • **Boro**-Fallow-Fallow	Silty loam	5.0-7.0 (6.00)	1.3-2.4 (1.60)	0.05-0.17 (0.08)
	Itna	Joyshiddhi	• **Boro**-Fallow-Fallow • **Boro**-Fallow-Fallow	Silty clay loam	5.3-5.4 (5.67)	0.71-1.1 (1.69)	0.06-0.11 (0.10)
	Austagram	Kastail	• **Boro**-Fallow-Fallow • **Boro**-Fallow-Fallow	Silty loam	5.5-5.8 (5.40)	1.4-1.6 (1.5)	0.08 (0.08)
		Doghar	• **Boro**-Fallow-Fallow • **Boro**-Fallow-Fallow • **Boro**-Fallow-Fallow	Silty loam	5.5-6.0 (5.54)	1.6-2.6 (1.49)	0.06-0.08 (0.08)
		Austagram	• **Boro**-Fallow-Fallow • **Boro**-Fallow-Fallow	Silty loam	5.4-6.0 (5.8)	1.4-2.0 (2.1)	0.08-0.06 (0.07)

Value in the parenthesis is average value of the respective column. Bolded word represents existing crop during sampling.

Biochemical and molecular characterization of potential bacteria: Potential bacteria from AEZ-19 were identified and characterized for nitrogen fixation, phosphate solubilizing and indoleacetic acid production (Table 59). Among the selected six bacteria, the highest N_2 fixation (21 ppm) was recorded in B4 and this strain was isolated from Uttor Barkanda union. The highest concentration of P solubilized from tri-calcium phosphate was recorded by the strain B2 (2166 ppm) followed by B5 (1844 ppm) and these two strains were isolated from Dokkhin Verala and Uttor Barkanda union, respectively. The highest concentration of IAA (11 ppm) was produced by the strain B6 that isolated from Uttor Barkanda union. The potential bacteria *Bacillus cereus* (B2) was identified from Dokkhin Verala and *Bacillus albus* (B4) from Uttor Barkanda union.

Table 59. Biochemical and molecular characteristics of the potential bacteria isolated from AEZ-19

District	Upazila	Union	Bacteria ID	Strain	Probability (%)	Population (Cfu/g soil)	Biochemical properties		
							N (ppm)	P (ppm)	IAA (ppm)
Cumilla	Burichang	Dokkhin Verala	B1	*Bacillus cereus*		3×10^6	14	943	7
			B2	*Bacillus cereus*		1×10^6	14	2166	7
			B3	-		3×10^6	14	535	5
	Deviddar	Uttor Barkanda	B4	*Bacillus albus*		1×10^6	21	30	9
			B5	-		8×10^5	14	1844	6
			B6	-		3×10^5	7	295	11

Here, IAA: Indoleacetic acid

Bio-physico-chemical properties of AEZ-22

The soil samples were collected from Habiganj and Moulvibazar district. (Fig. 56). A number of 40 soil samples from 0 to 15 cm depth (composite of 400 soils) were analysed to determine bio-physico chemical properties of AEZ-22 (details in methothology section). The field history such as existing crop, cropping pattern and farmers' details were recorded**.** In the Habiganj district, soil samples were collected form Deorgachi and Noropoti upazila. While, in Moulvibazar district, soil sampling was done in Giasnagar, and Chadnighat upazila.

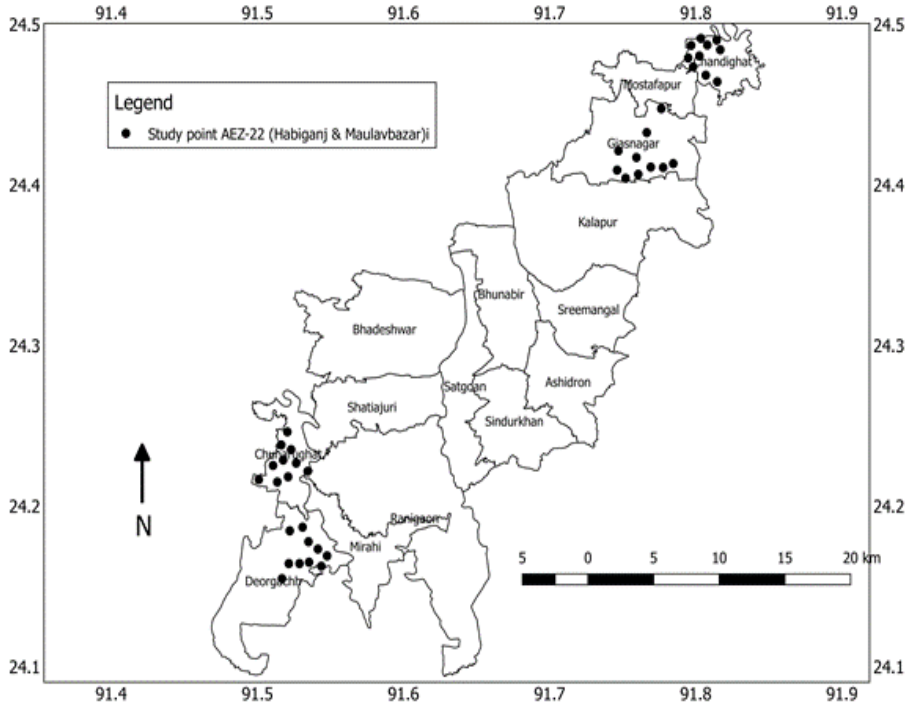


Fig. 56. Location map of AEZ-22 (Habiganj and Moulvibazar) originates from GPS information

Soil biology: Soil biological properties were described in the Table 60. In the Habiganj district, soil sample were collected from Deorgachi and Noropoti union of Chunarughat upazela. Between the tested two unions, the total bacteria population range (7×10^6 to 1×10^9 cfu/g soil) was higher in the Deorghaci union. The higher range (7×10^4 to 2×10^6 cfu/g soil) and average (5×10^5 cfu/g soil) population of free-living N_2 fixing bacteria was also found in Deorgachi union compared to Noropoti (3×10^4 cfu/g soil). The PSB and Actinomycetes population range were higher in the Noropoti union. Average fungus population was high in Deorgachi union compared to Noropoti. The average Rhizobium population was almost similar in both unions.

In the Moulvibazar district, total bacteria population was higher in Giasnagar union of Srimangal compared to Chadnighat union of Moulvibazar Sadar. The population range of free-living N_2 fixing bacteria was higher in the Chadnighat (1×10^5 to 2×10^6 cfu/g soil) of Moluvibazar Sadar. On the other hand, the population of phosphate solubilizing bacteria (2×10^5 to 2×10^6 cfu/g soil) was higher in Giasnagar union of Srimangal. The Actinomycetes population was similar in range and average value. The fungus population range (3×10^3 to 2×10^4 cfu/g soil) and average value (3×10^4 cfu/g soil) were higher in the Giasnagar union of Srimangal. Rhizobium population was higher in the Chadnighat of Moulvibazar Sadar upazila.

Soil physico-chemical properties: Soil physicochemical properties of AEZ-22 were described in Table 61a & 61b. The soil texture of the Deorgachi union was Silty clay loam and Noropoti union was Loam in nature. Soil pH ranged from 5.0 to 6.7 in Deorgachi and 5.6 to 6.3 in Noropoti union of Chunarughat upazila. The range of soil organic matter and total nitrogen in Deorgachi union were 2 to 2.5 and 0.11 to 1.7%, while, in Noropoti it was 1.2 to 2.1% and 0.05to 0.15%. The average pH value (5.49), soil organic matter (2.26%) and total nitrogen (0.14%) was higher in Deorgachi compared to Noropoti union (Table 61a). Soil samples were collected mostly from Boro rice containing cropping pattern.

In the Moulvibazar Sadar, soil texture of Giasnagar union was Loam and Chadnighat union Sandy clay loam. Soil pH of Giasnagar union ranged from 5.6 to 5.1 with an average value of 4.77. Whereas, the range of soil pH was 4.6 to 5.3 and average pH was 4.96 recorded in the Chadnighat union of Moulvibazar Sadar upazila. The higher average value of soil organic matter (3.9%) was found in Chadnighat compared to Giasnagar union (2.6%). The value of total nitrogen was ranged from 0.05 to 0.15% in Giasnagar union and 0.09 to 0.21% in the Chadnighat union. The crop in the cropping pattern of Moulvibazar Sadar was rice (Table 61b).

Table 60. Soil biology of AEZ-22 (Habiganj and Moulvibazar)

District	Upazila	Union	Microbial population ranges (cfu/g soil)					
			TB	NFB	PSB	Act	Fungus	Rhizobium
Habiganj	Chunarughat	Deorgachi	7×10^6 -1×10^9 (3×10^8)	7×10^4 -2×10^6 (5×10^5)	5×10^4 -8×10^5 (2×10^5)	1×10^3 -7×10^3 (2×10^3)	4×10^3 -2×10^4 (1×10^4)	7×10^4 -3×10^6 (3×10^5)
		Norpoti	9×10^5-1×10^8 (6×10^8)	3×10^5 -9×10^5 (3×10^4)	2×10^5 -4×10^5 (3×10^5)	2×10^3 -1×10^4 (3×10^3)	5×10^3 -2×10^4 (4×10^3)	6×10^5 -3×10^6 (2×10^5)
Moluvibazar	Srimangal	Giasnagar	2×10^6 -1×10^9 (2×10^8)	2. $\times10^5$ -7×10^5 (1×10^5)	2×10^5 – 2×10^6 (2×10^5)	1×10^3 -2×10^3 (4×10^3)	3×10^3-2×10^5 (3×10^4)	1×10^5 -2×10^5 (2×10^5)
	Moulvibazar Sadar	Chadnighat	2×10^6 -2×10^7 (9×10^8)	1×10^5 -2×10^6 (1×10^5)	8×10^4 -5×10^5 (3×10^5)	1×10^3 -8×10^3 (2×10^3)	2×10^3 -2×10^4 (4×10^3)	1×10^5 -1×10^6 (3×10^5)

Here, TB: total bacteria, NFB: Free-living N_2 fixing bacteria, PSB: phosphate solubilizing bacteria and Act: Actinomycetes.
Value in the parenthesis is average value of the respective population in each column.

Table 61a. Physico-chemical properties of AEZ-22 (Habiganj)

District	Upazila	Union	Cropping patterns of the sample collecting point	Physical property	Chemical properties		
				Texture	Soil pH	OM (%)	TN (%)
Habiganj	Chunarughat	Deorgachi	● **Boro**-Aus-T.Aman ● **Boro**-Aus-T.Aman ● **Boro**-Aus-T.Aman ● **Boro**-Aus-T.Aman ● **Boro**-Aus-T.Aman ● **Boro**-Aus-T.Aman ● **Boro**-Aus-T.Aman ● **Boro**-Aus-T.Aman ● **Boro**-Aus-T.Aman ● **Fallow**-Aus-T.Aman	Silty clay loam	5.0-6.7 (5.49)	2.0-2.5 (2.26)	0.11-0.17 (0.14)
		Noropoti	● **Boro**-Aus-T.Aman ● **Boro**-Aus-T.Aman ● **Boro**-Aus-T.Aman ● **Boro**-Aus-T.Aman ● **Boro**-Aus-T.Aman ● **Boro**-Aus-T.Aman ● **Boro**-Aus-T.Aman ● **Boro**-Aus-T.Aman ● **Boro**-Aus-T.Aman ● **Fallow**-Aus-T.Aman	Loam	0.6-3.2 (6.01)	1.2-2.1 (1.69)	0.05-0.15 (0.10)

Value in the parenthesis is average value of the respective column. Bolded word represents existing crop during sampling.

Table 61b. Physico-chemical properties of AEZ-22 (Moulvibazar)

District	Upazila	Union	Cropping patterns of the sample collecting point	Physical property	Chemical properties		
				Texture	Soil pH	OM (%)	TN (%)
Moulvibazar	Srimangal	Gias nagar	• **Fallow** -Aus-Aman • **Fallow**-Fallow-T.Aman • **Fallow**-Fallow-T.Aman • **Fallow**-Fallow-T.Aman • **Fallow**-Aus-T.Aman • **Fallow**-Fallow-T.Aman • **Fallow**-Fallow-T.Aman • **Fallow**-Aus-T.Aman • **Fallow**-Aus-T.Aman • **Fallow**-Aus-T.Aman • **Fallow**-Aus-T.Aman	Loam	51-5.6 (5.35)	0.6-3.7 (2.15)	0.05-0.15 (0.10)
	Moulovi bazar Sadar	Chadnighat	• **Fallow** -Fallow-T.Aman • **Fallow** -Fallow-T.Aman • **Fallow** -Fallow-T.Aman • **Fallow** -Fallow-T.Aman • **Fallow** -Fallow-T.Aman • **Fallow** -Fallow-T.Aman • **Fallow** -Aus-Aman • **Fallow**-Aus-T.Aman • **Fallow** -Fallow-T.Aman • **Fallow** -Fallow-T.Aman	Sandy clay loam	4.6-5.3 4.96)	2.4-6.0 (4.2)	0.09-0.21 (0.16)

Value in the parenthesis is average value of the respective column. Bolded word represents existing crop during sampling.

Biochemical and molecular characterization of potential bacteria: Potential bacteria from AEZ-22 were identified and characterized for nitrogen fixation, phosphate solubilizing and indoleacetic acid production (Table 62). Among the selected six bacteria, the highest N_2 fixation (21 ppm) was recorded in B34 and this strain was isolated from Chadnighat union. The highest concentration of P solubilized from tri-calcium phosphate was recorded by the strain B32 (3681ppm) followed by B31 (2616 ppm) and these two strains were isolated from Giasnagar union. The highest concentration of IAA (43 ppm) was produced by the strain B28 that isolated from Noropoti union. The potential bacteria *Stenotrophomonas sp.* (B32) was identified from Giasnagar union.

Table 62. Biochemical and molecular characteristics of the potential bacteria isolated from AEZ-22

District	Upazila	Union	Bacteria ID	Strain	Probability (%)	Population (cfu/g soil)	Biochemical properties		
							N (ppm)	P (ppm)	IAA (ppm)
Habiganj	Chuna rughat	Deorgachi	B25			1×10^7	14	329	75
			B26			1×10^6	14	1135	5
			B27			5×10^5	7	37	5
		Noropoti	B28			2×10^5	14	111	43
			B29			3×10^6	14	1643	6
			B30			2×10^6	14	26	7
Moulvibazar	Srimangal	Giasnagar	B31			3×10^6	14	2616	7
			B32	*Stenotrophomonas sp.*		9×10^5	7	3681	10
			B33			2×10^6	14	578	6
	Moulvibazar Sadar	Chadnighat	B34			1×10^5	21	321	8
			B35			1×10^6	21	746	9
			B36			5×10^5	14	68	4

IAA, Indoleacetic acid.

Bio-physico-chemical properties of AEZ-27

The soil samples were collected from Rangpur and Bogura district **(Fig.57).** A number of 41 soil samples from 0 to 15 cm depth (composite of 410 soils) were analysed to determine bio-physicochemical properties of AEZ-27 (details in methothology section). The field history such as existing crop, cropping pattern and farmers' details were recorded. In the Rangpur district, soil samples were collected form Chengmari, Badarganj and Mitipur unions of Kutubpur, Mithapukur and Pirganj upazela, respectively. While, in Bogura district, soil sampling was done in Namuja and Aria unions of Bogura Sadar and Shajahanpur upazila, respectively.

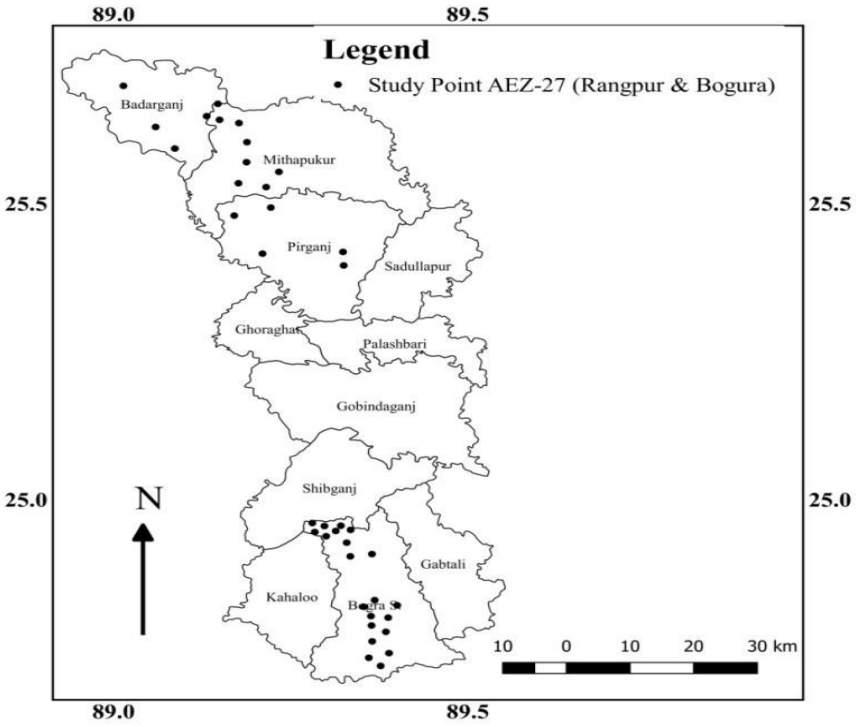


Fig. 57. Location map of AEZ-27 (Rangpur and Bogura) originates from GPS information

Soil biology: Soil biological properties were described in the Table 63. In the Rangpur district, soil sample were collected from Mithapukur, Chengmari and Bodorganj upazila. Among the tested three unions, the range of total bacteria population (1×10^6 to 5×10^8 cfu/g soil) was the highest in the Chenmari union of Mithapukur followed by Kutubpur union of Badarganj (9×10^5 to1×10^7 cfu/g soil) and Mitipur union of (2×10^6 to 7×10^6 cfu/g soil) Pirganj. The highest range (2×10^5 to1×10^6 cfu/g soil) of free-living N_2 fixing bacteria population was also found in Chengmari union compared to other two unions of Rangpur districts. The PSB population range were higher in the Chengmari (2×10^5 to10×10^6 cfu/g soil) and Mitipur (2×10^5 to 2×10^6 cfu/g soil) union compared to Kutubpur (2×10^5 to 4×10^5 cfu/g soil) union. Actinomycetes and fungus population range were lower in the Mitipur compared to Kutubpur and Chengmari union. Among the three unions, average fungus population was high in Badarganj union. The highest Rhizobium population was found in the Chengmari union (1×10^6 to 6×10^8 cfu/g soil) followed by Kutubpur (6×10^5 to 3×10^6 cfu/g soil) and Mitipur (1×10^5 to 2×10^5 cfu/g soil) union.

In the Bogura district, total bacteria population range was almost similar between two tested unions however; average total bacteria population was higher (1×10^7 cfu/g soil) in the Aria union. The population

range of free-living N_2 fixing bacteria was higher in the Aria (1×10^5 to 2×10^6 cfu/g soil) of Shahjahanpur upazila. On the other hand, similar population range and average population of phosphate solubilizing bacteria and actinomycetes were found in the both unions. The range of fungus population was higher in the Aria union; however, the average population range was similar in both unions. Rhizobium population was range were also higher in the Aria of Shajanpur upazila compared to Namuja union of Bogura Sadar.

Soil physico-chemical properties: Soil physicochemical properties of AEZ-27 were described in Table 64a & 64b. The soil texture of the Chengmari, Kutubpur and Mitipur unions of Rangpur were Silty Loam in nature. Soil pH ranged from 6.0 to 7.6 in Chengmari, 5.3 to 5.9 in Kutubpur and 5.7 to 5.8 in the Mitipur union. The range of soil organic matter and total nitrogen in Chengmari union were 1.8 to 2.5 and 0.04 to 0.11%, while, in Kutubpur it was 1.4 to 2.0% and 0.05to 0.05%. The average pH value (5.34), soil organic matter (2.10%) and total nitrogen (0.08%) was higher in Chengmari compared to Kutubpur and Mitipur unions of Rangpur (Table 64a). Soil samples were collected mostly from Boro and Potato containing cropping pattern.

Table 63. Soil biology of AEZ-27 (Rangpur and Bogura)

District	Upazila	Union	Microbial population ranges (cfu/g soil)					
			TB	NFB	PSB	Act	Fungus	Rhizobium
Rangpur	Mithapukur	Chengmari	1×10^6 -5×10^8 (8×10^7)	2×10^5 -1×10^6 (6×10^5)	2×10^5 -10×10^6 (5×10^5)	2×10^3 -2×10^4 (8×10^3)	3×10^3 -1×10^4 (7×10^3)	1×10^6 -6×10^8 (1×10^5)
	Badarganj	Kutub pur	9×10^5-1×10^7 (4×10^6)	3×10^5 -9×10^5 (6×10^5)	2×10^5 -4×10^5 (2×10^5)	2×10^3 -1×10^4 (5×10^3)	5×10^3 -2×10^4 (1×10^4)	6×10^5 -3×10^6 (1×10^5)
	Pirganj	Mitipur	2×10^6 -7×10^6 (4×10^6)	2×10^5 -7×10^5 (6×10^5)	2×10^5 – 2×10^6 (2×10^5)	1×10^3 -2×10^3 (2×10^3)	3×10^3-7×10^3 (5×10^3)	1×10^5 -2×10^5 (2×10^5)
Bogura	Shahjahan pur	Aria	2×10^6 -2×10^7 (1×10^7)	1×10^5 -2×10^6 (8×10^5)	8×10^4 -5×10^5 (3×10^5)	1×10^3 -8×10^3 (3×10^3)	2×10^3 -2×10^4 (7×10^3)	1×10^5 -1×10^6 (5×10^5)
	Bogura Sadar	Namuja	2×10^6 -1×10^7 (5×10^6)	3×10^5 -8×10^5 (7×10^5)	8×10^4 -3×10^5 (2×10^5)	1×10^3 -3×10^3 (2×10^3)	2×10^3 -9×10^3 (4×10^3)	3×10^5 -8×10^5 (5×10^5)

Here, TB: total bacteria, NFB: Free-living N_2 fixing bacteria, PSB: phosphate solubilizing bacteria and Act: Actinomycetes. Value in the parenthesis is average value of the respective population in each column.

Table 64a. Physico-chemical properties of AEZ- 27 (Rangpur)

District	Upazila	Union	Cropping patterns of the sample collecting point	Physical property	Chemical properties		
				Texture	Soil pH	OM (%)	TN (%)
Rangpur	Mitha pukur	Cheng mari	• **Boro**-Fallow. -Aman • **Sweetgourd**/ Potato Cucumber -T. Aman • **Boro**-Fallow-T. Aman-Potato • **Boro**/Maize-Fallow-T.Aman-Potato • **Boro**/Maize-Fallow-T.Aman-Potato • **Boro**-Fallow-T. Aman • **Boro**-Fallow- T. Aman	Silty loam	6.0-7.6 (6.34	1.8-2.5 (2.10)	0.04-0.11 (0.08)
	Badarganj	Kutub pur	• **Boro**-Fallow-T. Aman • **Potato**/Maize- Fallow-T. Aman • **Boro**-Fallow- T. Aman-Mustard • **Boro**-Fallow- T. Aman-Mustard • **Boro**/Maize-Fallow-T.Aman • **Boro**- Fallow- Aman • **Boro**-Fallow- T. Aman-Potato • **Boro**-Jute- T. Aman	Silty loam	5.3-5.9 (5.55)	1.4-2.0 (1.70	0.04-0.09 (0.05)
	Pirganj	Mitipur	• **Potato**-Aus- T. Aman • **Potato**/Maize- Fallow-T. Aman	Silty loam	5.7-5.8 (5.7)	1.5	0.03-0.04 (0.03)

Value in the parenthesis is average value of the respective column. Bolded word represents existing crop during sampling.

In Bogura Sadar, soil texture of Namuja union was Silty loam and Aria union of Shajanpur upazila was Clay loam in nature. Soil pH of Namuja union ranged from 6.0 to 7.0 with an average value of 6.43. Whereas, the range of soil pH was 4.7 to 6.8 and average pH was 5.64 recorded in the Aria union of Shajahanpur upazela. The range and average value of soil organic matter was almost similar in both unions. The value of total nitrogen was ranged from 0.05 to 0.07% in Namuja union and 0.05to 0.07% in the Aria union. Major crop in the cropping pattern of Bogura were rice and vegetables (Table 64b).

Table 64b. Physico-chemical properties of AEZ- 27 (Bogura)

District	Upazila	Union	Cropping patterns of the sample collecting point	Physical property	Chemical properties		
				Texture	Soil pH	OM (%)	TN (%)
Bogura	Bogura Sadar	Namuja	• Boro-Mustard-Potato-**Fallow** • Boro-Potato-**Fallow** • Boro-Potato- **Vegetable** • **Fallow-**Vegetable-T. Aman • **Fallow-**Vegetable-T. Aman • **Boro**/Mustard-Potato-Fallow • Bean-Taro-Potato-**Sweetgourd** • **Boro**-Fallow -T. Aman • **Boro** /Mustard – Potato- T. Aman • **Boro**/Mustard-Potato-Vegetable	Silty loam	6.0-7.0 (6.43)	1.2-2.6 (1.83)	0.05-0.09 (0.07)
	Shahjahan pur	Aria	• Boro/Maize-Potato-**Taro**/Aman • Boro-Vegetable- **Taro** /Aman • Boro-Potato- **Taro** /Aman • Mustard/Vegetable- **Taro** /Aman • Mustard/Vegetable- Aman • **Boro**/Mustard-Potato- **Taro** /Aman • **Bean**-Taro-Potato-Sweetgourd • Boro- Fallow-**Vegetable** • Boro /Mustard – Fallow- **T. Aman** • Boro /Mustard – Fallow- **T. Aman**	Clay loam	4.7-6.8 (5.64)	1.0-2.5 (1.85)	0.08-0.11 (0.09)

Value in the parenthesis is average value of the respective column. Bolded word represents existing crop during sampling.

Biochemical and molecular characterization of potential bacteria: Potential bacteria from AEZ-27 were identified and characterized for nitrogen fixation, phosphate solubilizing and indoleacetic acid production (Table 65). Among the selected six bacteria, the highest N_2 fixation (28 ppm) was recorded in B49 and this strain was isolated from Kutubpur union of Badarganj upazela of Rangpur. The highest concentration of P solubilized from tri-calcium phosphate was recorded by the strain B53 (3746ppm) followed by B57 (2475 ppm) and these two strains were isolated from Aria and Namuja union, respectively. The highest concentration of IAA (29 ppm) was produced by the strain B54 that isolated from Aria union of Shajahanpur union of Bogura. The potential bacteria *Bacillus thuringiensis* (B49) from Kutubpur and *Stenotrophomonas maltophilia* (B53) was identified from Shajahanpur union of AEZ-27.

Table 65. Biochemical and molecular characteristics of the potential bacteria isolated from AEZ-27 (Rangpur and Bogura)

District	Upazila	Union	Bacteria ID	Strain	Probability (%)	Population (cfu/g soil)	Biochemical properties		
							N (ppm)	P (ppm)	IAA (ppm)
Rangpur	Mithapukur	Chengmari	B46			4×10^6	14	36	4
			B47			4×10^6	14	2002	12
			B48			4×10^6	14	249	8
	Badarganj	Kutubpur	B49	*Bacillus thuringiensis*	98	7×10^6	28	1763	5
			B50			2×10^6	14	1094	8
			B51			3×10^6	14	1744	19
	Pirganj	Mitipur	-						
			-						
Bogura	Bogura Sadar	Namuja	B55			7×10^6	14	2027	15
			B56			1×10^6	14	86	2
			B57			3×10^6	7	2475	7
	Shahjahanpur	Aria	B52			2×10^7	14	61	5
			B53	*Stenotrophomonas maltophilia*	99	3×10^6	7	3746	6
			B54			4×10^6	14	1	29

IAA, Indoleacetic acid

Relationship among the isolated Identified strains

The evolutionary history was inferred using the Neighbor-Joining method. The optimal tree is shown (Fig. 58). The percentage of replicate trees in which the associated taxa clustered together in the bootstrap test (1000 replicates) was shown next to the branches. The tree is drawn to scale, with branch lengths in the same units as those of the evolutionary distances used to infer the phylogenetic tree. The evolutionary distances were computed using the p-distance method and were in the units of the number of base differences per site. This analysis involved 20 nucleotide sequences. All positions containing gaps and missing data were eliminated (complete deletion option). There were a total of 360 positions in the final dataset. Evolutionary analyses were conducted in MEGA11.

In this study, we found three majore clusters among the tested bacteria. In the cluster 1, the consensus tree showed 41% similarity of confidence levels within five strains (B70, B1, B14, B78 and B45), 99% confidence levels of similarity among B14, B78, B38, B2, B4, B81 and B75. Whereas, 100% similarities were found within B80 and above all mentioned *Bacillus* strains. Moreover, B39 showed 91% similarity with all other teseted strains in the cluster 1. In the seccond cluster, (*Stenotrophomonas* sp.) were represented at 75 to 100% confidence levels. *Bacillus thuringensis* (B49) formed another cluster (cluster 3). Our results indicate that the tested soils (eight AEZ's) of Bangladesh were dominated by the *Bacillus* sp followed by *Stenotrophomanas* sp.

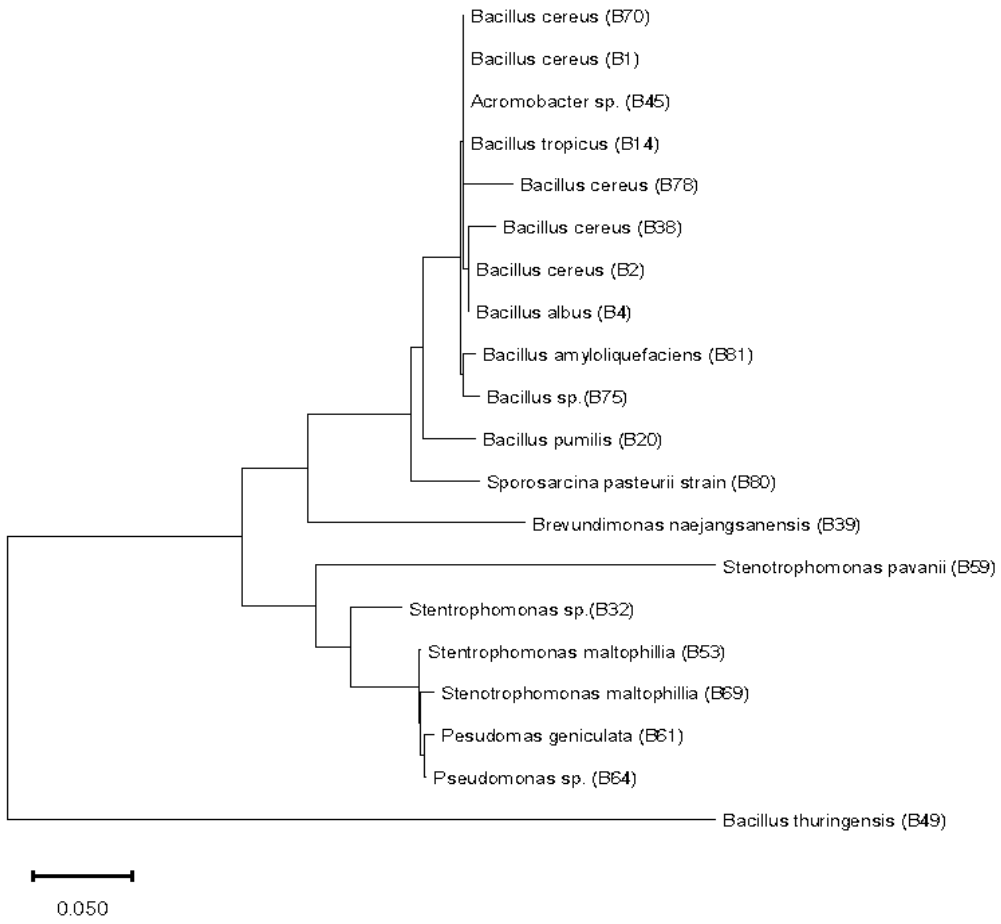


Fig. 58. Phylogenetic tree of identified potential strains. Tree constructed using Neighbor-Joining (NJ) method.

Climate smart biofertilizer

Efficacy of 'Bio-coated TSP' and 'Urea fertilizer'

Strain survival in the biofertilizer

In the present study, two climates smart biofertilizer was developed and tested for the strain survival in the formulation (details in methothology section). For Acid soil bio-coated TSP fertilizer was formulated and for the Saline soil Bio-coated urea fertilizer was developed. Bio-coated TSP and Bio-coated urea fertilizer was prepared using five *Bacillus* spp., *Bacillus Pumilis*, *Pseudomonas geniculata Bacillus alba*, and *Proteous* sp. *Bacillus amyloliquefaciens, Stenotrophomonas maltophilia, Bacillus cereus*, *and Acromobactor* sp. The survival of the bacteria in the Bio-coated TSP and Bio-coated urea were checked every month using Pikovskaya and N_2 free media. The result was given in the Table 66. From the Data we can see a good number of PSB and free-living N_2 fixing bacteria population maintained after six months of formulation.

Table 66. Growth of beneficial bacteria population in the Pikovskaya and nitrogen free media

Media	Month-1	Month-2	Month-3	Month-4	Month-5	Month-6
Pikovasakaya	4×10^9	1×10^8	3×10^9	4×10^9	2×10^8	4×10^8
N-free media	1×10^8	4×10^7	4×10^8	4×10^8	4×10^6	4×10^8

Evaluation of Bio-coated TSP fertilizer for the improvement of phosphorus fertilizer use efficiency and rice yield in acid soil

1. A) Incubation study

The result of one-month incubation study proved that Bio-coated TSP is the best option to increase bio-available P in acid soil. Among the treatments the highest available P was found in the Bio-coated TSP (@10 kg P ha) followed by Bio-coated TSP (@30 kg P ha) and Bio-coated TSP (@20 kg P ha) treatment (Fig.59). The lowest available P was found in the Control treatment. At the initial day available P was higher in the TSP treatment (51 ppm) followed by Bio-coated TSP where 10 kg P applied (41 ppm). Among the treatments the highest available P (144 ppm) was found in the Bio-coated applied TSP (30 kg P/ha) followed by Bio-coated applied TSP (10 kg P/ha) treatment. Within 30 days of incubation period, the highest available P observed in all treatments at second day. After second day of incubation available P drastically reduced and showed a plateau line however at 30 day also available P was higher in the bio-coated TSP treatments compared to only TSP applied treatment. The population of phosphate solubilizing bacteria was enumerated and higher population of PSB was recorded in the bio-coated TSP treatments compared to control and TSP fertilizer treatment (Table 67).

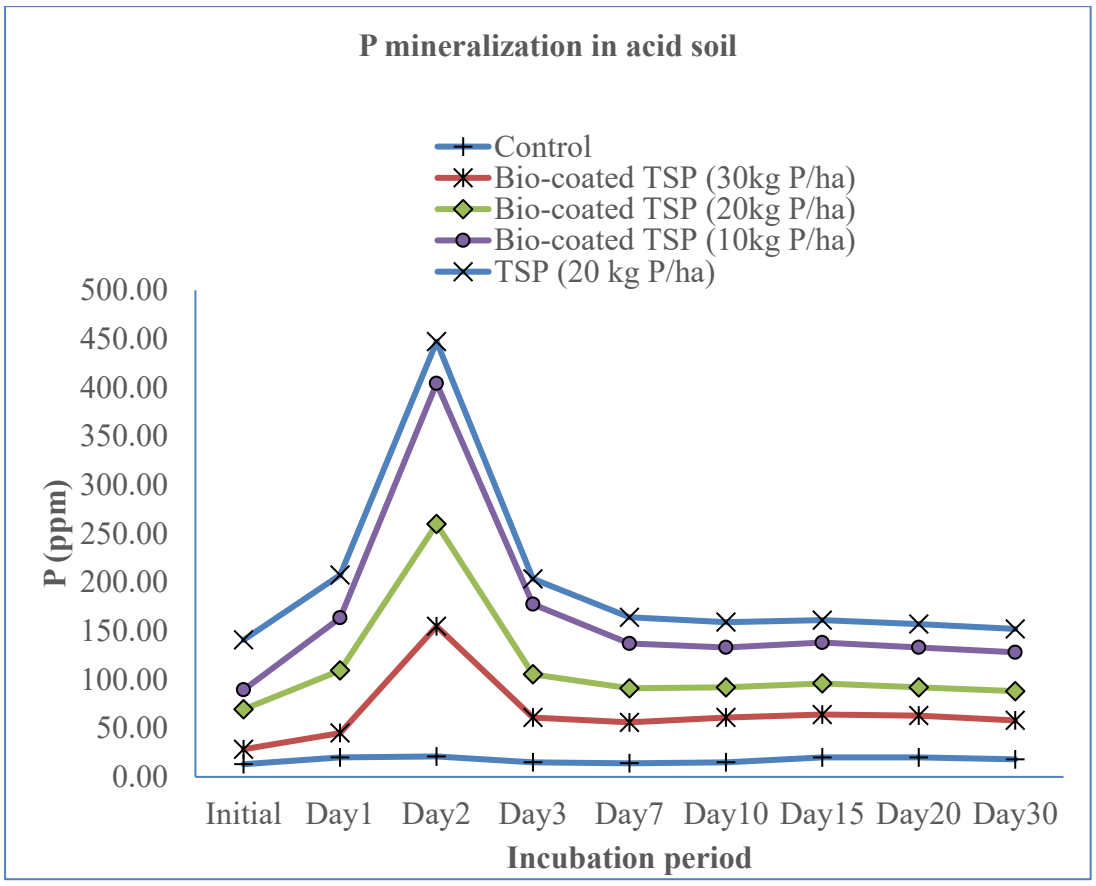


Fig. 59. Effect of Bio-coated TSP and TSP fertilizer on available P mineralization in Acid soil.

Table 67. Effect of Bio-coated TSP and TSP fertilizer on phosphate solubilizing bacteria population during incubation in the acid soil

Acid soil		Population of Phosphate solubilizing bacteria (cfu/g soil)							
Treatment	Initial	Day1	Day 2	Day 3	Day 7	Day10	Day15	Day20	Day30
Control	$1.7x10^5$	$1.7x10^5$	$8.7x10^4$	$8.0x10^5$	$6.2x10^4$	$3x10^4$	$3x10^4$	$3x10^4$	$2x10^4$
Bio-coated TSP (@30kg P/ha)	$1.1x10^5$	$2.8x10^5$	$2.5x10^6$	$1.6x10^6$	$4.5x10^6$	$2.8x10^6$	$2.8x10^6$	$1.8x10^6$	$1x10^6$
Bio-coated TSP (@20kg P/ha)	$7.5x10^4$	$1.7x10^5$	$3x10^6$	$3.5x10^6$	$1.8x10^6$	$1.6x10^6$	$1.6x10^6$	$1.2x10^6$	$2x10^6$
Bio-coated TSP (@10kg P/ha)	$8.7x10^4$	$3.6x10^5$	$1.7x10^6$	$3.5x10^6$	$4.0x10^6$	$3.1x10^6$	$3.1x10^6$	$2.5x10^6$	$2.5x10^6$
TSP (@20 kg P/ha)	$6.2x10^4$	$6.5x10^4$	$2.1x10^4$	$2.0x10^4$	$7.5x10^4$	$1.2x10^4$	$1.2x10^5$	$1.1x10^5$	$1.0x10^5$

1. B) Glasshouse study

Plant growth and yield: Significant variation was found in the plant growth parameters, grain and straw yield, and grain yield contributing characters. The results of the glasshouse study proved that Bio-coated TSP improved plant growth and grain yield over TSP fertilizer (Table 68). The greater plant height was observed in Bio-coated TSP followed by TSP fertilizer treatment. Significantly high number of panicle/hill found in Bio-coated TSP, where P was applied @ 30 kg /ha. However, it was statistical similar to the Bio-coated treatment with @10 kg P/ha treatment. Panicle number per hill was statistically similar in rest of the treatments. Significantly high panicle length was found in the Bio-coated TSP @ 20 kg P treatment. However, the highest straw (7.0 g/plant) and grain weight (7.6 g/plant) were recorded in the Bio-coated TSP @10kg P/ha treatment and it were statistically similar with other Bio-coated treatments. The lowest growth parameters, straw and grain yield was recorded the control treatment. Higher population of phosphate solubilizing bacteria was found in the Bio-coated TSP treatments.

Table 68. Effect of Bio-coated TSP and TSP fertilizer on growth, yield of BRRI dhan28 and PSB population after harvest.

Treatments	Plant height (cm)	Panicle /hill	Panicle length (cm)	Tiller /hill	Straw weight. (gm)	Root length (cm)	Yield/ plant (g)	PSB population (cfu/g soil)
Control	67.5 b	5.0c	24.6c	6.7	4.9b	6.8	4.3c	$3x10^3$
Bio-coated-TSP (@30 kgP/ha)	68.3 b	7.2a	25.5b	7.2	6.7a	6.4	7.0ab	$2x10^6$
Bio-coated-TSP (@20 kgP/ha)	73.0 ab	5.8bc	26.6a	5.8	6.8a	6.8	7.0ab	$4x10^6$
Bio-coated-TSP (@10 kg P/ha)	69.0 ab	6.7ab	25.9b	6.7	7.0a	7.1	7.6a	$5x10^6$
TSP (@20 kg P/ha)	75.2 b	5.0 c	24.8c	5.0	5.3b	6.9	5.6bc	$3x10^4$
LSD (0.05)	6.5	1.1	0.5	NS	1.1	NS	1.6	1000
CV (%)	7.8	15.4	1.7	32.9	14.9	36.4	21.0	8

PSB; Phosphate solubilizing bacteria.
In the Colum, means followed by the letter were significant at 5% level of significance.
Treatment means were separated using LSD values.

Nutrient uptake in the grain and straw: There were significant variation found for grain and straw nutrient uptake within assigned treatments (Table 69). The highest plant N uptake (121 g/kg) was found in the bio-coated TSP treatment, where P was applied @ 10 kg P/ha, however it was statistically similar to the other bio-coated treatments and TSP @ 20 kg P/ha treatment. The highest P uptake was noticed in the Bio-coated TSP @ 10 kg P/ha and that was statistical similar to the Bio-coated @ 20 kg P/ha treatment. The lowest P uptake was in the control and TSP @ 20 kg/ha treatments. Total plant K uptake was similar in all of the treatments except control.

Conclusion

Bio-coated TSP @ 10kg P/ha was the best treatment for rice cultivation in the acid soil.

Table 69. Effect of Bio-coated TSP and TSP fertilizer on grain and straw nutrient uptake in the acid soil

Treat.	N uptake (g/kg)		P uptake (g/kg)		K uptake (g/kg)		Plant total N uptake (g/kg)	Plant total P uptake (g/kg)	Plant total K uptake (g/kg)
	Grain	Straw	Grain	Straw	Grain	Straw			
Control	44.45c	27.09 bc	2.34 b	0.04 b	14.45 ab	196 b	71.5 c	4.1 d	249.4 b
Bio-coated TSP (@30kgP /ha)	7.95 ab	21.83 c	3.98 ab	0.06 ab	14.85 ab	323 a	94 bc	8.2 bc	417.3 a
Bio-coated TSP (@20kg P/ha)	61.06 bc	37.75 ab	3.92 ab	0.08 a	13.08 b	280 a	99 ab	9.6 ab	368.3 a
Bio-coated TSP (@10kg P/ha)	81.14 a	40.01 a	5.04 a	0.08 a	13.73 ab	334 a	121 a	12.0 a	441.4 a
TSP (@20 kgP/ha)	70.08 ab	33.36 abc	3.24b	0.04 b	15.84 a	272 a	103 ab	5.9 cd	351.1 a
LSD (0.05)	17.47	12.03	1.74	0.03	2.52	76.12	26	3.6	97.5
CV (%)	22.35	31.62	30.50	20.68	14.77	22.78	22.3	38.1	22.4

In the Colum, means followed by the letter were significant at 5% level of significance.
Treatment means were separated using LSD values.

Evaluation of 'Bio-coated urea' fertilizer for the improvement of growth and yield of BRRI dhan99 in saline soil

1. B) Incubation study

The result of the incubation study proved that Bio-coated urea was capable to release significantly higher ammonium compared to conventional prilled urea (Fig 60). The highest concentration of ammonium (588 ppm) was mineralized at day-1 in T5 treatment (N, P, K, S (kg/ha) @120-20-120-20). In this treatment, N was applied from Bio-coated urea. During the incubation period, the highest concentration of ammonium was released by the T5 treatment followed by T4 and T3 treatments. The lowest ammonium was released by the control (T1) treatment. The populations of free-living N_2 fixing bacteria in the bio-coated treatments were up to the mark during the incubation period (Table 70).

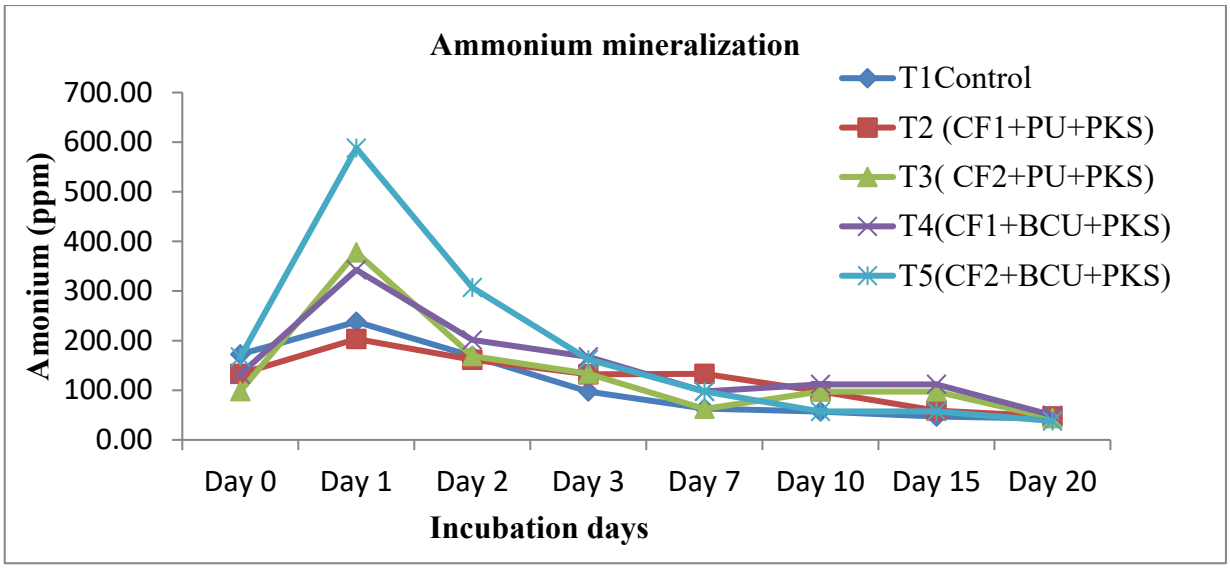


Fig. 60. Effect of Bio-coated urea and urea fertilizer on N mineralization in saline soil.

Table 70. Effect of Bio-coated urea and urea fertilizer on free-living N_2 fixing bacteria population during incubation

Saline soil	Population of free-living N_2 fixing bacteria (cfu/g soil)							
Treatment	Day 0	Day 1	Day 2	Day 3	Day 7	Day 10	Day 15	Day 20
T_1	$2x10^6$	$2x10^6$	$1x10^6$	$1x10^6$	$2x10^6$	$2x10^6$	$2x10^6$	$2x10^6$
T_2	$6x10^5$	$1x10^6$	$3x10^6$	$2x10^6$	$2x10^6$	$2x10^6$	$2x10^6$	$2x10^6$
T_3	$1x10^5$	$3x10^5$	$2x10^6$	$3x10^6$	$2x10^6$	$2x10^6$	$2x10^6$	$2x10^6$
T_4	$2x10^5$	$4x10^5$	$1x10^5$	$1x10^5$	$6x10^5$	$5x10^6$	$4x10^5$	$4x10^5$
T_5	$3x10^5$	$2x10^6$	$1.5x10^6$	$4x10^5$	$2x10^6$	$2x10^6$	$2x10^6$	$2x10^6$

T1= control, T2= CF1: NPKS (kg/ha) @ 120-20-50-10, source of N was prilled urea, T3= CF2: NPKS (kg/ha) @ 120-20-50-10, source of N was prilled urea T4 = NPKS (kg/ha) @ 120-20-50-10, source of N was Bio-coated urea, T5 = NPKS (kg/ha) @ 120-20-120-10, source of N was Bio-coated urea.

1. B) Glasshouse study

Plant growth and yield: There were significant differences in plant growth parameters, grain and straw yield among the treatments (Table 71). Compared to control higher number of tiller, panicle/hill, panicle length, grain and straw weight obtained due to application of treatments. In between two fertilizer packages (CF1 and CF2), CF2 showed better performance. However, the highest grain yield (16.8 g/plant) obtained in the T4, followed by T5 where Bio-coated urea was applied. After harvest, population of free living N_2 fixing bacteria were enumerated from all pot soil. The population of free-living N_2 fixing bacteria was found high in T4 and T5 treatments.

Table 71. Effect of Bio-coated urea on growth and yield of BRRI dhan99.

Treatments	Plant height (cm)	Panicle /hill	Panicle length (cm)		Tiller /hill	Straw weight. (gm)	Root length (cm)	Yield/ plant (g)	NFB population (cfu/g soil)
T1	85.7 b	6 b	26 b		6 b	18.8 b	19.3	13.7 d	$3.1x10^4$
T2	88.5 ab	10 a	27.8 a		10 a	26.8 ab	20.6	15.2 bc	$3.2x10^4$
T3	92.7 a	11 a	27.7 a		11 a	29.6 a	20.7	15.0 c	$3.5x10^4$
T4	90.7 ab	11 a	28 a		11 a	31.7 a	20.4	16.58 a	$4.6x10^6$
T5	92.8 a	10 a	27.7 a		10 a	31.2 a	20.4	16.25ab	$4.6x10^6$
LSD (0.05)	5	1.4	1.4		1.4	9	NS	1.05	1000
CV(%)	5	11.8	5		11.8	27	20	5.97	10

In the Colum, means followed by the letter were significant at 5% level of significance. Treatment means were separated using LSD values.

T_1= control, T_2= CF1: NPKS (kg/ha) @ 120-20-50-10, source of N was prilled urea, T_3= CF2: NPKS (kg/ha) @ 120-20-50-10, source of N was prilled urea T_4 = NPKS (kg/ha) @ 120-20-50-10, source of N was Bio-coated urea, T_5 = NPKS (kg/ha) @ 120-20-120-10, source of N was Bio-coated urea.

Conclusion: Bio-coated urea can be an option to mitigate saline stress in rice cultivation.

Fig. 61. Glasshouse experiment with bio-coated TSP in acid soil

Bio-Coated Urea: a new approach to improve rice yield in saline soil

Fig. 62. Glasshouse experiment at saline soil

Fig. 63. Lab visits by NATP-2 monitoring team

BINA Component

Soil bio-physico-chemical properties of different AEZ's of Bangladesh:

Table 72. Microbial population in soils of different districts of different AEZs of Bangladesh

AEZ	District	Total Bac.	Rhizo.	B.Rhizo	FLNFB	PSB	Fungi	Actino
3	Rangpur	4.81×10^7	2.99×10^5	5.48×10^4	1.85×10^6	3.00×10^5	3.05×10^5	3.33×10^5
	Nilfamari	4.31×10^7	3.61×10^5	4.04×10^5	4.20×10^6	3.48×10^5	4.13×10^5	2.83×10^5
	Mean	4.56×10^7	3.3×10^5	2.29×10^5	3.03×10^6	3.24×10^5	3.59×10^5	3.08×10^5
7	Kurigram	5.51×10^7	5.05×10^5	6.45×10^5	4.88×10^6	3.58×10^5	3.1×10^5	4.19×10^5
	Sirajgonj	1.58×10^7	2.02×10^5	1.40×10^5	1.73×10^5	4.06×10^4	1.84×10^5	1.29×10^4
	Mean	3.55×10^7	3.54×10^5	3.93×10^5	2.52×10^6	19.93×10^4	2.47×10^5	21.6×10^4
9	Mymen singh	3.88×10^7	3.98×10^5	4.54×10^5	3.91×10^6	3.18×10^4	4.09×10^4	4.25×10^5
	Netrakona	4.20×10^7	4.34×10^5	4.49×10^5	4.47×10^6	3.79×10^4	4.05×10^4	3.72×10^5
	Mean	4.04×10^7	4.16×10^5	4.52×10^5	4.19×10^6	3.49×10^4	4.07×10^3	3.99×10^5
12	Faridpur	4.52×10^7	2.22×10^5	3.09×10^5	2.98×10^6	3.23×10^5	3.11×10^5	2.96×10^5
	Pabna	3.42×10^7	2.74×10^5	2.05×10^5	3.83×10^5	4.87×10^4	3.01×10^5	3.47×10^5
	Mean	3.97×10^7	2.48×10^5	2.57×10^5	1.68×10^6	18.59×10^4	3.06×10^5	3.22×10^5
14	Gopalgonj	7.91×10^7	4.64×10^5	3.86×10^5	5.29×10^6	4.57×10^5	6.13×10^5	4.12×10^5
	Khulna	13.59×10^7	4.63×10^6	4.35×10^6	4.04×10^6	4.57×10^5	13.64×10^5	3.25×10^5
	Mean	10.75×10^7	25.47×10^5	26.83×10^5	4.67×10^6	4.57×10^5	9.89×10^5	3.69×10^5
17	Chandpur	3.46×10^7	2.84×10^5	2.97×10^5	3.37×10^5	5.55×10^4	5.15×10^4	6.06×10^4
	Laxmipur	2.62×10^7	6.02×10^4	6.41×10^4	4.19×10^5	6.43×10^4	5.81×10^4	7.13×10^4
	Mean	3.04×10^7	17.22×10^4	18.06×10^4	3.78×10^5	5.99×10^4	5.48×10^4	6.60×10^4
25	Bogura	8.35×10^7	3.97×10^5	4.23×10^5	10.15×10^5	15.51×10^5	23.75×10^4	6.06×10^4
	Naogoan	2.63×10^7	8.77×10^4	0.69×10^5	5.69×10^5	1.59×10^5	8.76×10^4	5.97×10^4
	Mean	5.49×10^7	2.42×10^5	2.46×10^5	7.92×10^5	8.55×10^5	16.26×10^4	6.02×10^4
26	Chapai	10.75×10^7	11.02×10^4	5.83×10^4	22.2×10^5	10.7×10^5	12.75×10^4	10.45×10^4
	Rajshahi	7.85×10^7	3.22×10^5	1.27×10^5	12.25×10^5	2.29×10^5	20.65×10^4	9.18×10^4
	Mean	9.30×10^7	2.16×10^5	3.55×10^5	17.23×10^5	6.50×10^5	16.7×10^4	9.82×10^4

N.B: **Total Bac**.=Tatal bancteria; **Rhizo.**=Rhizobium; **B.Rhizo**=Bradyrhizobium; **FLNFB**=Free living nitrogen fixing bacteria; **PSB**=Phosphate solubilizing bacteria; **Actino**=Actinomycetes;

Table 73. Physico-chemical properties of soil of different AEZ of Bangladesh

AEZ	District	pH	%OC	%OM	%N	Textural class (common)
3	Rangpur	5.72	1.29	2.24	0.183	Sandy Loam
	Nilfamari	5.75	1.53	2.65	0.241	Sandy Loam
	Mean	5.74	1.41	2.45	0.212	
7	Kurigram	5.96	1.12	1.98	0.233	Sandy Loam, Loam
	Sirajgonj	6.68	0.79	1.34	0.110	Sandy Loam, Loam
	Mean	6.32	0.96	1.66	0.172	
9	Mymensingh	6.36	1.13	1.93	0.121	Sandy Loam, Sandy Clay Loam
	Netrakona	6.50	1.05	1.62	0.184	Sandy Loam, Sandy Clay Loam
	Mean	6.43	1.09	1.78	0.153	
12	Faridpur	7.62	1.25	2.17	0.293	Clay Loam
	Pabna	7.92	1.23	2.09	0.135	Sandy Loam
	Mean	7.77	1.24	2.13	0.214	
14	Gopalgonj	7.73	1.77	3.07	0.305	Clay Loam, Loam
	Khulna	7.57	2.43	4.17	0.324	Clay Loam, Loam
	Mean	7.65	2.10	3.62	0.315	
17	Chandpur	6.69	0.78	1.33	0.131	Sandy Loam
	Laxmipur	7.17	0.82	1.40	0.141	Sandy Loam
	Mean	6.93	0.80	1.37	0.136	
25	Bogura	6.11	0.57	0.99	0.112	Sandy Clay Loam, Sandy Loam
	Naogoan	6.32	0.53	0.91	0.085	Sandy Clay Loam, Sandy Loam
	Mean	6.22	0.55	0.95	0.099	
26	Chapainawabgonj	7.32	0.57	0.96	0.123	Clay Loam, Sandy Clay Loam
	Rajshahi	7.43	0.69	1.21	0.097	Sandy Clay Loam, Sandy Loam
	Mean	7.38	0.63	1.09	0.110	

Means of location, union and upazila.

Soil bio-physico-chemical properties of AEZ-3 (Rangpur and Nilphamari):

The soil samples were collected from Rangpur Sadar and Mithapukur of Ranpur Sadar, and Joldhaka and Domar of Nilphamari district. A number of 40 soil samples from 0 to 15 cm depth were analysed to determine bio-physicochemical properties (details in methothology section).

Soil Bio-physico-chemical properties of AEZ 3

Soil Biological properties:

Soil biological properties of AEZ-3 was presented in Table 74 and 4-5. Soils of Rangpur recorded little bit higher total bacterial population (4.81×10^7 cfu g^{-1} soil) as compared to Nilphamari (4.31×10^7 cfu g^{-1} soil). Soils of Mithapukur upazila showed higher population (6.29×10^7 cfu g^{-1}

soil) over Rangpur Sadar soil (3.32×10^7 cfu g^{-1} soil). With the ranges of 4.4×10^7 cfu g^{-1} soil to 12.4×10^7 cfu g^{-1} soil in Bamikokor union and 1.9×10^7 cfu g^{-1} soil to 7.6×10^7 cfu g^{-1} soil) in Khoragas union of Mithapukur upazila were recorded. Higher population of soil bacteria was found in Momenpur (3.58×10^7 cfu g^{-1} soil) over Razendrapur (3.06×10^7 cfu g^{-1} soil) union of Rangpur Sadar upazila. In Nilphamari district, higher population was observed in Domar upazila (5.19×10^7 cfu g^{-1} soil) over Joldhaka upazila (3.42×10^7 cfu g^{-1} soil) soil. Sonarai union showed higher total bacterial population (5.42×10^7 cfu g^{-1} soil) over Horinchora union (4.96×10^7 cfu g^{-1} soil). With the range of 1.6×10^7 to 8.3×10^7 cfu g^{-1} soil in Sonarai and 1.9×10^7 to 9.6×10^7 cfu g^{-1} soil in Horinchora Union was found. Balagram union (3.86×10^7 cfu g^{-1} soil) showed higher population of soil bacteria over Gulna union (2.98×10^7 cfu g^{-1} soil) of Jaldhaka Union. A range of 1.2×10^7 to 8.0×10^7 cfu g^{-1} soil population in Balagram and 1.3×10^7 to 6.5×10^7 cfu g^{-1} soil in Gulna union was found in soils of Joldhaka upazila. *Rhizobium* population was found higher in soils of Nilphamari (3.61×10^5 cfu g^{-1} soil) over Rangpur District (2.99×10^5 cfu g^{-1} soil). *Rhizobium* population in Rangpur Sadar upazila showed higher (3.67×10^5 cfu g-1 soil) over Mithapukur upazila (1.91×10^5 cfu g^{-1} soil) of Rangpur district. Momenpur union recorded higher *Rhizobium* population over Rajendrapur union of Rangpur Sadar. *Rhizobium* population ranged from 0.8×10^5 to 8.4×10^5 cfu g^{-1} soil in Rangpur Sadar and 0.3×10^5 to 4.4×10^5 cfu g^{-1} soil in Mithapukur upazila. In Nilphamari district, Joldhaka upazila (4.51×10^5 cfu g^{-1} soil) showed higher population over Domar upazila (2.7×10^5 cfu g-1 soil). With the range of 1.6×10^5 to 8.4×10^5 cfu g-1 soil in Joldhaka and 1.2×10^5 to 5.4×10^5 cfu g-1 soil in Domar Upazila was found. Nilphamari recorded higher *Bradyrhizobium* population (4.04×10^5 cfu g^{-1} soil) over Rangpur (5.48×10^4 cfu g^{-1} soil). In Rangpur, a range of 1.3×10^4 to 14.0×10^4 cfu g^{-1} soil in Rangpur Sadar and 1.4×10^4 to 18.0×10^4 cfu g^{-1} soil in Mithapurkur Upazila. In Nilphamari, 1.3×10^5 to 6.5×10^5 cfu g^{-1} soil in Jaldhaka Upazila and 1.4×10^5 to 8.3×10^5 cfu g^{-1} soil in Domar Upazila was found. Nilphamari exhibited higher free-living nitrogen fixing bacteria (FLNFB) population (4.20×10^6 cfu g^{-1} soil) compared to Rangpur (1.85×10^6 cfu g-1 soil). In Rangpur, soils of Mithapukur recorded higher population (2.51×10^6 cfu g^{-1} soil) over Rangpur Sadar Upazila (1.19×10^6 cfu g^{-1} soil). In Nilphamari, Jaldhaka Upazila recorded higher FLNFB population (4.68×10^6 cfu g^{-1} soil) over Domar upazila (3.71×10^6 cfu g^{-1} soil). Nilphamari resulted little bit higher PSB population (3.48×10^5 cfu g^{-1} soil) over Rangpur (3.0×10^5 cfu g^{-1} soil). In Rangpur, soils of Mithapukur showed higher population (3.09×10^5 cfu g^{-1} soil) compared to Rangpur Sadar (2.91×10^5 cfu g^{-1} soil). With the range of 0.8×10^5 to 7.4×10^5 cfu g^{-1} soil in Mithapukur and 1.6×10^5 to 4.6×10^5 cfu g^{-1} soil in Rangpur Sadar was found. In Nilphamari, more or less similar PSB population was found in Domar (3.65×10^5 cfu g^{-1} soil) and Jaldhaka (3.31×10^5 cfu g^{-1} soil). With the range of 1.2×10^5 to 8.4×10^5 cfu g^{-1} soil in Domar Upazila and 1.6×10^5 to 7.4×10^5 cfu g^{-1} soil in Jaldhaka Upazila was found. District of Nilphamari recorded higher Fungi population (4.13×10^5 cfu g^{-1} soil) over Rangpur (3.05×10^5 cfu g^{-1} soil). Fungi population ranged from 0.3×10^5 to 3.4×10^5 cfu g^{-1} soil in Rangpur Sadar and from 1×10^5 to 12.6×10^5 cfu g^{-1} soil in Mithapukur Upazila of Rangpur. In Nilphamari, with the range of 1×10^5 to 24×10^5 cfu g^{-1} soil in Jaldhaka Upazila and 0.2×10^5 to 5.5×10^5 cfu g^{-1} soil in Domar Upazila was found. Similar Actinomyceties population in Rangpur (3.33×10^5 cfu g^{-1} soil) and Nilphamari (2.83×10^5 cfu g^{-1} soil) was recorded. A range of 0.5×10^5 to 5.6×10^5 cfu g^{-1} soil in Rangpur Sadar while Mithapukur showed with the range of 1.2×10^5 to 6.6×10^5 cfu g^{-1} soil. In Nilphamari, Actinomycities population ranged from 0.3×10^5 to 5.6×10^5 cfu g^{-1} soil in Jaldhaka and 0.5×10^5 to 6.6×10^5 cfu g^{-1} soil in Domar Upazila.

Table 74. Soil Biological properties of AEZ-3 (Rangpur)

Upazila	Union	Total Bac.	Rhizo.	B.Rhizo	FLNFB	PSB	Fungi	Actino
Rangpur Sadar	Momenpur	1.4×10^7 - 6.5×10^7 (3.58×10^7)	3.1×10^5- 8.4×10^5 (4.42×10^5)	1.3×10^4- 6.4×10^4 (3.28×10^4)	0.8×10^6- 3.4×10^6 (1.84×10^6)	1.6×10^5- 4.3×10^5 (2.3×10^5)	0.6×10^5- 3.4×10^5 (1.92×10^5)	0.5×10^5- 5.6×10^5 (2.78×10^5)
	Razendrapur	1.2×10^7- 6.2×10^7 (3.06×10^7)	0.8×10^5- 4.4×10^5 (2.92×10^5)	4.1×10^4- 14.0×10^4 (6.72×10^4)	0.12×10^6- 0.72×10^6 (0.53×10^6)	1.6×10^5 - 4.6×10^5 (3.52×10^5)	0.3×10^5- 0.78×10^5 (0.56×10^5)	1.1×10^5- 5.6×10^5 3.82×10^5
	Mean (Upazila)	1.2×10^7- 6.5×10^7 (3.32×10^7)	0.8×10^5- 8.4×10^5 (3.67×10^5)	1.3×10^4- 14.0×10^4 5.74×10^4	0.12×10^6- 3.4×10^6 (1.19×10^6)	1.6×10^5 - 4.6×10^5 (2.91×10^5)	0.3×10^5- 3.4×10^5 (1.24×10^5)	0.5×10^5- 5.6×10^5 (3.3×10^5)
Mithapukur	Khoragas	1.9×10^7- 7.6×10^7 (4.56×10^7)	1.2×10^5- 4.4×10^5 (2.48×10^5)	1.4×10^4- 18×10^4 (7.5×10^4)	0.4×10^6- 5.4×10^6 (2.06×10^6)	0.8×10^5- 3.2×10^5 (1.6×10^5)	2.2×10^5- 12.6×10^5 (6.82×10^5)	1.4×10^5- 6.6×10^5 (3.98×10^5)
	Bami kokor	4.4×10^7- 12.4×10^7 (8.02×10^7)	0.3×10^5- 2.8×10^5 (1.34×10^5)	1.5×10^4- 6.4×10^4 (4.38×10^4)	0.7×10^6- 5.8×10^6 (2.96×10^6)	1.6×10^5- 7.4×10^5 (4.58×10^5)	1.0×10^5- 6.2×10^5 (2.88×10^5)	1.2×10^5- 5.4×10^5 (2.74×10^5)
Mean (Upazila)		6.29×10^7	1.91×10^5	5.95×10^4	2.51×10^6	3.09×10^5	4.85×10^5	3.36×10^5
Mean (District)		4.81×10^7	2.99×10^5	5.48×10^4	1.85×10^6	3.00×10^5	3.05×10^5	3.33×10^5

N. B: **Total Bac**. =Total bancteria; **Rhizo.** =*Rhizobium*; **B. Rhizo**=*Bradyrhizobium*; **FLNFB**=Free living nitrogen fixing bacteria; **PSB**=Phosphate solubilizing bacteria; **Actino**=Actinomycetes;

Table 75. Soil Biological properties of AEZ- 3 (Nilphamari)

Upazila	Union	Total Bac.	Rhizo.	B.Rhizo	FLNFB	PSB	Fungi	Actino
Joldhaka	Gulna	1.3×10^7 - 6.5×10^7 (2.98×10^7)	3.1×10^5 - 8.4×105 (4.62×10^5)	1.3×10^5 - 6.4×105 (3.28×10^5)	1.4×10^6 -8.1×10^6 (4.3×10^6)	1.6×10^5 - 4.3×10^5 (2.3×10^5)	1.0×10^5 - 24×10^5 (6.6×10^5)	0.8×10^5 - 5.6×10^5 (2.38×10^5)
	Balagram	1.2×10^7 - 8.0×10^7 (3.86×10^7)	1.6×10^5 - 8.2×10^5 (4.4×10^5)	1.4×10^5 - 6.5×10^5 (4.2×10^5)	0.12×10^6 - 7.2×10^6 (5.06×10^6)	1.6×10^5 - 7.4×10^5 (4.32×10^5)	3.0×10^5 - 7.8×10^5 (5.62×10^5)	0.3×10^5 - 5.6×10^5 (3.20×10^5)
	Mean (Upazila)	3.42×10^7	4.51×10^5	3.74×10^5	4.68×10^6	3.31×10^5	6.11×10^5	2.79×10^5
Domar	Horinchora	1.9×10^7 - 9.6×10^7 (4.96×10^7)	1.2×10^5 - 4.4×10^5 (2.48×10^5)	1.4×10^5 - 8.3×10^5 (4.28×10^5)	1.0×10^6 -5.7×10^6 (3.16×10^6)	1.2×10^5 - 8.4×10^5 (3.12×10^5)	1.0×10^5 - 5.5×10^5 (2.62×10^5)	1.4×10^5 - 6.6×10^5 (3.98×10^5)
	Sonarai	1.6×10^7 - 8.3×10^7 (5.42×10^7)	1.4×10^5 - 5.4×10^5 (2.92×10^5)	1.5×10^5 - 6.4×10^5 (4.38×10^5)	1.0×10^6 -7.2×10^6 (4.26×10^6)	1.6×10^5 - 7.4×10^5 (4.18×10^5)	0.2×10^5 - 4.3×10^5 (1.68×10^5)	0.5×10^5 -3.6×10^5 (1.76×10^5)
Mean (Upazila)		5.19×10^7	2.7×10^5	4.33×10^5	3.71×10^6	3.65×10^5	2.15×10^5	2.87×10^5
Mean (District)		4.31×10^7	3.61×10^5	4.04×10^5	4.20×10^6	3.48×10^5	4.13×10^5	2.83×10^5

N. B: **Total Bac**. =Total bancteria; **Rhizo.** =*Rhizobium*; **B. Rhizo**=*Bradyrhizobium*; **FLNFB**=Free living nitrogen fixing bacteria; **PSB**=Phosphate solubilizing bacteria; **Actino**=Actinomycetes

Soil physico-chemical properties:

Physico-chemical properties of soils of AEZ-3 was presented in Table 76. A number of 40 soil samples from 0 to 15 cm depth were analysed to determine bio-physicochemical properties (details in methothology section). The field history such as existing crop, cropping pattern and location details were added. AEZ-3 contained mainly sandy loam textured soil. Both the districts Rangpur and Nilphamari showed sandy loam soil in all the union and upazila. Soil reaction was found slightly acidic in all the areas of Rangpur and Nilphamari. Razendrapor union of Rangpur Sadar recoded the lowest pH of 5.45 while Khuragass of Mithapukur exhibited the highest (5.78) of Rangpur. Nilphamari showed more or less similar pH with Rangpur with the range of 5.45 to 5.78 in different unions. Organic matter was found 2.24% in Rangpur and 2.65% in Nilphamari district. Total nitrogen was found 0.183 % in Rangpur and 0.241% in Nilphamari district with the ranges of 0.084 to 0.199% in Rangpur and 0.216 to 0.258% in Nilphamari (Table 77).

Table 76. Physico-chemical properties of AEZ-3 (Rangpur)

Upazila	Union	pH	% OC	% OM	% N	Textural Class
Rangpur Sadar	Mean (Union)	5.51-5.85 (5.68)	0.85-1.77 (1.33)	1.47-3.07 (2.31)	0.140-0.256 (0.185)	Sandy loam
	Rajendropur	5.45-6.01 (5.45)	0.92-1.42 (0.92)	1.59-2.45 (1.59)	0.084-0,224 (0.084)	Sandy loam
Methapukur	Khuragaas	5.71-5.86 (5.78)	1.28-1.84 (1.49)	2.21-3.19 (2.58)	0,084-0.280 (0.196)	Sandy loam
	Ranipokur	5.54-5.82 (5.66)	0.99-1.49 (1.28)	1.72-2.56 (2.20)	0.098-0.252 (0.199)	Sandy loam, Sand
Mean (District)		5.72	1.29	2.24	0.183	
Range (District)		5.45-6.01	0.85-1.84	1.47-3.19	0.084-0.28	Sandy loam

Table 77. Physico-chemical properties of AEZ-3 (Nilphamari)

Upazila	Union	pH	% OC	% OM	% N	Textural Class
Joldhaka	Gulna	5.72-5.97 (5.86)	1.06-1.99 (1.57)	1.84-3.43 (2.72)	0.168-0.288 (0.216)	Sandy loam
	Valagram	5.20-5.99 (5.66)	0.95-1.71 (1.38)	1.64-2.94 (2.39)	0.196-0.282 (0.247)	Sandy loam
Domer	Horinchora	5.41-6.25 (5.78)	1.48-1.91 (1.71)	2.58-3.31 (2.97)	(0.258)	Sandy loam
	Sonarai	5.29-6.02 (5.71)	1.13-1.63 (1.45)	1.96-2.82 (2.50)	0.140-0.476 (0.242)	Sandy loam
Mean (District)		5.75	1.53	2.65	0.241	
Range (District)		5.20-6.25	0.95-1.99	1.64-3.43	0.140-0.476	Sandy loam

Soil Bio-physico-chemical properties of AEZ 7

Soil Biological properties:

In AEZ-7 (Table 78 and 84-85) higher total bacterial population in soils of Kurigram district (5.51×10^7 cfu g^{-1} soil) over Sirajganj (1.58×10^7 cfu g^{-1} soil) was recorded. In Kurigram, higher population was recorded in Olepur upazila (7.59×10^7 cfu g^{-1} soil) over Rajarhat upazila (3.42×10^7 cfu g^{-1} soil). Begumganj union showed higher population of total bacteria (11.62×10^7 cfu g^{-1} soil) over Durgapur union (3.56×10^7 cfu g^{-1} soil). With the range of 8.3×10^7 to 14.4×10^7 cfu g^{-1} soil was observed in Begumgonj while Durgapur union recorded 1.9×10^7 to 6.2×10^7 cfu g^{-1} soil. Union Omormajid (3.86×10^7 cfu g^{-1} soil) showed higher total bacteria over Cenai union (2.98×10^7 cfu g^{-1} soil). Bacterial population of 1.3×10^7 to 6.5×10^7 cfu g^{-1} soil in Cenai union and 1.2×10^7 to 8.0×10^7 cfu g^{-1} soil of Omormajid Union of Rajarhat upazila was found. In Sirajgonj district, Belkuchi upazila recorded higher total soil bacteria (1.85×10^7 cfu g^{-1} soil) over Shahzadpur upazila (1.3×10^7 cfu g^{-1} soil). Borodhul union recorded higher bacterial population (2.32×10^7 cfu g^{-1} soil) over Rajapur union (1.38×10^7 cfu g^{-1} soil) of Belkuchi. A range of 1.4×10^7 to 3.2×10^7 cfu g^{-1} soil in Borodhul union and 0.7×10^7 to 2.4×10^7 cfu g^{-1} soil in Rajapur Union of Belkuchi Upazila was found. Both the union Sonatali and Koizuri of Shahzadpur recorded similar population (1.34×10^7 and 1.26×10^7 cfu g^{-1} soil, respectively). With the range of 0.6×10^7 to 1.8×10^7 cfu g^{-1} soil population was observed in Koizuri Union and 0.2×10^7 to 2.3×10^7 cfu g^{-1} soil in Sonatali union of Shahzadpur.

Table 78. Soil Biological properties of AEZ- 7 (Kurigram)

Upazila	Union	Total Bac.	Rhizo.	B.Rhizo	FLNFB	PSB	Fungi	Actino
Rajarhat	Cenai	1.3×10^7- 6.5×10^7 (2.98×10^7)	3.1×10^5- 8.4×10^5 (10.38×10^5)	4.6×10^5- 25×10^5 (13×10^5)	0.8×10^6- 14×10^6 (6.82×10^6)	1.6×10^5- 4.3×10^5 (2.3×10^5)	1.0×10^5- 3.4×10^5 (2.28×10^5)	2.8×10^5- 14×10^5 (6.2×10^5)
	Omor Majid	1.2×10^7- 8.0×10^7 (3.86×10^7)	1.6×10^5- 8.2×10^5 (4.4×10^5)	1.4×10^5- 6.5×10^5 (4.2×10^5)	1.2×10^5- 7.2×10^6 (5.28×10^6)	1.6×10^5- 7.4×10^5 (4.32×10^5)	3.0×10^5- 7.8×10^5 (5.62×10^5)	1.1×10^5- 5.6×10^5 (3.82×10^5)
	Mean (Upazila)	3.42×10^7	7.39×10^5	8.6×10^5	6.05×10^6	3.31×10^5	3.95×10^5	5.01×10^5
Olepur	Durgapur	1.9×10^7- 6.2×10^7 (3.56×10^7)	1.2×10^5- 4.4×10^5 (2.48×10^5)	1.4×10^5- 8.3×10^5 (4.28×10^5)	1.0×10^5- 5.7×10^6 (3.16×10^6)	1.2×10^5- 8.4×10^5 (3.12×10^5)	1.0×10^5- 5.5×10^5 (2.62×10^5)	1.4×10^5- 6.6×10^5 (3.98×10^5)
	Begamgonj	8.3×10^7- 14.4×10^7 (11.62×10^7)	1.4×10^5- 5.4×10^5 (2.92×10^5)	1.5×10^5- 6.4×10^5 (4.38×10^5)	7.2×10^6- 1.0×10^6 (4.26×10^6)	1.6×10^5- 7.4×10^5 (4.58×10^5)	1.0×10^5- 4.3×10^5 (1.88×10^5)	1.2×10^5- 5.4×10^5 (2.74×10^5)
Mean (Upazila)		7.59×10^7	2.7×10^5	4.33×10^5	3.71×10^6	3.85×10^5	2.25×10^5	3.36×10^5
Mean (District)		5.51×10^7	5.05×10^5	6.45×10^5	4.88×10^6	3.58×10^5	3.1×10^5	4.185×10^5

N. B: **Total Bac**. =Total bancteria; **Rhizo.** =*Rhizobium*; **B. Rhizo**=*Bradyrhizobium*; **FLNFB**=Free living nitrogen fixing bacteria; **PSB**=Phosphate solubilizing bacteria; **Actino**=Actinomycetes;

Rhizobium population got higher in soils of Kurigram (5.05×10^5 cfu g^{-1} soil) over Sirajganj (2.02×10^5 cfu g^{-1} soil). In Kurigram district, Rhizobium population ranged from 1.6×10^5 to 8.4×10^5 cfu g^{-1} soil in Rajarhat and 1.4×10^5 to 5.4×10^5 cfu g^{-1} in Olepur Upazila. In Sirajgonj district, Rhizobium population was found higher in Belkuchi upazila (2.05×10^5 cfu g^{-1} soil) over Shahzadpur upazila (1.99×10^5 cfu g -1 soil). Belkuchi upazila ranged from 0.6×10^5 to 4.8×10^5 cfu g -1 soil where Shahzadpur 0.3×10^5 to 4.1×10^5 cfu g -1 soil soil. Soils of Kurigram recorded higher Bradyrhizobium population (6.45×10^5 cfu g^{-1} soil) compared to soils of Sirajganj (1.4×10^5 cfu g^{-1} soil). In Kurigram, Rajarhat Upazila recorded higher Bradyrhizobium population (8.6×10^5 cfu g^{-1} soil) over Olepur Upazila (4.33×10^5 cfu g^{-1} soil). A range of 1.4×10^5 to 25×10^5 cfu g^{-1} soil in Rajarhat and 1.4×10^5 to 8.3×10^5 cfu g^{-1} soil in Olepur was found. In Sirajganj district, *Bradyrhizobium* population was found with the range of 0.1×10^5 to 2.2×10^5 cfu g^{-1} soil in Shahzadpur Upazila and mean population of 0.71×10^5 cfu g^{-1} soil. With the range of 0.1×10^5 to 4.2×10^5 cfu g^{-1} soil and mean population of 2.08×10^5 cfu g^{-1} soil was founf in Belkuchi Upazila. Soils of Kurigram District exhibited higher (FLNFB) population (4.88×10^6 cfu g^{-1} soil) compared to Sirajganj (1.73×10^5 cfu g^{-1} soil). In Kurigram, soils of Rajarhat recorded higher population (6.05×10^6 cfu g^{-1} soil) over Olepur (3.71×10^6 cfu g^{-1} soil). A range of 0.8×10^6 to 14×10^6 cfu g^{-1} soil in Rajarhat Upazila and 1×10^6 to 7.2×10^6 cfu g^{-1} soil in Olepur. In Sirajganj, (FLNFB) population ranged from 0.4×10^5 to 7.5×10^5 cfu g^{-1} soil in Shagzadpur Upazila was determined and 0.1×10^5 to 3.1×10^5 cfu g^{-1} soil in Belkuchi Upazila. PSB population was found higher in Kurigram (3.58×10^5 **cfu g** $^{-1}$ soil) over Sirajganj (4.06×10^4 cfu g^{-1} soil). In Kurigram, soils of Olepur recorded higher PSB population (3.85×10^5 cfu g^{-1} soil) compared to Rajarhat (3.31×10^5 cfu g^{-1} soil). A range of 1.2×10^5 to 8.4×10^5 cfu g^{-1} soil in Olepur and 1.6×10^5 to 7.4×10^5 cfu g^{-1} soil was found in different locations of Rajarhat Upazila. In Sirajganj District, higher PSB population was found in Belkuchi Upazila (4.55×10^4 cfu g^{-1} soil) compared to Shahzadpur Upazila (3.56×10^4 cfu g^{-1} soil). With the range of 0.6×10^4 to 7.2×10^4 cfu g^{-1} soil in Belkuchi and 0.2×10^4 to 9.5×10^4 cfu g^{-1} soil was found in Shahzadpur. Fungi population showed higher in Kurigram (3.1×10^5 cfu g^{-1} soil) over Sirajganj (1.84×10^5 cfu g^{-1} soil). In Kurigram District, with the range of 1×10^5 to 7.8×10^5 cfu g^{-1} soil in Rajarhat Upazila and 1×10^5 to 5×10^5 cfu g^{-1} soil in Olepur Upazila was found. In Sirajganj, Fungi population ranged from 0.4×10^5 to 4.2×10^5 cfu g^{-1} soil in Belkuchi and 0.2×10^5 to 5×10^5 cfu g^{-1} soil in Shahzadpur Upazila was recorded. In AEZ-7, soils of Kurigram recorded higher Actinomyceties population (4.19×10^5 cfu g^{-1} soil) over soils of Sirajganj (1.29×10^4 cfu g^{-1} soil). In Kurigram, with the range of 1.1×10^5 to 14.0×10^5 cfu g^{-1} soil was found in Rajarhat and 1.2×10^5 to 6.6×10^5 cfu g^{-1} soil in Olepur. In Sirajganj, 0.2×10^4 to 2.5×10^4 cfu g^{-1} soil in Shahzadpur and 0.1×10^4 to 5.1×10^4 cfu g^{-1} soil in Belkuchi Upazila. Over all FLNFB population was found higher over *Rhizobium*, *Bradyrhizobium*, Fungi and Actiomycetes in this AEZ.

Table 79. Soil Biological properties of AEZ- 7 (Sirajgang)

Upazila	Union	Total Bac.	Rhizo.	B.Rhizo	FLNFB	PSB	Fungi	Actino
Shahzadpur	Sonatali	0.2×10^7 - 2.3×10^7 (1.34×10^7)	0.3×10^5 - 3.7×10^5 (1.86×10^5)	0.4×10^5 - 2.2×10^5 (1.08×10^5)	1.1×10^5 - 7.5×10^5 (3.04×10^5)	1.2×10^4 - 9.5×10^4 (4.1×10^4)	0.4×10^5 - 5×10^5 (2.04×10^5)	0.2×10^4 - 2.5×10^4 (1.1×10^4)
	Koizuri	0.6×10^7- 1.8×10^7 (1.26×10^7)	1×10^5-4.1×10^5 (2.12×10^5)	0.1×10^5-0.5 $\times10^5$ (0.34×10^5)	0.4×10^5 - 3.2×10^5 (1.62×10^5)	0.2×10^4 - 7.2×10^4 (3.02×10^4)	0.2×10^5- 2.5×10^5 (1.5×10^5)	0.3×10^4- 1.6×10^4 (0.92×10^4)
	Mean (Upazila)	1.3×10^7	1.99×10^5	0.71×10^5	2.33×10^5	3.56×10^4	1.77×10^5	1.01×10^4
Belkuchi	Borodhul	1.4×10^7- 3.2×10^7 (2.32×10^7)	0.6×10^5- 3.1×10^5 (1.92×10^5)	0.8×10^5-4×10^5 (2.3×10^5)	0.1×10^5- 3.1×10^5 (1.42×10^5)	3.8×10^4- 7.2×10^4 (5.48×10^4)	0.5×10^5- 4.2×10^5 (1.88×10^5)	0.2×10^4- 5.1×10^4 (1.72×10^4)
	Rajapur	0.7×10^7- 2.4×10^7 (1.38×10^7)	0.6×10^5- 4.8×10^5 (2.18×10^5)	0.1×10^5- 4.2×10^5 (1.86×10^5)	0.4×10^5- 1.2×10^5 (0.84×10^5)	0.6×10^4- 6.2×10^4 (3.62×10^4)	0.4×10^5- 3.6×10^5 (1.92×10^5)	0.1×10^4- 2.3×10^4 (1.42×10^4)
Mean (Upazila)		1.85×10^7	2.05×10^5	2.08×10^5	1.13×10^5	4.55×10^4	1.9×10^5	1.57×10^4
Mean (District)		1.58×10^7	2.02×10^5	1.40×10^5	1.73×10^5	4.06×10^4	1.84×10^5	1.29×10^4

N. B: **Total Bac**. =Tatal bancteria; **Rhizo.** =*Rhizobium*; **B. Rhizo**=Bradyrh*i*zobium; **FLNFB**=Free living nitrogen fixing bacteria; **PSB**=Phosphate solubilizing bacteria; Actino=Actinomycetes;

Soil physico-chemical properties:

Physico-chemical properties of soils of AEZ-7 was presented in Table 80-81. A number of 40 soil samples from 0 to 15 cm depth were analysed to determine bio-physicochemical properties (details in methothology section). The field history such as existing crop, cropping pattern and location details were recorded. The soils of AEZ-7 were found mainly with the textural class of Sandy loam. Only one union (Omormazid) of Rajarhat of Kurigram showed loam in texture. Soil reaction was observed acidic in Kurigram (5.27-5.96) while slightly acidic to neutral in Sirajganj (5.93-6.95). Organic matter was found at an average 1.98% in Kurigram with the range of 0.98-3.81% and 1.34 % in Sirajganj with the range of 1.06-1.60%. Total soil nitrogen recorded 0.233% in Rangpur and 0.110% in Sirajganj district. Belkuchi upazila showed higher soil nitrogen as compared to Shahzadpur in Sirajganj district.

Table 80. Physico-chemical properties of AEZ-7 (Kurigram)

Upazila	Union	pH	% OC	% OM	% N	Textural Class
Rajarhat	Cenai	4.90-5.90 (5.27)	0.37-1.23 (0.78)	0.64-2.12 (1.43)	0.196-0.280 (0.230)	Sandy loam
	Omormajid	5.42-6.11 (5.68)	1.89-2.34 (2.13)	3.28-4.65 (3.81)	0.196-0.288 (0.254)	Loam
Olepur	Durgapur Gobisorarpar	5.69-5.88 (5.83)	0.48-1,49 (0.98)	0.84-2.51 (1.68)	0.196-0.252 (0.218)	Sandy loam
	Begumganj	6.85-7.35 (7.06)	0.44-0.74 (0.57)	0.77-1.23 (0.98)	0.168-0.280 (0.230)	Sandy loam
Mean (District)		5.96	1.12	1.98	0.233	
Range (District)		4.9-7.35	0.37-2.34	0.64-4.65	0.168-0.288	Sandy loam

Table 81. Physico-chemical properties of AEZ-7 (Sirajganj)

Upazila	Union	pH	% OC	% OM	% N	Textural Class
Shahzadpur Shahzadpur	Shonatali	6.73-7.46 (6.96)	0.52-0.76 (0.62)	0.90-1.29 (1.06)	0.062-0.112 (0.088)	Sandy loam
	Koizuri	5.62-7.38 (6.89)	0.52-0.88 (0.68)	0.88-1.49 (1.16)	0.070-0.112 (0.087)	Sandy loam
Belkuchi	Borodhul	5.19-6.52 (5.93)	0.56-1.32 (0.90)	0.95-2.24 (1.54)	0.098-0.154 (0.129)	Sandy loam
	Rajapur	6.66-7.65 (6.95)	0.64-1.16 (0.94)	1.09-1.97 (1.60)	0.056-0.140 (0.112)	Sandy loam
Mean (District)		6.68	0.79	1.34	0.11	
Range (District)		5.19-7.65	0.52-1.32	0.88-2.24	0.056-0.154	Sandy loam

Soil Bio-physico-chemical properties of AEZ 9

Soil Biological properties:

Total bacterial population in AEZ-9 was found 4.04×10^7 cfu g $^{-1}$ soil (Table 82-83). Total bacteria population in soil of Netrakona recorded higher (4.20×10^7 cfu g $^{-1}$ soil) over Mymensingh (3.88×10^7 cfu g $^{-1}$ soil). In Mymensingh, Sadar Upazila soil showed higher bacterial population (4.04×10^7 cfu g $^{-1}$ soil) over soil of Nandail Upazila (3.72×10^7 cfu g $^{-1}$ soil). Vabokhali Union recorded higher population (4.12×10^7 cfu g $^{-1}$ soil) over Ghagra Union (3.96×10^7 cfu g $^{-1}$ soil) of Mymensingh Sadar. In Nandail, Muazzempur Union showed higher population of total bacteria (4.08×10^7 cfu g $^{-1}$ soil) compared to Betagoir Union (3.36×10^7 cfu g $^{-1}$ soil). In Nerakona, higher total bacteria population was recorded Netrakona Sadar (4.95×10^7 cfu g -1 soil) over Pubadhala upazila (3.44×10^7 cfu g $^{-1}$ soil). Challisha union showed higher total bacteria (5.16×10^7 cfu g $^{-1}$ soil) compared to Kailati union (4.74×10^7 cfu g $^{-1}$ soil) of Netrakona Sadar. In Purbadhala upazila, Narandia union and Khalishpur union showed similar pupulation but khalishpur resulted higher. *Rhizobium* population was found 4.16×10^5 cfu g -1 soil in this AEZ. Netrakona recorded higher *Rhizobium* population (4.34×10^5 cfu g $^{-1}$ soil) compared to Mymensingh district (3.98×10^5 cfu g -1 soil). Similar population was found in Netrokona Sadar (4.32×10^5 cfu g $^{-1}$ soil) and Purbadhala Upazila (4.36×10^5 cfu g $^{-1}$ soil). In Mymensingh, Nandail Upazila showed little bit higher population (4.03×10^5 cfu g $^{-1}$ soil) over Mymensingh Sadar Upazila (3.92×10^5 cfu g $^{-1}$ soil).

Table 82. Soil Biological properties of AEZ- 9 (Mymensngh)

Upazila	Union	Total Bac.	Rhizo.	B.Rhizo	FLNFB	PSB	Fungi	Actino
Mymensingh Sadar	Vabokhali	2.4×10^7-6.5×10^7 (4.12×10^7)	1.3×10^5-7.5×10^5 (4.82×10^5)	1.6×10^5-8.9×10^5 (4.74×10^5)	2.5×10^6-5.7×10^6 (3.62×10^6)	1.9×10^4-5.9×10^4 (4.08×10^4)	2.2×10^4-6.2×10^4 (3.88×10^4)	3.2×10^5-8.3×10^5 (5.82×10^5)
	Ghagra	6.9×10^6-5.8×10^7 (3.96×10^7)	6.9×10^6-5.8×10^7 (3.96×10^7)	3.3×10^5-6.5×10^5 (4.98×10^5)	1.1×10^6-7.1×10^6 (4.42×10^6)	$.3\times10^4$-3.4×10^4 (2.6×10^4)	2.5×10^4-5.9×10^4 (4.04×10^4)	2.3×10^5-6.1×10^5 (4.22×10^5)
	Mean (Upazila)	4.04×10^7	3.92×10^5	4.86×10^5	4.02×10^6	3.34×10^4	3.96×10^4	5.02×10^5
Nandail	Moazzempur	1.3×10^7-6.2×10^7 (4.08×10^7)	4.1×10^5-5.1×10^5 (4.6×10^5)	3.1×10^5-5.1×10^5 (3.98×10^5)	2.5×10^6-5.0×10^6 (3.82×10^6)	1.3×10^4-3.8×10^4 (2.38×10^4)	1.3×10^4-5.2×10^4 (3.58×10^4)	1.1×10^5-8.2×10^5 (4.1×10^5)
	Betagoir	0.8×10^7-6.1×10^7 (3.36×10^7)	1.2×10^5-4.7×10^5 (3.46×10^5)	2.2×10^5-6.1×10^5 (4.44×10^5)	1.0×10^6-4.3×10^6 (3.76×10^6)	1.9×10^4-5.3×10^4 (3.64×10^4)	2.2×10^4-6.5×10^4 (4.84×10^4)	2.0×10^5-3.3×10^5 (2.84×10^5)
Mean (Upazila)		3.72×10^7	4.03×10^5	4.21×10^5	3.79×10^6	3.01×10^4	4.21×10^4	3.47×10^5
Mean (District)		3.88×10^7	3.98×10^5	4.54×10^5	3.91×10^6	3.18×10^4	4.09×10^4	4.25×10^5

N. B: **Total Bac**. =Tatal bancteria; **Rhizo.** =*Rhizobium*; **B. Rhizo**=*Bradyrhizobium*; **FLNFB**=Free living nitrogen fixing bacteria; **PSB**=Phosphate solubilizing bacteria; **Actino**=Actinomycetes;

With the ranges of 2.4×10^5 to 6.5×10^5 cfu g $^{-1}$ soil in Vabokhali union and 1.5×10^5 to 6.9×10^5 cfu g $^{-1}$ soil in Ghagra union were found in Mymensingh Sadar. Mymensingh showed higher population of *Bradyrhizobium* (4.54×10^5 cfu g $^{-1}$ soil) over Netrakona (4.49×10^5 cfu g $^{-1}$ soil). Mymensingh Sadar recorded higher *Bradyrhizobium* population (4.86×10^5 cfu g $^{-1}$ soil) over Nandail Upazila (4.21×10^5 cfu g $^{-1}$ soil). *Bradyrhizobium* population ranged from 1.6×10^5 to 8.9×10^5 cfu g $^{-1}$ soil in Mymensingh Sadar while Nandail ranged from 2.2×10^5 to 6.1×10^5 cfu g $^{-1}$ soil in Nandail. In Netrokona District, Netrokona Sadar Upazila recorded higher population (5.59×10^5 cfu g $^{-1}$ soil) compared to Purba Dhala Upazila (3.39×10^5 cfu g $^{-1}$ soil). *Bradyrhizobium* population ranged from 2.9×10^5 to 7.2×10^5 cfu g $^{-1}$ soil in Netrokona Sadar and 1.1×10^5 to 5.5×10^5 cfu g $^{-1}$ soil in Purbadhala. Similar population of *Rhizobium* as well as *Bradyrhizobium* was observed in this AEZ. Netrokona recorded higher FLNFB population (4.47×10^6 cfu g $^{-1}$ soil) compared to Mymensingh (3.91×10^6 cfu g $^{-1}$ soil). In Mymensingh, Sadar Upazila showed higher FLNFB population (4.02×10^6 cfu g $^{-1}$ soil) over Nandail Upazila (3.79×10^6 cfu g $^{-1}$ soil). A range of 1.1×10^6 to 7.1×10^6 cfu g $^{-1}$ soil in Mymensingh Sadar Upazila where Nandail Upazila showed 1.0×10^6 to 7.5×10^6 cfu g $^{-1}$ soil soil. In Netrokona district, Purbadhala recorded higher population (5.09×10^6 cfu g $^{-1}$ soil) over Netrokona Sadar (3.84×10^6 cfu g $^{-1}$ soil). A range of 1.1×10^6 to 5.3×10^6 cfu g $^{-1}$ soil was found in Narandia and 5×10^6 to 9.5×10^6 cfu g $^{-1}$ soil in Khalishpur union of Purbadhala Upazila and Netrakona Sadar Upazila showed 2.1×10^6 to 5.7×10^6 cfu g -1 soil in Kailati and 1.3×10^6 to 5.5×10^6 cfu g $^{-1}$ soil in Challisha union. Netrakona exhibited higher PSB population (3.79×10^4 cfu g $^{-1}$ soil) over Mymensingh (3.18×10^4 cfu g $^{-1}$ soil). Soils of Mymensingh Sadar Upazila recorded higher population (3.34×10^4 cfu g $^{-1}$ soil) over soils of Nandail Upazila (3.01×10^4 cfu g $^{-1}$ soil). With the range of 1.3×10^4 to 5.9×10^4 cfu g $^{-1}$ soil in Mymensingh Sadar and 1.3×10^4 to 5.3×10^4 cfu g $^{-1}$ soil was found in Nandail Upazila. Netrakona Sadar Upazila recorded higher population (4.05×10^4 cfu g $^{-1}$ soil) over Purbadhala Upazila of Netrakona (3.52×10^4 cfu g $^{-1}$ soil). With the range of 1.1×10^4 to 8.5×10^4 cfu g $^{-1}$ soil in Netrakona Sadar and 1.5×10^4 to 8.2×10^4 cfu g $^{-1}$ soil was found in Purbadhala Upazila. In AEZ-9, Mymensingh recorded higher Fungi population (4.09×10^4 cfu g $^{-1}$ soil) over Netrakona (4.05×10^4 cfu g $^{-1}$ soil). Fungi population ranged from 2.2×10^4 to 6.2×10^4 cfu g $^{-1}$ soil in Mymensingh Sadar and 1.3×10^4 to 6.5×10^4 cfu g $^{-1}$ soil in Nandail Upazila. In Netrakona, Fungi population ranged from 1×10^4 to 5.5×10^4 cfu g $^{-1}$ soil in Netrakona Sadar and 3×10^4 to 8.1×10^4 cfu g $^{-1}$ soil in Purbadhala Upazila. The highest Actinomycities population was found in soils of AEZ-9 (3.99×10^5 cfu g -1 soil). Higher Actinomycities population was found in Mymensingh (2.25×10^5 cfu g $^{-1}$ soil) over Netrakona (3.72×10^5 cfu g $^{-1}$ soil). In Mymensingh, with the range of 2.3×10^5 to 8.3×10^5 cfu g $^{-1}$ soil in Mymensingh Sadar and 2×10^5 to 8.2×10^5 cfu g $^{-1}$ soil in Nandail Upazila. In Netrakona, Actinomycities population ranged from 1.5×105 to 7.8×105 cfu g $^{-1}$ soil in Netrakona Sadar while soils of Purbadhala showed 1.5×105 to 5.3×105 cfu g $^{-1}$ soil.

Table 83. Soil Biological properties of AEZ- 9 (Netrakona)

Upazila	Union	Total Bac.	Rhizo.	B.Rhizo	FLNFB	PSB	Fungi	Actino
Netrakona Sadar	Kailati	2.5×10^{7}-9.9×10^{6} (4.74×10^{7})	2.9×10^{5}-8.9×10^{5} (5.3×10^{5})	2.9×10^{5}-6.5×10^{5} (4.2×10^{5})	2.1×10^{6}-5.7×10^{6} (4.2×10^{6})	2.1×10^{4}-5.8×10^{4} (3.96×10^{4})	1.0×10^{4}-5.5×10^{4} (3.66×10^{4})	2.8×10^{5}-6.1×10^{5} (4.32×10^{5})
	Challisha	2.1×10^{7}-8.8×10^{6} (5.16×10^{7})	2.2×10^{5}-4.4×10^{5} (3.34×10^{5})	6.5×10^{5}-7.2×10^{5} (6.98×10^{5})	1.3×10^{6}-5.5×10^{6} (3.48×10^{6})	1.1×10^{4}-8.5×10^{4} (4.14×10^{4})	1.5×10^{4}-4.9×10^{4} (3.72×10^{4})	1.5×10^{5}-7.8×10^{5} (4.36×10^{5})
	Mean (Upazila)	4.95×10^{7}	4.32×10^{5}	5.59×10^{5}	3.84×10^{6}	4.05×10^{4}	3.69×10^{4}	4.34×10^{5}
Purbadhala	Narandia	2.2×10^{7}-7.1×10^{7} (4.76×10^{7})	2.2×10^{5}-3.8×10^{5} (3.04×10^{5})	2.8×10^{5}-5.5×10^{5} (4.04×10^{5})	1.1×10^{6}-5.3×10^{6} (2.54×10^{6})	1.7×10^{4}-8.2×10^{4} (4.44×10^{4})	3.0×10^{4}-8.1×10^{4} (4.54×10^{4})	1.5×10^{5}-3.9×10^{5} (2.58×10^{5})
	Khalishpur	0.5×10^{7}-4.2×10^{7} (2.12×10^{7})	2.8×10^{5}-8.5×10^{5} (5.68×10^{5})	1.1×10^{5}-4.9×10^{5} (2.74×10^{5})	5.0×10^{6}-9.5×10^{6} (7.64×10^{6})	1.5×10^{4}-3.3×10^{4} (2.6×10^{4})	3.1×10^{4}-5.2×10^{4} (4.28×10^{4})	2.5×10^{5}-5.3×10^{5} (3.6×10^{5})
Mean (Upazila)		3.44×10^{7}	4.36×10^{5}	3.39×10^{5}	5.09×10^{6}	3.52×10^{4}	4.41×10^{4}	3.09×10^{5}
Mean (District)		4.20×10^{7}	4.34×10^{5}	4.49×10^{5}	4.47×10^{6}	3.79×10^{4}	4.05×10^{4}	3.72×10^{5}

N. B: **Total Bac**. =Tatal bancteria; **Rhizo.** =*Rhizobium*; **B. Rhizo**=*Bradyrhizobium*; **FLNFB**=Free living nitrogen fixing bacteria; **PSB**=Phosphate solubilizing bacteria; **Actino**=Actinomycetes;

Soil physico-chemical properties:

Physico-chemical properties of soils of AEZ-9 were presented in Table 84-85. A number of 40 soil samples from 0 to 15 cm depth were analysed to determine bio-physicochemical properties (details in methothology section). The field history such as existing crop, cropping pattern and location details were recorded. Soil texture was observed in AEZ-9 was found sandy loam to sandy clay loam. Betagoir union of Nandail upazila was found loamy sand and Narandia union of Durgapur upazila of Netrakona recorded sandy clay loam of textural class. Soil was recorded neutral to slightly acidic in reaction both in Mymensingh (mean pH of 6.36) and Netrakona (mean pH of 6.50). Organic matter was found higher in Mymensingh (1.93) as compared to Netrakona (1.62). Soil nitrogen recorded higher in Netrakona (0.184%) as compared to Mymensingh (0.121%). A range of 0.101-0.146% was found in Mymensingh while 0.137- 0.207% in Netrakona district.

Table 84. Physico-chemical properties of AEZ-9 (Mymensingh)

Upazila	Union	pH	% OC	% OM	% N	Textural Class
Mym Sadar	Vabokhali	6.07-7.67 (6.81)	0.88-1.18 (1.06)	1.50-2.07 (1.80)	0.084-0.126 (0.101)	Sandy loam
	Ghagra	6.16-6.86 (6.38)	0.65-1.39 (1.15)	1.12-2.43 (1.95)	0.078-0.154 (0.111)	Sandy loam
Nandail	Moazzempur	5.56-6.32 (5.92)	1.05-1,76 (1.44)	1.79-2.99 (2.44)	0.098-0.196 (0.146)	Sandy loam
	Betagoir	5.92-6.51 (6.32)	0.70-1.05 (0.89	1.21-1.80 (1.53)	0.104-0.154 (0.127)	Loamy sand,
Mean (District)		6.36	1.13	1.93	0.121	
Range (District)		5.56-7.67	0.65-1.76	1.12-2.99	0.078-0.196	Sandy loam

Table 85. Physico-chemical properties of AEZ-9 (Netrakona)

Upazila	Union	pH	% OC	% OM	% N	Textural Class
Netrakona Sadar	Kailati	5.77-6.69 (6.20)	0.80-1.72 (1.34)	1.22-2.72 (1.93)	0.140-0.238 (0.207)	Sandy loam
	Challisha	6.30-6.92 (6.57)	0.67-1.47 (1.14)	1.14-2.50 (1.94)	0.168-0.210 (0.193)	Sandy loam
Durgapur	Narandia	6.13-7.44 (6.63)	0.59-1.68 (1.03)	1.00-2.14 (1.42)	0.140-0.294 (0.199)	Sandy loam, Sandy clay loam
	Khalispur	6.48-6.85 (6.59)	0.63-0.80 (0.68)	1.07-1.36 (1.16)	0.084-0.182 (0.137)	Sandy loam
Mean (District)		6.50	1.05	1.62	0.184	
Range (District)		5.77-7.44	0.59-1.72	1.00-2.72	0.084-0.294	Sandy loam

Soil Bio-physico-chemical properties of AEZ 12

Soil Biological properties:

In AEZ-12 (Table86, Table 87), higher bacterial population was found in Faridpur district (4.52×10^7 cfu g $^{-1}$ soil) over Pabna district (3.42×10^7 cfu g $^{-1}$ soil). Sadarpur upazila of Faridpur showed higher population (6.06×10^7 cfu g $^{-1}$ soil) over Bhanga upazila (2.97×10^7 cfu g $^{-1}$ soil). Soils of Kistopur union recorded higher population of total bacteria (7.78×10^7 cfu g $^{-1}$ soil) compared to Sadarpur union (4.34×10^7 cfu g $^{-1}$) of Faridpur Sadar. A range of 5.2×10^7 to 12.0×10^7 cfu g $^{-1}$ soil soil of Kistopur union was observed while Sadarpur union recorded 1.1×10^7 to 12.2×10^7 cfu g $^{-1}$ soil. In Bhanga upazila, Chanda union recorded higher population of bacteria compared to Algi union. With the ranges of 2.1×10^7 to 6.1×10^7 cfu g $^{-1}$ soil in Chanda and 2.1×10^7 to 4.0×10^7 cfu g $^{-1}$ soil in Algi union of Bhanga upazila was recorded. In Pabna, Pabna Sadar (3.38×10^7 cfu g $^{-1}$ soil) and Sathia upazila (3.46×10^7 cfu g $^{-1}$ soil) showed more or less similar total bacterial population where Sathia exhibited higher over Pabna Sadar. Dhulauri union (3.58×10^7 cfu g $^{-1}$ soil) recorded higher population over Dhopadaha union (3.34×10^7 cfu g $^{-1}$ soil) of Sathia. Dhopadaha ranged from 1.3×10^7 to 7.1×10^7 cfu g $^{-1}$ while Dholauri ranged from 1.2×10^7 to 6.1×10^7 cfu g $^{-1}$ soil soil. Bharara union recorded higher bacterial population (3.52×10^7 cfu g $^{-1}$ soil) over Dogasi union (3.24×10^7 cfu g $^{-1}$ soil) of Pabna Sadar upazila. Bharara union ranged from 1.5×10^7 to 5.1×10^7 cfu g $^{-1}$ soil while Dogasi showed 2.1×10^7 to 4.1×10^7 cfu g $^{-1}$ soil.

Table 86. Soil Biological properties of AEZ- 12 (Faridpur)

Upazila	Union	Total Bac.	Rhizo.	B.Rhizo	FLNFB	PSB	Fungi	Actino
Sadarpur	Kishtopur	5.2×10^7-12×10^7 (7.78×10^7)	1.2×10^5-6.6×10^5 (3.38×10^5)	2×10^5-8×10^5 (5.2×10^5)	1×10^6-7.6×10^6 (3.82×10^6)	1.8×10^5-6.8×10^5 (4.44×10^5)	1.2×10^5-7×10^5 (3.54×10^5)	1.25×10^5-9×10^5 (3.33×10^5)
	Sadarpur	1.1×10^7-12.2×10^7 (4.34×10^7)	1.2×10^5-3.6×10^5 (1.98×10^5)	1.6×10^5-5×10^5 (2.58×10^5)	1×10^6-4.2×10^6 (2.5×10^6)	1×10^5-3.3×10^5 (2.62×10^5)	2.1×10^5-5.2×10^5 (3.22×10^5)	0.7×10^5-5.3×10^5 (2.94×10^5)
	Mean (Upazila)	6.06×10^7	2.68×10^5	3.89×10^5	3.16×10^6	3.53×10^5	3.38×10^5	3.14×10^5
Bhanga	Chanda	2.1×10^7-6.1×10^7 (3.44×10^7)	1×10^5-3.1×10^5 (1.96×10^5)	1.5×10^5-5×10^5 (3.06×10^5)	1.2×10^6-5.5×10^6 (2.96×10^6)	1.3×10^5-6.1×10^5 (3.5×10^5)	0.9×10^5-5.2×10^5 (2.96×10^5)	0.7×10^5-5.1×10^5 (3.04×10^5)
	Algi	2.1×10^7-4×10^7 (2.5×10^7)	0.2×10^5-2.5×10^5 (1.56×10^5)	1.2×10^5-3.3×10^5 (1.5×10^5)	1.4×10^6-4.1×10^6 (2.62×10^6)	1.1×10^5-4.3×10^5 (2.34×10^5)	1.1×10^5-5.3×10^5 (2.7×10^5)	1×10^5-4.4×10^5 (2.5×10^5)
Mean (Upazila)		2.97×10^7	1.76×10^5	2.28×10^5	2.79×10^6	2.9×10^5	2.83×10^5	2.77×10^5
Mean (District)		4.52×10^7	2.22×10^5	3.09×10^5	2.98×10^6	3.23×10^5	3.11×10^5	2.96×10^5

N. B: **Total Bac**. =Tatal bancteria; **Rhizo.** =*Rhizobium*; **B. Rhizo**=*Bradyrhizobium*; **FLNFB**=Free living nitrogen fixing bacteria; **PSB**=Phosphate solubilizing bacteria; **Actino**=Actinomycetes;

Mean population of *Rhizobium* was found 2.84×10^5 cfu g -1 soil. Pabna district (2.74×10^5 cfu g $^{-1}$ soil) showed higher population over Faridpur district (2.22×10^5 cfu g $^{-1}$ soil). Sadarpur upazila recorded higher *Rhizobium* population (2.68×10^5 cfu g $^{-1}$ soil) compared to Bhanga Upazila (1.76×10^5 cfu g $^{-1}$ soil). With the range of 1.2×10^5 to 6.6×10^5 cfu g $^{-1}$ soil in Sadarpur upazila and 0.2×10^5 to 3.1×10^5 cfu g $^{-1}$ soil in Bhanga Upazila was recorded. In Pabna, higher *Rhizobium* population in Pabna Sadar was recorded (2.94×10^5 cfu g $^{-1}$ soil) over Sathia Upazila (2.53×10^5 cfu g -1 soil). *Rhizobium* population ranged 1×10^5 to 5.1×10^5 cfu g $^{-1}$ soil in Pabna Sadar and 1×10^5 to 5×10^5 cfu g $^{-1}$ soil in Sathia Upazila. In AEZ-12 (Table 86, Table 87), higher *Bradyrhizobium* population was observed in Faridpur (3.09×10^5 cfu g $^{-1}$ soil) over Pabna district (2.05×10^5 cfu g $^{-1}$ soil). In Faridpur District, a range of 1.6×10^5 to 8.0×10^5 cfu g $^{-1}$ soil in Sadarpur Upazila and 1.2×10^5 to 3.4×10^5 cfu g $^{-1}$ soil in Bhanga Upazila was recorded. In Pabna, a range of 0.2×10^5 to 3.0×10^5 cfu g $^{-1}$ soil in Pabna Sadar Upazila and 1.5×10^5 to 4.0×10^5 cfu g $^{-1}$ soil in Sathia Upazila was recorded. Soils of Faridpur exhibited higher FLNFB population (2.98×10^6 cfu g $^{-1}$ soil) compared to Pabna (3.83×10^5 cfu g $^{-1}$ soil). In Faridpur Sadarpur Upazila showed higher FLNFB population (3.16×10^6 cfu g -1 soil) over Bhanga Upazila (2.79×10^6 cfu g $^{-1}$ soil). A range of 1×10^6 to 7.6×10^6 cfu g $^{-1}$ soil in Sadarpur Upazila and 1.2×10^6 to 5.5×10^6 cfu g $^{-1}$ soil in Bhanga Upazila. In Pabna, Pabna Sadar exhibited higher FLNFB population (4.37×10^5 cfu g $^{-1}$ soil) compared to Sathia Upazila (3.29×10^5 cfu g $^{-1}$ soil). A range of 2×10^5 to 8.2×10^5 cfu g $^{-1}$ soil in Pabna Sadar and 1.3×10^5 to 8.2×10^5 cfu g $^{-1}$ soil in Sathia Upazila of Pabna. PSB population was found higher in Faridpur (3.23×10^5 cfu g $^{-1}$ soil) compared to Pabna district (4.87×10^4 cfu g $^{-1}$ soil). In Faridpur, PSB population was found higher in Sadarpur Upazila (3.53×10^5 cfu g $^{-1}$ soil) over Bhanga Upazila (2.9×10^5 cfu g $^{-1}$ soil). With the range of 1×10^5 to 6.8×10^5 cfu g $^{-1}$ soil in Sadarpur and 1.1×10^5 to 6.1×10^5 cfu g $^{-1}$ soil in Bhanga Upazila was observed. In Pabna, PSB population was found in Sathia (5.76×10^4 cfu g $^{-1}$ soil) over Pabna Sadar Upazila (3.97×10^4 cfu g $^{-1}$ soil). PSB population ranged from 2.3×10^4 to 20×10^4 cfu g $^{-1}$ soil in Sathia and 1×10^4 to 7×10^4 cfu g $^{-1}$ soil in Pabna Sadar. Faridpur showed higher Fungi population (3.11×10^5 cfu g $^{-1}$ soil) over Pabna (3.01×10^5 cfu g $^{-1}$ soil). In Faridpur with the range of 1.2×10^5 to 7×10^5 cfu g $^{-1}$ soil in Sadarpur and 0.9×10^5 to 5.3×10^5 cfu g $^{-1}$ soil in Bhanga Upazila. Sadarpur exhibited higher Fungi population over Bhanga. In Pabna, Fungi population ranged from 1.8×10^5 to 7.1×10^5 cfu g $^{-1}$ soil in Pabna Sadar and 1×10^5 to 5×10^5 cfu g $^{-1}$ soil in Sathia. Pabna Sadar recorded higher Fungi population over soils of Sathia Upazila. Actinomycities population ranged from 0.7×10^5 to 9×10^5 cfu g $^{-1}$ soil in Sadarpur and 0.7×10^5 to 5.1×10^5 cfu g $^{-1}$ soil in Bhanga Upazila of Faridpur district. In Pabna, with the range of 1.0×10^5 to 7.5×10^5 cfu g $^{-1}$ soil was found in Pabna Sadar while 2×10^5 to 7.5×10^5 cfu g $^{-1}$ soil in Sathia of Pabna.

Table 87. Soil Biological properties of AEZ- 12 (Pabna)

Upazila	Union	Total Bac.	Rhizo.	B.Rhizo	FLNFB	PSB	Fungi	Actino
Pabna Sadar	Dogasi	2.1×10^{7}-4.1×10^{7} (3.24×10^{7})	1×10^{5}-5×10^{5} (2.76×10^{5})	0.2×10^{5}-2×10^{5} (1.22×10^{5})	3.8×10^{5}-8.2×10^{5} (5.68×10^{5})	1×10^{4}-7×10^{4} (3.72×10^{4})	1.8×10^{5}-5×10^{5} (2.82×10^{5})	1.2×10^{5}-7.5×10^{5} (4.40×10^{5})
	Bharara	1.5×10^{7}-5.1×10^{7} (3.52×10^{7})	2.2×10^{5}-5.1×10^{5} (3.12×10^{5})	1.3×10^{5}-3×10^{5} (2.5×10^{5})	2×10^{5}-5×10^{5} (3.06×10^{5})	2×10^{4}-6.5×10^{4} (4.22×10^{4})	2.3×10^{5}-7.1×10^{5} (4.1×10^{5})	1.0×10^{5}-4.1×10^{5} (2.38×10^{5})
	Mean (Upazila)	3.38×10^{7}	2.94×10^{5}	1.86×10^{5}	4.37×10^{5}	3.97×10^{4}	3.46×10^{5}	3.39×10^{5}
Sathia	Dhulauri	1.2×10^{7}-6.1×10^{7} (3.58×10^{7})	1.1×10^{5}-5×10^{5} (2.78×10^{5})	1.5×10^{5}-4×10^{5} (2.46×10^{5})	1.4×10^{5}-8.2×10^{5} (3.42×10^{5})	2.3×10^{4}-7.1×10^{4} (4.34×10^{4})	1×10^{5}-5×10^{5} (2.32×10^{5})	2.1×10^{5}-5.1×10^{5} (3.04×10^{5})
	Dhopadaha	1.3×10^{7}-7.1×10^{7} (3.34×10^{7})	1×10^{5}-4.1×10^{5} (2.28×10^{5})	1.5×10^{5}-3.3×10^{5} (2.02×10^{5})	1.3×10^{5}-5.3×10^{5} (3.16×10^{5})	2.4×10^{4}-6.2×10^{4} (7.18×10^{4})	2×10^{5}-4.1×10^{5} (2.78×10^{5})	2×10^{5}-7.5×10^{5} (4.06×10^{5})
Mean (Upazila)		3.46×10^{7}	2.53×10^{5}	2.24×10^{5}	3.29×10^{5}	5.76×10^{4}	2.55×10^{5}	3.55×10^{5}
Mean (District)		3.42×10^{7}	2.74×10^{5}	2.05×10^{5}	3.83×10^{5}	4.87×10^{4}	3.01×10^{5}	3.47×10^{5}

N. B: **Total Bac**. =Tatal bancteria; **Rhizo.** =*Rhizobium*; **B. Rhizo**=*Bradyrhizobium*; **FLNFB**=Free living nitrogen fixing bacteria; **PSB**=Phosphate solubilizing bacteria; **Actino**=Actinomycetes;

Soils of Faridpur exhibited higher FLNFB population (2.98×10^6 cfu g^{-1} soil) compared to Pabna (3.83×10^5 cfu g^{-1} soil). In Faridpur Sadarpur Upazila showed higher FLNFB population (3.16×10^6 cfu g^{-1} soil) over Bhanga Upazila (2.79×10^6 cfu g^{-1} soil). A range of 1×10^6 to 7.6×10^6 cfu g^{-1} soil in Sadarpur Upazila and 1.2×10^6 to 5.5×10^6 cfu g^{-1} soil in Bhanga Upazila. In Pabna, Pabna Sadar exhibited higher FLNFB population (4.37×10^5 cfu g^{-1} soil) compared to Sathia Upazila (3.29×10^5 cfu g^{-1} soil). A range of 2×10^5 to 8.2×10^5 cfu g^{-1} soil in Pabna Sadar and 1.3×10^5 to 8.2×10^5 cfu g^{-1} soil in Sathia Upazila of Pabna. PSB population was found higher in Faridpur (3.23×10^5 cfu g^{-1} soil) compared to Pabna district (4.87×10^4 cfu g^{-1} soil). In Faridpur, PSB population was found higher in Sadarpur Upazila (3.53×10^5 cfu g^{-1} soil) over Bhanga Upazila (2.9×10^5 cfu g^{-1} soil). With the range of 1×10^5 to 6.8×10^5 cfu g^{-1} soil in Sadarpur and 1.1×10^5 to 6.1×10^5 cfu g^{-1} soil in Bhanga Upazila was observed. In Pabna, PSB population was found in Sathia (5.76×10^4 cfu g^{-1} soil) over Pabna Sadar Upazila (3.97×10^4 cfu g^{-1} soil). PSB population ranged from 2.3×10^4 to 20×10^4 cfu g^{-1} soil in Sathia and 1×10^4 to 7×10^4 cfu g^{-1} soil in Pabna Sadar. Faridpur showed higher Fungi population (3.11×10^5 cfu g^{-1} soil) over Pabna (3.01×10^5 cfu g^{-1} soil). In Faridpur with the range of 1.2×10^5 to 7×10^5 cfu g^{-1} soil in Sadarpur and 0.9×10^5 to 5.3×10^5 cfu g^{-1} soil in Bhanga Upazila. Sadarpur exhibited higher Fungi population over Bhanga. In Pabna, Fungi population ranged from 1.8×10^5 to 7.1×10^5 cfu g^{-1} soil in Pabna Sadar and 1×10^5 to 5×10^5 cfu g^{-1} soil in Sathia. Pabna Sadar recorded higher Fungi population over soils of Sathia Upazila. Actinomycities population ranged from 0.7×10^5 to 9×10^5 cfu g^{-1} soil in Sadarpur and 0.7×10^5 to 5.1×10^5 cfu g^{-1} soil in Bhanga Upazila of Faridpur district. In Pabna, with the range of 1.0×10^5 to 7.5×10^5 cfu g^{-1} soil was found in Pabna Sadar while 2×10^5 to 7.5×10^5 cfu g^{-1} soil in Sathia of Pabna.

Soil physico-chemical properties:

Physico-chemical properties of soils of AEZ-12 was presented in Table 88 and Table 89. A number of 40 soil samples from 0 to 15 cm depth were analysed to determine bio-physicochemical properties (details in methothology section). The field history such as existing crop, cropping pattern and location details were recorded. The soil texture of AEZ 12 was observed loam to clay loam in Faridpur and sandy loam in Pabna district. Slightly alkaline soil reaction was found in soils of AEZ 12. With the pH range from 7.45 to 7.68 was recorded in different unions of Faridpur (mean pH of 7.62) and 7.69 to 8.03 in different unions of Pabna (mean pH of 7.92).

Table 88. Physico-chemical properties of AEZ-12 (Faridpur)

Upazila	Union	pH	% OC	% OM	% N	Textural Class
Sadarpur	Kistopur	7.55-7.85 (7.67)	0.82-1.41 (1.01)	1.41-2.44 (1.75)	0.224-0.364 (0.291)	Clay loam, Loam
	Sadarpur	7.36-7.920 (7.68)	0.59-1.71 (1.04)	1.02-2.96 (1.80)	0.252-0.280 (0.269)	Loam
Vanga	Chanda	7.65-7.70 (7.68)	0,67-1,63 (1.25)	1.16-2.83 (2.16)	0.224-0.364 (0.286)	Loam
	Algi	7.12-7.72 (7.45)	1.26-2.45 (1.71)	2.18-4.24 (2.95)	0.280-0.364 (0.325)	Clay loam
Mean (District)		7.62	1.25	2.17	0.293	
Range (District)		7.12-7.92	0.59-2.45	1.02-4.24	0.224-0.364	

Similar organic matter contents were recorded in Faridpur and Pabna with values of 2.17 % in Faridpur and 2.09% in Pabna. Nitrogen content in soil was recorded higher in Faridpur (0.293%) with the range of 0.269 to 0.325% in as compared to Pabna with 0.118 to 0.148% (mean value of 0.135).

Table 89. Physico-chemical properties of AEZ-12 (Pabna)

Upazila	Union	pH	% OC	% OM	% N	Textural Class
Pabna Sadar	Dogasi	7.75-8.13 (7.96)	1.00-1.52 (1.19)	1.70-2.58 (2.02)	0.112-0.184 (0.140)	Sandy loam
	Varara	7.92-8.11 (8.03)	1.00-1.64 (1.26)	1.70-2.79 (2.14)	0.112-0.154 (0.134)	Sandy loam
Shathia	Dhulauri	6.80-8.23 (7.69)	1.12-1.60 (1.28)	1.66-2.72 (2.18)	0.084-0.154 (0.118)	Sandy loam
	Dhopadaha	7.89-8.06 (7.99)	1.04-1.36 (1.18)	1.77-2.31 (2.01)	0.126-0.210 (0.148)	Sandy loam
Mean (District)		7.92	1.23	2.09	0.135	
Range (District)		6.8-8.23	0.96-1.64	1.66-2.79	0.084-0.21	

Soil Bio-physico-chemical properties of AEZ 14:

Soil Biological properties of AEZ 14:

Results on Soil biological properties of AEZ-14 were presented in Table 90 and Table 91. Microbial population of total bacteria (10.75×10^7 cfu g^{-1}soil), *Rhizobium* (25.47×10^5 cfu g^{-1} soil), *Bradyrhizobium* (26.83×10^5 cfu g^{-1} soil), free-living nitrogen fixing bacteria (4.67×10^6 cfu g^{-1} soil) and fungi (9.89×10^5 cfu g^{-1} soil) were found highest in AEZ-14 among 8 AEZs studied**.** The soils of Khulna district recorded higher total bacteria over Gopalganj district (13.59×10^7 cfu g^{-1} soil and 7.91×10^7 cfu g^{-1} soil soil, respectively). In soils of Khulna, Dumuria upazila showed higher total bacterial population (15.1×10^7 cfu g^{-1} soil) compared to Terokhada upazila (12.08×10^7 cfu g^{-1} soil). At Dumuria upazila, higher population of total bacteria was observed in Roghunathpur union (15.38×10^7 cfu g^{-1} soil) over Rangpur union (14.82×10^7 cfu g^{-1} soil). In Roghunathpur union, village Mesemill recorded the highest number of total bacteria (18.5×10^7 cfu g^{-1} soil) where a range of 11.8×10^7 to 18.5×10^7 cfu g^{-1} soil soil were recorded in Derulia and Mesemill, respectively. In Terokhada upazila, soils of Madhupur union (12.66×10^7 cfu g-1 soil) recorded little bit higher total bacteria over Barasat union (11.5×10^7 cfu g^{-1} soil). At Barasat union, village Barna showed the highest bacterial population (13.2×10^7 cfu g^{-1} soil) and lowest was found in Purba Barasat (9.2×10^7 cfu g^{-1} soil). Parhazigram explored the highest population (13.3×10^7 cfu g^{-1} soil) among Madhupur union soils. A range of 11.4×10^7 to 13.3×10^7 cfu g^{-1} soil soil was found with the mean population of 12.66×10^7 cfu g^{-1} soil in Madhupur union. At Gopalganj district, higher population of bacteria was counted in soils of Moksedpur upazila (11.43×10^7 cfu g^{-1} soil) over Gopalganj Sadar upazila (4.38×10^7 cfu g^{-1} soil). Gobindapur union recorded higher bacterial population (12.6×10^7 cfu g^{-1} soil) compared to Moksedpur union (8.84×10^7 cfu g^{-1} soil). Village Kulakona exhibited the highest bacterial population (15.8×10^7 cfu g^{-1} soil) among five locations of Gabindapur union. Hugladanga-2 showed the highest population of bacteria (17×10^7 cfu g^{-1} soil) among five locations of Moksedpur union. In Gopalganj Sadar upazila, similar population of soil bacteria were found in Korpara and Kazulia union where Korpara (6.1×10^7 cfu g^{-1} soil) showed higher population over Kazulia (2.66×10^7 cfu g^{-1} soil) union. Khulna showed higher *Rhizobium*

population (4.63×10^6 cfu g $^{-1}$ soil) over Gopalganj (4.64×10^5 cfu g $^{-1}$ soil). In Khulna, Dumuria Upazila sh cfu g $^{-1}$ soil owed higher *Rhizobium* population (4.8×10^6 cfu g $^{-1}$ soil) over Terokhada upazila (4.46×10^6 cfu g $^{-1}$ soil). With the range of 1. 4×10^6 to 9.5×10^6 cfu g $^{-1}$ soil in Dumuria and 0.27×10^6 to 14×10^6 cfu g $^{-1}$ soil in Terokhada Upazila was found. In Gopalganj, soils of Moksedpur Upazila showed higher *Rhizobium* population (4.8×10^5 cfu g $^{-1}$ soil) compared to Gopalganj Sadar Upazila (4.47×10^5 cfu g $^{-1}$ soil). With the range of 1.42×10^5 to 9.5×10^5 cfu g $^{-1}$ soil in Moksedpur and 1.0×10^5 to 8.2×10^5 cfu g $^{-1}$ soil in Gopalganj Sadar Upazila was found. *Bradyrhizobium* population was found higher in Khulna district (4.35×10^6 cfu g $^{-1}$ soil) over Gopalganj district (3.86×10^5 cfu g $^{-1}$ soil). Accroding to Upazila, Moksedpur recorded higher population (4.07×10^5 cfu g $^{-1}$ soil) over Gopalgonj Sadar (3.64×10^5 cfu g $^{-1}$ soil). A range of 1.4×10^5 to 8.5×10^5 cfu g $^{-1}$ soil was recorded in Moksedpur while Gopalganj Sadar showed with a range of 1.2×10^5 to 6.1×10^5 cfu g $^{-1}$ soil. Upazila Dumuria showed higher *Bradyrhizobium* population (5.49×10^6 cfu g -1 soil) over Terokhada (3.20×10^6 cfu g -1 soil) in Khulna district. A range of 0.4×10^6 to 30×10^5 cfu g -1 soil was recorded in Dumuria while Terokhada showed with a range of 0.4×10^6 to 55×10^5 cfu g $^{-1}$ soil. Moksedpur Upazila of Gopalganj recorded higher FLNFB population (6.23×10^6 cfu g $^{-1}$ soil) compared to Gopalganj Sadar Upazila (4.35×10^6 cfu g $^{-1}$ soil). A range of 1.2×10^6 to 20×10^6 cfu g $^{-1}$ soil in Moksedpur Upazila where Gopalganj Sadar Upazila recorded 1.0×10^6 to 9.5×10^6 cfu g $^{-1}$ soil in Gopalganj Sadar. In Khulna district, FLNFB population in soils of Terokhada Upazila showed higher (4.35×10^6 cfu g $^{-1}$ soil) over Dumuria Upazila (3.73×10^6 cfu g $^{-1}$ soil). A range of 0.23×10^6 to 22×10^6 cfu g $^{-1}$ soil in Terokhada Upazila where Dumuria recorded 0.78×10^6 to 7.2×10^6 cfu g $^{-1}$ soil. The mean population of PSB in Gopalganj and Khulna was found similar. In Gopalganj, higher population of PSB was recorded in Gopalganj Sadar Upazila (5.31×10^5 cfu g $^{-1}$ soil) compared to Moksedpur Upazila (3.83×10^5 cfu g $^{-1}$ soil) with the range of 3.1×10^5 to 8.3×10^5 cfu g $^{-1}$ soil in Gopalganj Sadar and 1.1×10^5 to 8.4×10^5 cfu g $^{-1}$ soil in Moksedpur. In Khulna district, higher PSB population was observed in Terokhada Upazila (5.31×10^5 cfu g $^{-1}$ soil) over Dumuria Upazila (3.83×10^5 cfu g $^{-1}$ soil). PSB population ranged from 3.1×10^5 to 8.3×10^5 cfu g $^{-1}$ soil in Terokhada and 1.1×10^5 to 8.4×10^5 cfu g $^{-1}$ soil in Dumuria. Higher Fungi population was found in Khulna (13.64×10^5 cfu g $^{-1}$ soil) over Gopalganj (6.13×10^5 cfu g $^{-1}$ soil). In Gopalganj, higher Fungi population was found in Moksedpur (8.74×10^5 cfu g $^{-1}$ soil) compared to Gopalganj Sadar (3.51×10^5 cfu g $^{-1}$ soil). Fungi population ranged from 1.2×10^5 to 16×10^5 cfu g $^{-1}$ soil in Moksedpur and 1.2×10^5 to 6.6×10^5 cfu g $^{-1}$ soil in Gopalganj Sadar. In Khulna, Terokhada showed higher population (23.48×10^5 cfu g $^{-1}$ soil) over Dumuria (3.79×10^5 cfu g $^{-1}$ soil).

In Gopalganj, Actinomycetes population was found with a range of 1.2×10^5 to 8.2×10^5 cfu g $^{-1}$ soil in Gopalganj Sadar and 1.5×10^5 to 8.8×10^5 cfu g $^{-1}$ soil in Moksedpur. In Khulna, with the range of 0.22×10^5 to 6×10^5 cfu g $^{-1}$ soil in Terokhada and 1.5×10^5 to 13×10^5 cfu g $^{-1}$ soil in Dumuria was found.

Table 90. Soil Biological properties of AEZ- 14 (Gopalganj)

Upazila	Union	Total Bac.	Rhizo.	B.Rhizo	FLNFB	PSB	Fungi	Actino
Gopalganj Sadar	Korpara	2.4×10^7-11.5×10^7 (6.1×10^7)	1.0×10^5-8.0×10^5 (4.7×10^5)	1.4×10^5-5.5×10^5 (3.68×10^5)	1.0×10^6-9.5×10^6 (4.44×10^6)	4.3×10^5-8.3×10^5 (5.88×10^5)	1.2×10^5-6.2×10^5 (2.88×10^5)	1.2×10^5-8.2×10^5 (4.28×10^5)
	Kazulia	1.4×10^7-3.3×10^7 (2.66×10^7)	1.4×10^5-8.2×10^5 (4.24×10^5)	1.2×10^5-6.1×10^5 (3.6×10^5)	1.2×10^6-9.4×10^6 (4.26×10^6)	3.1×10^5-6.6×10^5 (4.74×10^5)	2.4×10^5-6.6×10^5 (4.14×10^5)	1.4×10^5-6×10^5 (3.28×10^5)
	Mean (Upazila)	4.38×10^7	4.47×10^5	3.64×10^5	4.35×10^6	5.31×10^5	3.51×10^5	3.78×10^5
Moksedpur	Moksedpur	4.4×10^7-11.8×10^7 (8.84×10^7)	1.4×10^5-9.5×10^5 (4.94×10^5)	2.4×10^5-8.5×10^5 (4.66×10^5)	1.3×10^6-20×10^6 (8.16×10^6)	1.5×10^5-6.4×10^5 (3.48×10^5)	2.5×10^5-14×10^5 (11.46×10^5)	1.5×10^5-13×10^5 (4.38×10^5)
	Gobindapur	12.6×10^7-15.8×10^7 (14.02×10^7)	1.5×10^5-9.2×10^5 (4.66×10^5)	1.4×10^5-8.3×10^5 (3.48×10^5)	1.2×10^6-7.2×10^6 (4.3×10^6)	1.1×10^5-8.4×10^5 (4.18×10^5)	1.2×10^5-16×10^5 (6.02×10^5)	1.7×10^5-8.8×10^5 (4.54×10^5)
Mean (Upazila)		11.43×10^7	4.8×10^5	4.07×10^5	6.23×10^6	3.83×10^5	8.74×10^5	4.46×10^5
Mean (District)		7.91×10^7	4.64×10^5	3.86×10^5	5.29×10^6	4.57×10^5	6.13×10^5	4.12×10^5

N. B: **Total Bac**. =Tatal bancteria; **Rhizo.** =*Rhizobium*; **B. Rhizo**=*Bradyrhizobium*; **FLNFB**=Free living nitrogen fixing bacteria; **PSB**=Phosphate solubilizing bacteria; **Actino**=Actinomycetes;

Table 91. Soil Biological properties of AEZ- 14 (Khulna)

Upazila	Union	Total Bac.	Rhizo.	B.Rhizo	FLNFB	PSB	Fungi	Actino
Terokhada	Barasat	9.2×10^7-13.2×10^7 (11.5×10^7)	0.27×10^6-8.0×10^6 (4.7×10^6)	1.4×10^5-55×10^5 (13.6×10^5)	0.95×10^6-9.4×10^6 (2.73×10^6)	4.3×10^5-8.3×10^5 (5.88×10^5)	1.2×10^5-6.2×10^5 (2.88×10^5)	0.22×10^5-3.3×10^5 (1.24×10^5)
	Modhupur	11.4×10^7-13.3×10^7 (12.66×10^7)	2.4×10^6-14×10^6 (4.21×10^6)	0.4×10^6-12×10^6 (5.04×10^6)	0.23×10^6-22×10^6 (9.97×10^6)	3.1×10^5-6.6×10^5 (4.74×10^5)	0.33×10^6-4.2×10^6 (2.36×10^6)	0.5×10^5-6×10^5 (2.38×10^5)
	Mean (Upazila)	12.08×10^7	4.46×10^6	3.20×10^6	4.35×10^6	5.31×10^5	23.48×10^5	1.81×10^5
Dumuria	Roghunathpur	11.8×10^7-18.5×10^7 (15.38×10^7)	1.4×10^6-9.5×10^6 (4.94×10^6)	0.24×10^6-30×10^6 (7.50×10^6)	0.78×10^6-6.6×10^6 (3.13×10^6)	1.5×10^5-6.4×10^5 (3.48×10^5)	1.4×10^5-8.2×10^5 (4.44×10^5)	1.5×10^5-13×10^5 (4.74×10^5)
	Rangpur	12.6×10^7-19×10^7 (14.82×10^7)	1.5×10^6-9.2×10^6 (4.66×10^6)	1.4×10^6-8.3×10^6 (3.48×10^6)	1.2×10^6-7.2×10^6 (4.3×10^6)	1.1×10^5-8.4×10^5 (4.18×10^5)	1.2×10^5-7.2×10^5 (3.14×10^5)	1.7×10^5-8.8×10^5 (4.54×10^5)
Mean (Upazila)		15.1×10^7	4.8×10^6	5.49×10^6	3.73×10^6	3.83×10^5	3.79×10^5	4.64×10^5
Mean (disttrict.)		13.59×10^7	4.63×10^6	4.35×10^6	4.04×10^6	4.57×10^5	13.64×10^5	3.25×10^5

N.B: **Total Bac**.=Tatal bancteria; **Rhizo.**=*Rhizobium*; **B.Rhizo**=*Bradyrhizobium*; **FLNFB**=Free living nitrogen fixing bacteria; **PSB**=Phosphate solubilizing bacteria; **Actino**=Actinomycetes

Soil physico-chemical properties:

Physico-chemical properties of soils of AEZ-14 was presented in Table 92 amd Table 93. A number of 40 soil samples from 0 to 15 cm depth were analysed to determine bio-physicochemical properties (details in methothology section).

AEZ 14 contains sandy loam to clay loam texture in District of Gopalganj and clay loam to clay in Khulna district. Soil reaction was found slightly alkaline in this AEZ. Slightly higher pH value was found in Gopalganj (7.73) as compared to Khulna (7.57). The pH Ranged from 7.43 to 7.91 in different unions of Gopalgonj and 7.48 to 7.70 in different unions of Khulna. Organic matter was observed higher in Khulna (4.17%) over Gopalganj (3.07%). Nitrogen in soil ranged from 0.258 to 0.359% in different unions of Gopalganj and 0.291 to 0.347% in different unions of Khulna.

Table 92. Physico-chemical properties of AEZ-14 (Gopalganj)

Upazila	Union	pH	% OC	% OM	% N	Textural Class
Sadar	Korpara	7.51-7.85 (7.69)	2.04-2.97 (2.38)	3.53-6.10 (4.62)	0.252-0.336 (0.297)	Sandy loam
	Kazulia	7.64-8.21 (7.86)	0.93-3.53 (2.04)	1.61-3.89 (3.10)	0.308-0.392 (0.359)	Loam
Moksedpur	Moksedpur	7.21-8.55 (7.91)	0.93-1.86 (1.15)	1.61-3.21 (1.99)	0.168-0.308 (0.258)	Loam
	Gobindopur	7.01-7.66 (7.43)	0.74-2.41 (1.48)	1.29- 4.18 (2.57)	0.252 -0.392 (0.308)	Clay loam
Mean (District)		7.73	1.77	3.07	0.305	
Range (District)		7.01-8.55	0.74-3.53	1.29-6.1	0.168-0.392	

Table 93. Physico-chemical properties of AEZ-14 (Khulna)

Upazila	Union	pH	% OC	% OM	% N	Textural Class
Terokhada	Barashat	7.20-7.90 (7.48)	1.49-2.79 (2.12)	2.57-4.82 (3.66)	0.308-0.392 (0.347)	Clay, Clay loam
	Modhupur	7.59-7.87 (7.70)	1.11-3.34 (1.97)	1.93-5.78 (3.40)	0.308-0.364 (0.336)	Clay Loam
Dumuria	Roghunath pur	7.05-7.98 (7.64)	1.86-3.53 (2.53)	3.21-6.10 (4.37	0.280-0.336 (0.325)	Clay loam
	Ragpur	7.01-7.80 (7.46)	2.23-3.90 (3.10)	3.86-6.75 (5.26)	0.252-0.336 (0.291)	Clay loam, Loam
Mean (District)		7.57	2.43	4.17	0.324	
Range (District)		7.01-7.98	1.11-3.9	1.93-6.75	0.252-0.392	

Soil Bio-physico-chemical properties of AEZ 17

Soil Biological properties

Soil biological properties of AEZ 17 were presented in Table 94 and Table 95. Total bacterial population AEZ 17 was found 3.46×10^7 cfu g $^{-1}$ soil. Higher population in Chandpur district (3.46×10^7 cfu g $^{-1}$ soil) over Laxmipur district (2.62×10^7 cfu g $^{-1}$ soil) was recorded. Soils of Faridganj upazila exhibited higher population of total bacteria (4.05×10^7 cfu g $^{-1}$ soil) over Chandpur Sadar upazila (2.87×10^7 cfu g $^{-1}$ soil) of Chandpur. East Gobindapur union showed higher population (4.72×10^7 cfu g $^{-1}$ soil) over West Gobindapur union (3.38×10^7 cfu g $^{-1}$ soil). With the range of 2.7×10^7 to 10.0×10^7 cfu g $^{-1}$ soil population was found in East Gobindapur union while 0.2×10^7 to 5.5×10^7 cfu g $^{-1}$ soil in West Gobindapur union in Faridganj upazila. In Chandpur Sadar upazila, Bagadi union obtained higher bacterial population (3.24×10^7 cfu g $^{-1}$ soil) over Koillanpur union. Bacterial population ranged from 2.1×10^7 to 4.3×10^7 cfu g $^{-1}$ soil in Bagadi union and 1.4×10^7 to 3.25×10^7 cfu g $^{-1}$ soil. Mean population of *Rhizobium* was recorded 17.22×10^4 cfu g $^{-1}$ soil in AEZ17. Chandpur district showed higher rhizobial population (2.84×10^5 cfu g $^{-1}$ soil) over Laxmipur district (6.02×10^4 cfu g $^{-1}$ soil). With the range of 1.1×10^5 to 4.2×10^5 cfu g $^{-1}$ soil in Faridganj upazila and 0.8×10^5 to 6.1×10^5 cfu g $^{-1}$ soil in Chandpur Sadar. In Laxmipur, Raipur upazila showed higher *Rhizobium* population (6.3×10^4 cfu g $^{-1}$ soil) over Laxmipur Sadar upazila (5.74×10^4 cfu g $^{-1}$ soil). Higher population was observed in Char Rohita union over West Laxmipur union of Laxmipur sadar upazila and Sonatoli union showed higher population over Char Mohona union of Raipur upazila of Laxmipur district. *Bradyrhizobium* population was found higher in Chandpur (2.97×10^5 cfu g $^{-1}$ soil) over Laxmipur (6.41×10^4 cfu g $^{-1}$ soil). In Chandpur, a range of 1×10^5 to 6.3×10^5 cfu g -1 soil in Faridganj Upazila and 1.2×10^5 to 5.1×10^5 cfu g $^{-1}$ soil in Chandpur Sadar Upazila were recorded. In Laxmipur, higher *Bradyrhizobium* population in Laxmipur Sadar Upazila (7.27×10^4 cfu g $^{-1}$ soil) over Raipur Upazila (5.54×10^4 cfu g $^{-1}$ soil) was found. With the range of 2.9×10^4 to 12.3×10^4 cfu g $^{-1}$ soil in Laxmipur Sadar while 1.3×10^4 to 9×10^4 cfu g $^{-1}$ soil in Raipur Upazila was recorded. In this AEZ, FLNFB population of (3.78×10^5 cfu g $^{-1}$ soil) was found with 4.19×10^5 cfu g $^{-1}$ soil in Laxmipur and 3.37×10^5 cfu g $^{-1}$ soil in Chandpur. A range of 1×10^5 to 17×10^5 cfu g $^{-1}$ soil in Faridganj Upazila while Chandpur Sadar with the range of 0.4×10^5 to 5.3×10^5 cfu g $^{-1}$ soil in Chandpur district. Soils of Laxmipur Sadar Upazila exhibited with the range of 1.2×10^5 to 10.3×10^5 cfu g $^{-1}$ soil while with the range of 0.7×10^5 to 7.2×10^5 cfu g $^{-1}$ soil was found in Raipur of Laxmipur District. PSB population was recorded 5.99×10^4 cfu g $^{-1}$ soil in AEZ 17. Higher PSB population was found in the soil of Laxmipur (6.43×10^4 cfu g $^{-1}$ soil) over Chandpur (5.55×10^4 cfu g $^{-1}$ soil). Chandpur Sadar recorded higher PSB population (6.99×10^4 cfu g $^{-1}$ soil) as compared to Faridganj Upazila (4.11×10^4 cfu g $^{-1}$ soil). PSB ranged from 0.2×10^4 to 15×10^4 cfu g $^{-1}$ soil in Chandpur Sadar while 1×10^4 to 8×10^4 cfu g $^{-1}$ soil in Faridganj. Laxmipur Sadar showed PSB population with the range of 2.2×10^4 to 10.1×10^4 cfu g $^{-1}$ soil and Raipur showed with the range of 1.1×10^4 to 14.5×10^4 cfu g $^{-1}$ soil. Higher Fungi population was found in Laxmipur (5.81×10^4 cfu g $^{-1}$ soil) compared to Chandpur (5.15×10^4 cfu g $^{-1}$ soil). In Laxmipur, with the range of 3.4×10^4 to 12.1×10^4 cfu g $^{-1}$ soil in Laxmipur Sadar and 1×10^4 to 5.7×10^4 cfu g $^{-1}$ soil in Raipur. In Chandpur, Fungi population ranged from 1×10^4 to 14×10^4 cfu g $^{-1}$ soil in Faridganj and 0.3×10^4 to 17.5×10^4 cfu g $^{-1}$ soil in Chandpur Sadar. Actinomycetes population recorded higher in Laxmipur (7.13×10^4 cfu g $^{-1}$ soil) over soils of Chandpur (6.06×10^4 cfu g $^{-1}$ soil). In Laxmipur, with the range of 2.9×10^4 to 15.0×10^4 cfu g $^{-1}$ soil was found in Laxmipur Sadar and 0.4×10^4 to 12.5×10^4 cfu g $^{-1}$ soil in Raipur Upazila. In Chandpur, Actinomycetes population ranged from 1×10^4 to 11.8×10^4 cfu g -1 soil in soils of Faridganj and 1×10^4 to 7.2×10^4 cfu g $^{-1}$ soil in Chandpur Sadar.

Table 94. Soil Biological properties of AEZ- 17 (Chandpur)

Upazila	Union	Total Bac.	Rhizo.	B.Rhizo	FLNFB	PSB	Fungi	Actino
Faridganj	East Gobindapur	2.7×10^7-10×10^7 (4.72×10^7)	1.1×10^5-4.1×10^5 (2.62×10^5)	2.3×10^5-4.1×10^5 (3.46×10^5)	2×10^5-17×10^5 (5.5×10^5)	3.5×10^4-8×10^4 (4.92×10^4)	3×10^4-14×10^4 (8.8×10^4)	7.9×10^4-11.8×10^4 (9.82×10^4)
	West Gobindapur	0.2×10^7-5.5×10^7 (3.38×10^7)	1.5×10^5-4.2×10^5 (2.72×10^5)	1×10^5-6.3×10^5 (3.18×10^5)	1×10^5-5×10^5 (2.62×10^5)	1×10^4-6.2×10^4 (3.3×10^4)	1×10^4-3.2×10^4 (2.2×10^4)	1×10^4-10.6×10^4 (5.62×10^4)
	Mean (Upazila)	4.05×10^7	2.67×10^5	3.32×10^5	4.06×10^5	4.11×10^4	5.5×10^4	7.72×10^4
Chandpur Sadar	Bagadi	2.1×10^7-4.3×10^7 (3.24×10^7)	0.8×10^5-6.1×10^5 (3.08×10^5)	2×10^5-4×10^5 (2.96×10^5)	1.4×10^5-5.3×10^5 (3.36×10^5)	0.2×10^4-15×10^4 (9.24×10^4)	2.1×10^4-17.5×10^4 (7.64×10^4)	1×10^4-6.4×10^4 (3.88×10^4)
	Koillanpur	1.4×10^7-3.25×10^7 (2.49×10^7)	1.3×10^5-4.5×10^5 (2.94×10^5)	1.2×10^5-5.1×10^5 (2.26×10^5)	0.4×10^5-3.2×10^5 (2.0×10^5)	2.2×10^4-7.5×10^4 (4.74×10^4)	0.3×10^4-4.3×10^4 (1.94×10^4)	2.2×10^4-7.2×10^4 (4.92×10^4)
Mean (Upazila)		2.87×10^7	3.01×10^5	2.61×10^5	2.68×10^5	6.99×10^4	4.79×10^4	4.4×10^4
Mean (District)		3.46×10^7	2.84×10^5	2.97×10^5	3.37×10^5	5.55×10^4	5.15×10^4	6.06×10^4

N. B: **Total Bac**. =Tatal bancteria; **Rhizo.** =*Rhizobium*; **B. Rhizo**=*Bradyrhizobium*; **FLNFB**=Free living nitrogen fixing bacteria; **PSB**=Phosphate solubilizing bacteria; **Actino**=Actinomycetes;

Table 95. Soil Biological properties of AEZ- 17 (Laxmipur)

Upazila	Union	Total Bac.	Rhizo.	B.Rhizo	FLNFB	PSB	Fungi	Actino
Laxmipur Sadar	Char Rohita	1.1×10^7-3.8×10^7 (2.48×10^7)	3.6×10^4-9.1×10^4 (6.74×10^4)	7.1×10^4-12.3×10^4 (9.08×10^4)	3.2×10^5-10.3×10^5 (6.8×10^5)	2.2×10^4-8.3×10^4 (5.74×10^4)	8.4×10^4-11×10^4 (9.58×10^4)	5.3×10^4-15×10^4 (9.96×10^4)
	West Laxmipur	1.1×10^7-6×10^7 (2.9×10^7)	3.7×10^4-5.6×10^4 (4.74×10^4)	2.9×10^4-6.8×10^4 (5.46×10^4)	$1.2\times1\ 0^5$-6.6×10^5 (3.74×10^5)	3.6×10^4-10.1×10^4 (7.4×10^4)	3.4×10^4-12.1×10^4 (7.14×10^4)	2.9×10^4-12.5×10^4 (7.82×10^4)
	Mean (Upazila)	2.69×10^7	5.74×10^4	7.27×10^4	5.27×10^5	6.57×10^4	8.36×10^4	8.89×10^4
Raipur	Sonapur	0.9×10^7-4.3×10^7 (2.54×10^7)	2.5×10^4-9.3×10^4 (6.46×10^4)	1.3×10^4-9×10^4 (4.92×10^4)	0.7×10^5-3.9×10^5 (1.88×10^5)	6.2×10^4-14.5×10^4 (9.42×10^4)	1×10^4-5.1×10^4 (3.1×10^4)	0.4×10^4-10.1×10^4 (5.04×10^4)
	Charmohona	1.1×10^7-4.3×10^7 (2.56×10^7)	3.9×10^4-8×10^4 (6.14×10^4)	3×10^4-8×10^4 (6.16×10^4)	2.2×10^5-7.2×10^5 (4.32×10^5)	1.1×10^4-5.5×10^4 (3.16×10^4)	1.7×10^4-5.7×10^4 (3.42×10^4)	2.1×10^4-12.5×10^4 (5.7×10^4)
Mean (Upazila)		2.55×10^7	6.3×10^4	5.54×10^4	3.11×10^5	6.29×10^4	3.26×10^4	5.37×10^4
Mean (District)		2.62×10^7	6.02×10^4	6.41×10^4	4.19×10^5	6.43×10^4	5.81×10^4	7.13×10^4

N.B: **Total Bac**.=Tatal bancteria; **Rhizo.**=*Rhizobium*; **B.Rhizo**=*Bradyrhizobium*; **FLNFB**=Free living nitrogen fixing bacteria; **PSB**=Phosphate solubilizing bacteria; **Actino**=Actinomycetes;

Soil physico-chemical properties:

Physico-chemical properties of soils of AEZ-17 was presented in Table 96 and Table 97. A number of 40 soil samples from 0 to 15 cm depth were analysed to determine bio-physicochemical properties (details in methothology section).

Soil Texture of AEZ- 17 was explored as sandy loam in both Chandpur and Laxmipur districts. Soil reaction was found neutral in both the districts. Soil pH ranged from 6.40 -6.94 in Chandpur (mean pH 6.69) and 7.08-7.7.26 in Laxmipur (mean pH 7.17). Organic matter was recorded low in AEZ 17 in both the districts. With the range of 0.95-1.81% in Chandpur (mean of 1.33%) and 1.26-1.64% in different unions of Laxmipur (mean of 1.40). Nitrogen content in soil showed little bit higher in Laxmipur (0.141) compared to Chandpur (0.131). Nitrogen content ranged from 0.092-0.162% in different unions of Faridganj of Chandpur Sadar of Chandpur district while 0.126-0.176% in different unions of Laxmipur district.

Table 96. Physico-chemical properties of AEZ-17 (Chandpur)

Upazila	Union	pH	% OC	% OM	% N	Textural Class
Faridganj	Gobindapur East	6.50-7.28 (6.94)	0.54-1.08 (0.89)	0.93-1.84 (1.46)	0.098-0.182 (0.140)	Sandy loam
	Gobindapur West	6.06-6.69 (6.40)	0.68-1.40 (1.06)	1.16-2.38 (1.81)	0.070-0.224 (0.162)	Sandy loam
Chandpur Sadar	Bagadi	6.33-7.32 (6.75)	0.50-0.64 (0.56)	0.88-1.09 (0.95)	0.070-0.098 (0.092)	Sandy loam
	Kaillanpur	6.29-7.15 (6.68)	0.50-0.96 (0.64)	0.87-1.63 (1.10)	0.098-0.154 (0.132)	Sandy loam
Mean (District)		6.69	0.78	1.33	0.131	
Range (District)		6.06-7.32	0.5-1.4	0.87-2.38	0.07-0.224	Sandy loam

Table 97. Physico-chemical properties of AEZ-17 (Laxmipur)

Upazila	Union	pH	% OC	% OM	% N	Textural Class
Laxmipur Sadar	Char Rohita	6.65-7.54 (7.25)	0.52-0.99 (0.80)	0.90-1.68 (1.37)	0.098-0.168 (0.132)	Sandy loam
	Mothurapur	6.82-7.52 (7.10)	0.52-1.08 (0.77)	0.90-1.84 (1.31)	0.112-0.182 (0.129)	Sandy loam
Raipur	Sonapur	6.19-7.85 (7.08)	0.48-0.99 (0.74)	0.83-1.68 (1.26)	0.076-0.168 (0.126)	Sandy loam
	Char mohona	6.50-7.79 (7.26)	0.52-1.45 (0.97)	0.88-2.47 (1.64)	0.084-0.238 (0.176)	Sandy loam
Mean (District)		7.17	0.82	1.40	0.141	
Range (District)		6.19-7.85	0.48-1.45	0.83-2.47	0.076-0.238	

Soil Bio-physico-chemical properties of AEZ 25

Soil Biological properties:

Soil biological properties of AEZ 25 were presented in Table 98 and Table 99. Total bacterial population was found 5.49×10^7 cfu g $^{-1}$ soil in AEZ 25. Soils of Bogura district showed higher population (8.35×10^7 cfu g $^{-1}$ soil) over Naogaon district (2.63×10^7 cfu g $^{-1}$ soil). Shibganj upazila recorded higher bacterial population (8.48×10^7 cfu g $^{-1}$ soil) over Bogura Sadar upazila (8.21×10^7 cfu g $^{-1}$ soil) but similar. Kichok union of Shibganj showed higher population compared to Bihar union of Shibganj upazila with the range of 7.2×10^7 to 17.8×10^7 cfu g $^{-1}$ soil in Kichok union and 2.5×10^7 to 6.0×10^7 cfu g $^{-1}$ soil in Bihar union. In Bogura Sadar, Erulia union showed higher population compared to Nungola union. Nungola union soil showed bacterial population of 1.5×10^7 to 9.0×10^7 cfu g $^{-1}$ soil while Erulia showed 3.2×10^7 to 27.6×10^7 cfu g $^{-1}$ soil. In Naogaon, Badalgasi upazila recorded higher total bacteria (3.61×10^7 cfu g $^{-1}$ soil) over Naogaon Sadar upazila (1.64×10^7 cfu g $^{-1}$ soil). Mothurapur union exhibited higher population (4×10^7 cfu g $^{-1}$ soil) over Badalgasi union (3.22×10^7 cfu g $^{-1}$ soil) of Naogaon Sadar with the ranges of 1.2×10^7 to 8.0×10^7 cfu g $^{-1}$ soil in Mothurapur and 1.5×10^7 to 6.3×10^7 cfu g $^{-1}$ soil in Badalgasi union. In Naogaon Sadar, Bolihar union exhibited higher total bacterial population (1.7×10^7 cfu g $^{-1}$ soil) in soil over Barshail union (1.58×10^7 cfu g $^{-1}$ soil). *Rhizobium* population was recorded 2.42×10^5 cfu g -1 soil in AEZ 25. Bogura showed higher population (3.97×10^5 cfu g $^{-1}$ soil) compared to Naogaon district (8.77×10^4 cfu g $^{-1}$ soil). In Bogura, Shibganj showed higher population (5.18×10^5 cfu g $^{-1}$ soil) over Bogura Sadar (2.76×10^5 cfu g $^{-1}$ soil). With the range of 1.4×10^5 to 18×10^5 cfu g $^{-1}$ soil in Shibganj upazila and 1×10^5 to 8×10^5 cfu g $^{-1}$ soil in Bogura Sadar. In Naogaon district, Badalgasi Upazila recorded higher *Rhizobium* population (6.68×10^5 cfu g $^{-1}$ soil) compared to Naogaon Sadar (10.85×10^4 cfu g $^{-1}$ soil). *Rhizobium* population ranged from 1.8×10^5 to 12.5×10^5 cfu g -1 soil in Badalgasi and 2×10^4 to 22.5×10^4 cfu g $^{-1}$ soil in Naogaon Sadar. *Bradyrhizobium* population showed higher in Bogura (4.23×10^5 cfu g $^{-1}$ soil) over Naogaon district (0.69×10^5 cfu g $^{-1}$ soil). In Bogura district, higher *Bradyrhizobium* population was observed in Shibganj Upazila (4.85×10^5 cfu g $^{-1}$ soil) over Bagura Sadar Upazila (3.6×10^5 cfu g $^{-1}$ soil). In Naogaon, Badalgasi Upazila recorded higher *Bradyrhizobium* population (5.34×10^5 cfu g $^{-1}$ soil) over Naogaon Sadar Upazila (8.37×10^4 cfu g $^{-1}$ soil). FLNFB population in Bogura was found higher (10.15×10^5 cfu g $^{-1}$ soil) compared to Naogaon (5.69×10^5 cfu g $^{-1}$ soil). Bogura Sadar exhibited higher population (13.34×10^5 cfu g $^{-1}$ soil) compared to Shibganj Upazila (6.55×10^5 cfu g $^{-1}$ soil) in Bogura. With the

range of 2.2×10^5 to 22.5×10^5 cfu g $^{-1}$ soil in Bogura Sadar and 3.4×10^5 to 8.6×10^5 cfu g $^{-1}$ soil in Shibganj Upazila. In Naogaon, Badalgasi recorded higher FLNFB population (6.23×10^5 cfu g $^{-1}$ soil) compared to Naogaon Sadar Upazila (5.14×10^5 cfu g -1 soil). With the range of 1.7×10^5 to 16×10^5 cfu g $^{-1}$ soil in Naogaon Sadar and 1.7×10^5 to 17.5×10^5 cfu g $^{-1}$ soil in Badalgasi Upazila. Bogura recorded higher PSB (15.51×10^5 cfu g $^{-1}$ soil) over Naogaon (1.59×10^5 cfu g $^{-1}$ soil). Bagura Sadar recorded higher PSB (21.95×10^5 cfu g $^{-1}$ soil) over Shibganj Upazila (9.06×10^5 cfu g $^{-1}$ soil). A range of 2.5×10^5 to 34×10^5 cfu g $^{-1}$ soil was found in Bagura Sadar while Shibganj showed the PSB range from 2.4×10^5 to 24×10^5 cfu g $^{-1}$ soil. Naogaon Sadar exhibited higher population (16.9×10^4 cfu g $^{-1}$ soil) compared to Badalgasi Upazila (14.9×10^4 cfu g $^{-1}$ soil). With the range of 2.1×10^4 to 33×10^4 cfu g $^{-1}$ soil in Naogaon Sadar and 5.5×10^4 to (30×10^4 cfu g $^{-1}$ soil in Badalgasi Upazila was found. Higher Fungi population was observed in Bogura (23.75×10^4 cfu g $^{-1}$ soil) over Naogaon (8.76×10^4 cfu g $^{-1}$ soil). In Bogura with the range of 5.4×10^4 to 126×10^4 cfu g $^{-1}$ soil in Shibganj and 2.5×10^4 to 10×10^4 cfu g $^{-1}$ soil in Bogura Sadar. Shibganj recorded higher Fungi population over Bogura Sadar. In Naogaon, Fungi population ranged from 1.5×10^4 to 17×10^4 cfu g $^{-1}$ soil in Badalgasi while 2.5×10^4 to 22×10^4 cfu g $^{-1}$ soil in Naogaon Sadar. Naogaon Sadar recorded higher Fungi population over Badalgasi. Ranges of 2.2×10^4 to 18×10^4 cfu g $^{-1}$ soil Actinomycities population in Shibganj and 1.5×10^4 to 10×10^4 cfu g $^{-1}$ soil in Bogura Sadar of Bogura. In Naogaon, with the range of 1.2×10^4 to 10×10^4 cfu g $^{-1}$ soil was found in Badalgasi while 1×10^4 to 17.5×10^4 cfu g $^{-1}$ soil in Naogaon Sadar.

Table 98. Soil Biological properties of AEZ- 25 (Bagura)

Upazila	Union	Total Bac.	Rhizo.	B. Rhizo	FLNFB	PSB	Fungi	Actino
Shibgonj	Kichak	7.2×10^7-17.8×10^7 (12.78×10^7)	1.4×10^5-18×10^5 (7.80×10^5)	2.5×10^5-8×10^5 (4.7×10^5)	3.4×10^5-8.6×10^5 (6.16×10^5)	2.4×10^5-12.8×10^5 (5.6×10^5)	5.4×10^4-72×10^4 (31.08×10^4)	2.6×10^4-18×10^4 (8.92×10^4)
	Bihar	2.5×10^7-6×10^7 (4.18×10^7)	1.40×10^5-3.8×10^5 (2.56×10^5)	2×10^5-7×10^5 (5×10^5)	$6.4\times108.3\times10^{55}$-($6.95\times10^5$)	6.2×10^5-24×10^5 (12.52×10^5)	12×10^4-126×10^4 (16.3×10^4)	2.2×10^4-8×10^4 (4.84×10^4)
	Mean (Upazila)	8.48×10^7	5.18×10^5	4.85×10^5	6.55×10^5	9.06×10^5	41.08×10^4	6.88×10^4
Bogura Sadar	Erulia	3.2×10^7-27.6×10^7 (10.86×10^7)	1.2×10^5-8×10^5 (3.76×10^5)	1.5×10^5-8×10^5 (4.7×10^5)	8×10^5-19.6×10^5 (12.7×10^5)	14×10^5-34×10^5 (25.8×10^5)	2.5×10^4-7.4×10^4 (5.94×10^4)	1.5×10^4-8×10^4 (4.42×10^4)
	Nungola	1.5×10^7-9×10^7 (5.55×10^7)	1×10^5-3.1×10^5 (1.76×10^5)	1.3×10^5-3.5×10^5 (2.5×10^5)	2.2×10^5-22.5×10^5 (13.99×10^5)	2.5×10^5-34×10^5 (18.1×10^5)	2.9×10^4-10×10^4 (6.9×10^4)	2.5×10^4-10×10^4 (6.04×10^4)
Mean (Upazila)		8.21×10^7	2.76×10^5	3.6×10^5	13.34×10^5	21.95×10^5	6.42×10^4	5.23×10^4
Mean (district)		8.35×10^7	3.97×10^5	4.23×10^5	10.15×10^5	15.51×10^5	23.75×10^4	6.06×10^4

. N. B: **Total Bac**. =Tatal bancteria; **Rhizo.** =*Rhizobium*; **B. Rhizo**=*Bradyrhizobium*; **FLNFB**=Free living nitrogen fixing bacteria; **PSB**=Phosphate solubilizing bacteria; **Actino**=Actinomycetes;

Table 99. Soil Biological properties of AEZ- 25 (Naogaon)

Upazila	Union	Total Bac.	Rhizo.	B.Rhizo	FLNFB	PSB	Fungi	Actino
Badalgasi	Badalgasi	1.5×10^7-6.3×10^7 (3.22×10^7)	3.8×10^5-12.5×10^5 (8.76×10^5)	3.25×10^5-10.1×10^5 (7.23×10^5)	2.5×10^5-17.5×10^5 (8.94×10^5)	7×10^4-30×10^4 (20×10^4)	1.5×10^4-6×10^4 (3.42×10^4)	1.2×10^4-10×10^4 (5.74×10^4)
	Mothurapur	1.2×10^7-8×10^7 (4×10^7)	1.8×10^5-10×10^5 (4.61×10^5)	1.25×10^5-7×10^5 (3.45×10^5)	1.7×10^5-5.5×10^5 (3.52×10^5)	5.5×10^4-17×10^4 (9.9×10^4)	4×10^4-17.5×10^4 (11.1×10^4)	1.3×10^4-7.5×10^4 (3.92×10^4)
	Mean (Upazila)	3.61×10^7	6.68×10^5	5.34×10^5	6.23×10^5	14.9×10^4	7.26×10^4	4.83×10^4
Naogaon Sadar	Barshail	1.3×10^7-2×10^7 (1.58×10^7)	2×10^4-7.5×10^4 (5.1×10^4)	2×10^4-22.5×10^4 (11.2×10^4)	2×10^5-5×10^5 (3.1×10^5)	2.1×10^4-33×10^4 (17×10^4)	12×10^4-22×10^4 (15.2×10^4)	1×10^4-12×10^4 (3.5×10^4)
	Balihar	1.1×10^7-2.5×10^7 (1.7×10^7)	10×10^4-22.5×10^4 (16.6×10^4)	2.5×10^4-12.5×10^4 (5.54×10^4)	1.5×10^5-16×10^5 (7.14×10^5)	11×10^4-22.5×10^4 (16.9×10^4)	2.5×10^4-8×10^4 (5.3×10^4)	2.1×10^4-17.5×10^4 (10.6×10^4)
Mean (Upazila)		1.64×10^7	10.85×10^4	8.37×10^4	5.14×10^5	16.9×10^4	10.25×10^4	7.1×10^4
Mean (District)		2.63×10^7	8.77×10^4	6.86×10^4	5.69×10^5	15.9×10^4	8.76×10^4	5.97×10^4

N. B: **Total Bac**. =Tatal bancteria; **Rhizo.** =*Rhizobium*; **B. Rhizo**=*Bradyrhizobium*; **FLNFB**=Free living nitrogen fixing bacteria; **PSB**=Phosphate solubilizing bacteria; **Actino**=Actinomycetes;

Soil physico-chemical properties:

Physico-chemical properties of soils of AEZ-25 was presented in Table 100 and Table 101. A number of 40 soil samples from 0 to 15 cm depth were analysed to determine bio-physicochemical properties (details in methothology section).

AEZ 25 contains sandy loam to sandy clay loam textured soil. Bogura exhibited sandy clay loam in most of the unions while Naogaon showed sandy loam in most unions. Soil reaction explored slightly acidic in all over the AEZ. Soils of Bogura showed pH value of 5.87-6.39 (mean 6.11) and 5.90-6.74 in different unions of Naogaon distrct (mean 6.32). Similar organic matter content in soil was observed in Bagura (0.99%) and Naogaon (0.91%) districts. Nitrogen content in soil found higher in Bogura (0.112%) over Naogaon (0.085%).

Table 100. Physico-chemical properties of AEZ-25 (Bagura)

Upazila	Union	pH	% OC	% OM	% N	Textural Class
Shibganj	Kichak	5.72-6.13 (5.90)	0.50-1.33 (0.70)	0.87-2.26 (1.20)	0.062-0.182 (0.112)	Sandy loam, Loam
	Bihar	5.62-6.44 (5.87)	0.50-0.54 (0.51)	0.87-0.93 (0.89)	0.056-0.210 (0.126)	Sandy clay loam
Bogura Sadar	Erulia	6.03-6.77 (6.39)	0.48-0.57 (0.53)	0.83-0.97 (0.92)	0.054-0.154 (0.106)	Sandy clay loam
	Nungola	5.70-6.84 (6.26)	0.50-0.67 (0.55)	0.88-1.14 (0.94)	0.070-0.112 (0.104)	Sandy clay loam, Sandy loam
Mean (District)		6.11	0.57	0.99	0.112	
Range (District)		5.62-6.84	0.48-1.33	0.83-2.26	0.054-0.21	

Table 101. Physico-chemical properties of AEZ-25 (Naogaon)

Upazila	Union	pH	% OC	% OM	% N	Textural Class
Badalgasi	Badalgasi	5.65-6.49 (6.04)	0.47-0.55 (0.50)	0.81-0.95 (0.86)	0.014-0.140 (0.070)	Sandy loam
	Mothurapur	5.04-6.52 (5.90)	0.49-0.61 (0.55)	0.83-1.04 (0.94)	0.056-0.126 (0.077)	Sandy loam
Naogaon Sadar	Barshail	5.88-7.94 (6.74)	0.51-0.57 (0.55)	0.88-0.97 (0.94)	0.062-0.126 (0.086)	Sandy loam
	Balihar	5.86-7.19 (6.592)	0.49-0.57 (0.54)	0.83-0.97 (0.92)	0.084-0.168 (0.106)	Sandy clay loam
Mean (District)		6.32	0.53	0.91	0.085	
Range (District)		5.04-7.94	0.47-0.61	0.81-1.04	0.014-0.168	

Soil Bio-physico-chemical properties of AEZ 26

Soil Biological properties:

Soil Biological properties of AEZ 26 were presented in Table 102 and Table 103. Chapainawabganj showed higher total bacterial population (10.75×10^7 ctug^{-1}) over Rajshahi soils (7.85×10^7 cfu g -1 soil). Gomostapur upazila soil showed higher bacterial population (14.4×10^7 cfu g $^{-1}$ soil) over Nachol upazila (7.1×10^7 ctug^{-1}). Higher population in Rohonpur union (15.3×10^7 cfu g -1 soil) was recorded over Parbatipur union (13.5×10^7 ctug^{-1}). With the range of 8.1×10^7 to 26.0×10^7 cfu g $^{-1}$ soil soil was found in Rohonpur and 10.0×10^7 to 18.0×10^7 cfu g $^{-1}$ soil in Parbatipur union at Gomostapur upazila. Koshba union recorded higher total bacterial population (8.16×10^7 cfu g $^{-1}$ soil) over Nezampur union (6.04×10^7 cfu g $^{-1}$ soil) of Nachol upazila of Chapainawabganj. Ranges of 3.0×10^7 to 10.4×10^7 cfu g $^{-1}$ soil in Nezampur and 3.6×10^7 to 14.0×10^7 cfu g $^{-1}$ soil in Koshba were observed in soils of Nachol upazila. Rajshahi recorded higher *Rhizobium* population (3.22×10^5 cfu g $^{-1}$ soil) compared to Chapainawabganj (11.02×10^4 cfu g -1 soil) with the mean population of 2.16×10^5 cfu g -1 soil. Gomostapur showed higher *Rhizobium* population (13.72×10^4 cfu g $^{-1}$ soil) over Nachol (8.32×10^4 cfu g -1 soil). *Rhizobium* population ranged from 3.3×10^4 to 14×10^4 cfu g $^{-1}$ soil in Nachol upazila and 8×10^4 to 18×10^4 cfu g -1 soil in Gomostapur. In Rajshahi, Paba Upazila recorded higher Rhizobium population (4.9×10^5 cfu g $^{-1}$ soil) over Godagari Upazila (15.4×10^4 cfu g $^{-1}$ soil). *Rhizobium* population ranged from 2.5×10^5 to 12.5×10^5 cfu g $^{-1}$ soil in Paba upazila and 1×10^4 to 25×10^4 cfu g $^{-1}$ soil in Godagari. Rajshahi recorded higher *Bradyrhizobium* population (1.27×10^5 cfu g $^{-1}$ soil) compared to Chapainawabganj (5.83×10^4 cfu g $^{-1}$ soil). In Rajshahi, 1.1×10^5 to 3.1×10^5 cfu g $^{-1}$ soil in Paba Upazila and 1×10^4 to 8×10^4 cfu g $^{-1}$ soil in Godagari Upazila was recorded. In Chapainawabganj, a range of 2.4×10^4 to 9.3×10^4 cfu g $^{-1}$ soil in Gomostapur Upazila and 2×10^4 to 8.8×10^4 cfu g $^{-1}$ soil in Nachol Upazila was recorded. Higher FLNFB population was found in Chapainawabganj (22.2×10^5 cfu g $^{-1}$ soil) compared to Rajshahi (12.25×10^5 cfu g $^{-1}$ soil). Gomostapur exhibited higher FLNFB population (24.3×10^5 cfu g $^{-1}$ soil) compared to Nachol Upazila (20.1×10^5 cfu g $^{-1}$ soil). With the range of 8.8×10^5 to 35.0×10^5 cfu g $^{-1}$ soil in Gomostapur and 8.8×10^5 to 34×10^5 cfu g $^{-1}$ soil in Nachol Upazila of Chapainawabganj was detected. In Rajshahi, soils of Godagari Upazila resulted with the range of 6.6×10^5 to 36×10^5 cfu g $^{-1}$ soil in Godagari and 2.5×10^5 to 15×10^5 cfu g $^{-1}$ soil of FLNFB in Poba Upazila was counted. Higher PSB population in Chapainawabganj (10.7×10^5 cfu

g $^{-1}$ soil) over Rajshahi District (2.29×10^5 cfu g $^{-1}$ soil) was found. Nachol Upazila recorded higher PSB population (19.9×10^4 cfu g $^{-1}$ soil) compared to Gomostapur (19.5×10^5 cfu g $^{-1}$ soil). With the range of 14×10^4 to 36×10^4 cfu g $^{-1}$ soil in Nachol Upazila and 6×10^5 to 36×10^5 cfu g $^{-1}$ soil in Gomostapur Upazila was found. Godagari Upazila recorded higher PSB population (26×10^4 cfu g $^{-1}$ soil) over Paba Upazila (19.9×10^4 cfu g $^{-1}$ soil) in Rajshahi. With the range of 10×10^4 to 44×10^4 cfu g $^{-1}$ soil in Godagari Upazila and 10×10^4 to 35×10^4 cfu g $^{-1}$ soil in Poba Upazila was found. Soils of Rajshahi recorded higher Fungi population (20.65×10^4 cfu g $^{-1}$ soil) over Chapainawabganj (12.75×10^4 cfu g $^{-1}$ soil). In Rajshahi, with the range of 6.12×10^4 to 45×10^4 cfu g $^{-1}$ soil in Godagari and 10×10^4 to 34×10^4 cfu g $^{-1}$ soil in Paba. In Chapainawabganj, Fungi population ranged from 10×10^4 to 25×10^4 cfu g $^{-1}$ soil in Gomostapur while 1.8×10^4 to 15.6×10^4 cfu g $^{-1}$ soil in Nachol Upazila. Gomostapur showed higher Fungi population over Nachol. Chapainawabganj (10.45×10^4 cfu g $^{-1}$ soil) exhibited higher Actinomycities population over Rajshahi (9.18×10^4 cfu g $^{-1}$ soil). In Chapainawabganj, with the range of 3.4×10^4 to 16×10^4 cfu g -1 soil in Nachol and 6×10^4 to 18×10^4 cfu g $^{-1}$ soil in Gomostapur. Gomostapur showed higher population over Nachol. In Rajshahi, with the range of 2.5×10^4 to 24×10^4 cfu g $^{-1}$ soil in Godagari and 2.5×10^4 to 10×10^4 cfu g $^{-1}$ soil in Paba was found. Higher Actinomycetes population was found in Godagari over Paba.

Table 102. Soil Biological properties of AEZ- 26 (Chapainawabganj)

Upazila	Union	Total Bac.	Rhizo.	B. Rhizo	FLNFB	PSB	Fungi	Actino
Nachol	Nezampur	3.2×10^7-10.4×10^7 (6.04×10^7)	3.3×10^4-14×10^4 (7.48×10^4)	2×10^4-8.8×10^4 (6.18×10^4)	8.8×10^5-13×10^5 (10.5×10^5)	13×10^4-28×10^4 (18.8×10^4)	1.8×10^4-10.8×10^4 (5.8×10^4)	3.4×10^4-16×10^4 (8.28×10^4)
	Koshba	3.6×10^7-14×10^7 (8.16×10^7)	3.8×10^4-14×10^4 (9.16×10^4)	3×10^4-8.2×10^4 (5.04×10^4)	19.7×10^5-34×10^5 (29.7×10^5)	14×10^4-36×10^4 (21×10^4)	4.2×10^4-15.6×10^4 (8×10^4)	6×10^4-10×10^4 (8.2×10^4)
	Mean (Upazila)	7.1×10^7	8.32×10^4	5.61×10^4	20.1×10^5	19.9×10^4	6.9×10^4	8.2×10^4
Gomostapur	Rohonpur	7.7×10^7-26×10^7 (15.3×10^7)	15×10^4-18×10^4 (16.4×10^4)	2.4×10^4-9.3×10^4 (6.78×10^4)	22×10^5-35×10^5 (29.8×10^5)	14×10^5-36×10^5 (26×10^5)	10.8×10^4-24×10^4 (18.5×10^4)	6×10^4-16×10^4 (12.4×10^4)
	Oparbatipu t	10×10^7-18×10^7 (13.5×10^7)	8×10^4-15×10^4 (11.04×10^4)	3.2×10^4-7.1×10^4 (5.3×10^4)	8.8×10^5-34×10^5 (18.8×10^5)	6×10^5-18×10^5 (13×10^5)	10×10^4-25×10^4 (18.8×10^4)	8×10^4-18×10^4 (13×10^4)
Mean (Upazila)		14.4×10^7	13.72×10^4	6.05×10^4	24.3×10^5	19.5×10^5	18.6×10^4	12.7×10^4
Mean (district)		10.75×10^7	11.02×10^5	5.83×10^5	22.2×10^5	10.7×10^5	12.75×10^4	10.45×10^4

N.B: **Total Bac**.=Tatal bancteria; **Rhizo.**=*Rhizobium*; **B.Rhizo**=*Bradyrhizobium*; **FLNFB**=Free living nitrogen fixing bacteria; **PSB**=Phosphate solubilizing bacteria; **Actino**=Actinomycetes;

Table 103. Soil Biological properties of AEZ- 26 (Rajshahi)

Upazila	Union	Total Bac.	Rhizo.	B. Rhizo	FLNFB	PSB	Fungi	Actino
Godagari	Bashudebpur	6.4×10^7-22.6×10^7 (14.4×10^7)	10×10^4-23×10^4 (19×10^4)	2×10^4-8×10^4 (4.8×10^4)	6.6×10^5-36×10^5 (23.9×10^5)	10×10^4-44×10^4 (30×10^4)	12×10^4-45×10^4 (27×10^4)	8×10^4-24×10^4 (13.2×10^4)
	Matikata	3×10^7-13.8×10^7 (8.1×10^7)	1×10^4-22.5×10^4 (11.7×10^4)	1×10^4-5.2×10^4 (3.1×10^4)	8×10^5-11.5×10^5 (9.7×10^5)	15×10^4-27.5×10^4 (22×10^4)	6.12×10^4-27.5×10^4 (17.5×10^4)	2.5×10^4-20×10^4 (10×10^4)
	Mean (Upazila)	11.2×10^7	15.4×10^4	3.95×10^4	16.8×10^5	26×10^4	22.3×10^4	11.6×10^4
Paba	Horipur	2×10^7-8.2×10^7 (4.5×10^7)	2.5×10^5-12.5×10^5 (6.2×10^5)	1×10^5-3×10^5 (1.82×10^5)	2.5×10^5-15×10^5 (10.8×10^5)	10×10^4-25×10^4 (19.2×10^4)	12.5×10^4-34×10^4 (22×10^4)	2.5×10^4-10×10^4 (7.5×10^4)
	Damkura	1×10^7-8×10^7 (4.50×10^7)	2.5×10^5-5×10^5 (3.6×10^5)	1.5×10^5-3.1×10^5 (2.46×10^5)	2.5×10^5-10×10^5 (4.6×10^5)	10×10^4-25×10^4 (20.6×10^4)	10×10^4-22.5×10^4 (16×10^4)	2.5×10^4-10×10^4 (6×10^4)
Mean (Upazila)		4.50×10^7	4.9×10^5	2.14×10^5	7.7×10^5	19.9×10^4	19×10^4	6.75×10^4
Mean (dist,)		7.85×10^7	3.22×10^5	1.27×10^5	12.25×10^5	22.95×10^4	20.65×10^4	9.18×10^4

N.B: **Total Bac**.=Tatal bancteria; **Rhizo.**=*Rhizobium*; **B.Rhizo**=*Bradyrhizobium*; **FLNFB**=Free living nitrogen fixing bacteria; **PSB**=Phosphate solubilizing bacteria; **Actino**=Actinomycetes;

Soil physico-chemical properties:

Physico-chemical properties of soils of AEZ-26 was presented in Table 104 and Table 105. A number of 40 soil samples from 0 to 15 cm depth were analysed to determine bio-physicochemical properties (details in methothology section).

Soil texture was observed clay loam to sandy clay loam in this AEZ. Clay loam in Nachol and Sandy clay loam in Gomostapur of Chapainawabganj and sandy clay loam in Godagari and Sandy loam in Paba of Rajshahi was found. Slightly alkaline soil reaction was observed both in Chapainawabganj (pH 7.32) and Rajshahi district (pH 7.43). Soil pH ranged from 7.17 to 7.42 in different unions of Chapainawabganj while 6.58 to 7.96 in different unions of Rajshahi. Organic matter ranged from 0.78 to 1.22% in Chapainawabgonj (mean 0.96%) and 0.95 to 1.34% in Rajshahi. Soil nitrogen was found higher in chapainawabgonj (0.123) over Rajshahi (0.097%). With the ranges of 0.102-0.140% in Chapainawabgonj and 0.077-0.118% soil nitrogen was found in Rajshahi district.

Table 104. Physico-chemical properties of AEZ-26 (Chapainawabganj)

Upazila	Union	pH	% OC	% OM	% N	Textural Class
Nachol	Nazampur	6.13-7.64 (7.30)	0.47-0.53 (0.50)	0.81-0.92 (0.87)	0.062-0.140 (0.102)	Clay loam
	Koshba	6.30-7.90 (7.17)	0.43-1.10 (0.60)	0.74-1.87 (1.02)	0.070-0.210 (0.140)	Clay loam
Gomostapur	Rohonpur	6.78-8.10 (7.39)	0.44-0.49 (0.46)	0.76-0.83 (0.78)	0.066-0.154 (0.122)	Sandy clay loam
	Parbatipur	6.88-7.95 (7.42)	0.41-1.30 (0.71)	0.70-2.21 (1.22)	0.070-0.154 (0.126)	Sandy clay loam
Mean (District)		7.32	0.57	0.96	0.123	
Range (District)		6.13-8.1	0.41-1.3	0.7-2.21	0.062-0.21	

Table 105. Physico-chemical properties of AEZ-26 (Rajshahi)

Upazila	Union	pH	% OC	% OM	% N	Textural Class
Godagari	Bashudebpur	6.32-7.01 (6.58)	0.53-1.22 (0.72)	0.90-2.07 (1.23)	0.070-0.154 (0.118)	Sandy clay loam
	Matikata	6.80-7.80 (7.34)	0.61-0.86 (0.71)	1.10-1.87 (1.34)	0.056-0.280 (0.110)	Sandy clay loam
Paba	Horipur	7.72-8.17 (7.96)	0.61-0.90 (0.77)	1.04-1.53 (1.32)	0.062-0.112 (0.085)	Sandy loam
	Damkura	7.20-8.16 (7.85)	0.51-0.57 (0.55)	0.88-1.00 (0.95)	0.058-0.112 (0.077)	Sandy loam
Mean (District)		7.43	0.69	1.21	0.097	
Range (District)		6.32-8.17	0.51-1.22	0.88-2.07	0.056-0.28	

Activity-1. Isolation and characterization of salinity tolerant rhizobia strains from root nodule of soybean grown in saline areas

A number of 15 Bradyrhizobial strains were isolated from root nodules of soybean grown in saline soils of Satkhira and Noakhali (Table 106 and Table 107). The isolates were round shaped colonies with short rod type bacterial cell and all were Gram negative in Gram reaction. The isolated strains were found alkali producer and showed no growth on GPA. The strains were found salinity tolerance from 0.3 to 2.0 percent (Table 107). The highest salinity tolerance strains were STR-3 and STR-4 (2.0 %). The strains could grow in the tepmperature of 15^0C to 42^0C. where STR-4 showed the growth ability in 42^0C. Only one strain (STR-4) showed a trace amount of Indole acetic acid. and STR-6 showed trace phosphate solubilizing ability.

Table 106. Characterization of salinity tolerant rhizobia strains

Sl. No.	Rhizobia isolates	Colony morphology	Cell shape	Gram reaction	BTB test	Growth on GPA
1	STR-1	Round	Short rod	Gram (-ve)	Alkali producing	No growth
2	STR-2	Round	Short rod	Gram (-ve)	Alkali producing	No growth
3	STR-3	Round	Short rod	Gram (-ve)	Alkali producing	No growth
4	STR-4	Round	Short rod	Gram (-ve)	Alkali producing	No growth
5	STR-5	Round	Short rod	Gram (-ve)	Alkali producing	No growth
6	STR-6	Round	Short rod	Gram (-ve)	Alkali producing	No growth
7	STR-7	Round	Short rod	Gram (-ve)	Alkali producing	No growth
8	STR-8	Round	Short rod	Gram (-ve)	Alkali producing	No growth
9	STR-9	Round	Short rod	Gram (-ve)	Alkali producing	No growth
10	STR-10	Round	Short rod	Gram (-ve)	Alkali producing	No growth
11	STR-11	Round	Short rod	Gram (-ve)	Alkali producing	No growth
12	STR-12	Round	Short rod	Gram (-ve)	Alkali producing	No growth
13	STR-13	Round	Short rod	Gram (-ve)	Alkali producing	No growth
14	STR-14	Round	Short rod	Gram (-ve)	Alkali producing	No growth
15	STR-15	Round	Short rod	Gram (-ve)	Alkali producing	No growth

Table 107. Biochecical characterization of salinity tolerant rhizobia strains/isolated from saline areas

Sl. No.	Rhizobia isolates	Salinity tolerance percent	Growth in different Temp. conditions (^{0}C)	IAA production	P solubilization
1	STR-1	0.4	35	-	-
2	STR-2	1.5	35	-	-
3	STR-3	2.0	40	-	-
4	STR-4	2.0	42	trace	-
5	STR-5	0.4	35	-	-
6	STR-6	0.4	35	-	trace
7	STR-7	0.5	35	-	-
8	STR-8	1.0	35	-	-
9	STR-9	0.35	35	-	-
10	STR-10	0.3	35	-	-
11	STR-11	0.3	34	-	-
12	STR-12	0.3	35	-	-
13	STR-13	0.3	35	-	-
14	STR-14	0.35	35	-	-
15	STR-15	0.35	35	-	-

Expt. 1: Evaluation of salinity tolerant rhizobia inoculation on growth, nodulation and dry matter production of soybean in pot condition

Result showed that inoculation had good effect on plant height of soybean. Strain STR-4 showed the highest plant height at both the sampling time at 40 and 70 DAS. All the un inoculated and nitrogen treated treatments showed lower plant height than inoculated treatments. Shoot dry weight of soybean plant was found the highest in the treatment STR-4 in both stages 40 and 70 DAS. STR-1, STR-2, STR-3, resulted higher shoot dry matter over uninoculated control (T_1) and inoculated treatments STR-5, STR-6 and STR-7. Root length showed higher in inoculated plants over uninoculated control. Inoculant STR-4 exhibited the higher number of nodule at both 40 and 70 DAS. Inoculant STR-2 and STR-3 recorded nodule number next to STR-4 at both the sampling times. STR-5, STR-6 and STR-7 recorded higher nodule number over control but lower than inoculant STR-4, STR-3, STR-2 and STR-1. Treatment STR-4 recorded the largest nodule dry weight of soybean at both 40 and 70 DAS. STR-3 showed as the second highest shoot dry weight producer. Strain STR-2 and STR-1 produced higher nodule dry weight over other three strains**.** (Table 108).

Conclusion: From overall growth, nodulation number and nodule dry weight strain STR-4 was found as the best performer. Inoculant STR-3, STR-2 and STR-1 also better in all respect. So, these 4 strains may be further evaluated in field condition in saline areas.

Table 108. Effect of Rhizobial inoculation on shoot and root growth of soybean in pot condition

Treatments	Plant height (cm)		Shoot dry weight (g/plant)		Root length (cm)	
	40 DAS	70 DAS	40 DAS	70 DAS	40 DAS	70 DAS
T1: Control	27.75 d	35.58d	1.35 a	2.83 c	8.03 d	9.08 c
T2: STR-1	34.50 a	45.60 a	2.62a	4.07 a	9.68 ab	11.78a
T3 : STR-2	35.00a	44.05ab	2.74a	4.30 a	8.68 cd	11.75 a
T4: STR-3	34.25a	45.48 a	2.75a	4.16 a	9.25 bc	11.00 ab
T5: STR-4	35.50a	45.83a	2.75a	4.22 a	9.60 b	11.00ab
T6: STR-5	31.73 b	42.60bc	2.62ab	3.73 b	10.35 a	10.75ab
T7: STR-6	29.98 c	40.85c	2.38bc	3.56 b	9.60 b	10.75ab
T8: STR-7	30.58bc	41.80bc	2.20 c	3.55 b	8.85 c	10.00 bc
Lsd	1.7047	2.7898	0.3574	0.3242	0.7135	1.2342
CV(%)	3.58	4.44	10.03	5.80	5.24	7.80

Significant at 5% level of probability.

Table 109. Effect of Rhizobial inoculation on nodule number and nodule dry weight of soybean in pot condition

Treatments	Number of Nodule (No./plant)		Nodule dry weight (mg/plant)	
	40 DAS	70 DAS	40 DAS	70 DAS
T1: Control	0.88 e	1.35 e	2.38 f	3.41f
T2: STR-1	11.63 bc	13.25bc	41.85 bc	71.13 bc
T3 : STR-2	12.27 b	14.30b	39.90 c	67.98 c
T4: STR-3	12.47 b	15.03ab	43.33 b	73.60 b
T5: STR-4	13.60a	17.08a	47.43 a	80.80 a
T6: STR-5	9.08 d	13.25 bc	30.68 d	49.93 d
T7: STR-6	10.90 c	11.50 cd	28.68 de	45.53 de
T8: STR-7	8.45 d	10.25 d	25.78 e	41.93 e
Lsd	0.9934	2.2331	3.2375	5.1851
CV (%)	6.82	12.52	6.77	6.50

Significant at 5% level of probability.

Table 110. Effect of Rhizobial inoculation on yield attribute, yield and nitrogen fixation of soybean in pot condition

Treatments	N fixation (mg/pot)	Grains/plant (No.)	Grain yield (g/pot)	Stover yield (g/pot)
T1: Control	37.7 e	19.2 e	10.7 e	16.53 d
T2: STR-1	66.4 c	32.3 b	16.7 c	25.23 b
T3 : STR-2	70.6 b	33.5 ab	17.2 bc	25.98 d
T4: STR-3	76.8 a	35.2 a	18.1 ab	28.2 a
T5: STR-4	78.3 a	35.6 a	18.6 a	28.55 a
T6: STR-5	59.0 d	29.5 c	15.3 d	23.23 c
T7: STR-6	55.6 e	27.6 c	14.2 d	21.68 c
T8: STR-7	52.2 f	24.4 d	14.5 d	20.68 **c**
CV (%)	2.85	5.08	5.29	4.50

Fig. **64.** Effect of salinity tolerant rhizobia inoculation on growth, nodulation and dry matter production and yield of soybeen in pot condition

Expt. 2: Evaluation of salinity tolerant rhizobia inoculants on plant growth, nodulation and yield of soybean in field environment in saline areas

Data (Table 111- Table 117) showed that inoculant STR-4 resulted highest plant height in both Satkhira and Noakhali. Plant height ranged from 19.67 to 26.33 cm (at 40 DAS) and 31.50 to 47.33 cm (at 70 DAS) at Satkhira and 18.50 to 24.71 cm at 40 DAS and 33.00 to 49.67 cm (at

70 DAS) at Noakhali. Uninoculcated control treatment recorded the lowest plant height in both the locations in both the growth stages. Shoot dry weight recorded the highest with treatment STR-4 in both locations and both sampling times followed by STR-3. Inoculant STR-2 and STR-1 showed higher shoot dry matter over un inoculated and nitrogen treated plots. Shoot dry weight ranged from 1.03 to 2.70 at 40 DAS and 3.23 to 8.70 g/plant at 70 DAS at Satkhira and 1.11 to 2.72 g/plant and 3.33 to 8.00 g/plant at (40 DAS and 70 DAS, respectively) Noakhali. Nodule number was found highest in the treatment T_5 (STR-4). Inoculant STR-3 recorded lower but similar number of nodules with inoculant STR-4 and higher than other inoculants. A very few nodules was found in un inoculated and nitrogen treated plots. Nodule number ranged from 1.17 to 11.83 (at 40 DAS) and 1.23 to 14.17 (at 70 DAS) per plant in Satkhira and 1.23 to 9.03 (at 40 DAS) and 1.30 to 17.33 per plant (at 70 DAS) at Noakhali, respectively. Inoculant STR-4 exhibited as the highest nodule dry matter producer followed by STR-3 in most cases. Inoculant STR-3 recorded the second highest nodule dry matter weight which was higher over other inoculants as well as nitrogen applied treatments. No significant variation was found in nodule dry weight among the nitrogen treated plots and un inoculated control. Nodule dry weight ranged from 3.03 to 41.00 mg/plant at 40 DAS and 3.57 to 86.67 mg/plant in Satkhira. Whereas in Noakhali ranged from 3.50 to 51.00 mg/plant at 40 DAS and 6.57 to 98.13 mg/plant at 70 DAS, respectively. Number of pod per plant was recorded the highest with treatment STR-4 in both Satkhira (29.00/plant) and Noakhali (30.26/plant). STR-3 showed lower number of pod per plant in Noakhali but lower in Satkhira than STR-2. Nitrogen treated plots recorded lower pod numbers per plant as compared to inoculated treatments. Pod per plant ranged from 12.33 to 29.00 in Satkhira and 17.30 to 30.26 per plant in Noakhali, respectively. Grains per pod ranged from 2.90 to 4.43 per plant at Satkhira and 2.67 to 3.43 in Noakhali location. The strain STR-4 exhibited the highest value of grains per pod in both the locations. Hundred seed weight was found significantly higher in inoculated treatments over un inoculated control. With the ranges of 10.30 to 10.93 in Satkhira location and 10.50 to 11.27 g in Noakhali location, respectively. The highest seed yield was recorded in the inoculant treatment of STR-4 in both locations Satkhira (1543 kg/ha) and Noakhali (1702 kg/ha) followed by inoculant STR-3. Inoculant STR-3 showed better better performance over other inoculants and nitrogen treatments. Nitrogen applied with the rate of 45 kg/ha showed significantly seed yield of soybean over un inoculated control but lower than inoculated plots both at Satkhira and Noakhali locations. Seed yield ranged from 848 to 1543 kg/ha in Satkhira and 962 to 1702 kg/ha in Noakhali location, respectively. Stover yield of soybean exhibited highest in inoculant STR-4 followed by inoculant STR-3 in both locations. Inoculant STR-3 showed higher stover yield over other inoculants STR-2, STR-1 and nitrogen treatments $N_{15,}$ N_{30} and N_{45} as well as un inoculated control. Higher stover yield was recorded in higher levels of nitrogen application. With the ranges of 1028 to 1881 kg/ha in Satkhira while 1156 to 1863 kg/ha in Noakhali was recorded. Organic matter in soil increased (2-7%) due to inoculation.

Table 111. Effect of Rhizobial inoculation on plant height of soybean in field environment at Satkhira and Noakhali

Treatments	Plant height (cm)			
	Satkhira		Noakhali	
	40 DAS	70 DAS	40 DAS	70 DAS
T1: Control	19.67 c	31.50 d	18.50 f	33.00 f
T2: STR-1	26.33 a	42.67 b	22.66 c	45.33 bc
T3 : STR-2	24.33 a	42.37 b	23.28 bc	44.00 cd
T4: STR-3	24.33 a	41.67 b	23.81 ab	47.67 ab
T5: STR-4	25.33 a	47.33 a	24.71 a	49.67 a
T6: N15	22.00 b	31.66 d	19.29 ef	34.00 ef
T7: N30	24.33 a	37.33 c	20.23 de	37.00 e
T8: N45	25.00 a	38.63 bc	21.10 d	41.67 d
Lsd	2.2769	4.1275	0.9302	3.2539
CV(%)	5.32	6.02	2.77	4.47

Significant at 5% level of probability.

Table 112. Effect of Rhizobial inoculation on shoot dry weight of soybean in field environment at Satkhira and Noakhali

Treatments	Shoot dry weight (g/plant)			
	Satkhira		Noakhali	
	40 DAS	70 DAS	40 DAS	70 DAS
T1: Control	1.03 c	3.23 e	1.11 e	3.88 f
T2: STR-1	2.11 ab	6.27 c	2.21 b	6.70 c
T3 : STR-2	1.91 b	7.93 b	2.06 bc	7.10 bc
T4: STR-3	2.59 a	8.43 ab	2.65 a	7.70 ab
T5: STR-4	2.70 a	8.70 a	2.72 a	8.00 a
T6: N15	1.78 b	3.97 e	1.57 d	4.54 ef
T7: N30	1.59 bc	4.83 e	1.70 d	5.20 de
T8: N45	1.88 b	5.17 d	1.86 cd	5.80 d
Lsd	0.5963	0.7555	0.3066	0.6887
CV(%)	8.15	7.11	8.82	6.43

Significant at 5% level of probability.

Table 113. Effect of Rhizobial inoculation on nodule number of soybean in field environment at Satkhira and Noakhali

Treatments	Number of Nodule (No./plant)			
	Satkhira		Noakhali	
	40 DAS	70 DAS	40 DAS	70 DAS
T1: Control	**1.17d**	1.233c	1.23b	1.30c
T2: STR-1	10.67b	12.83b	8.62a	15.20b
T3 : STR-2	9.00c	12.33b	9.00a	14.83b
T4: STR-3	11.00ab	12.97b	9.48a	15.27b
T5: STR-4	11.83a	14.17a	9.03a	17.33a
T6: N15	1.23d	1.53c	1.23b	1.33c
T7: N30	1.32d	1.33c	1.43b	1.50c
T8: N45	1.47d	1.27c	1.20b	1.47c
Lsd	1.0693	1.1609	0.6263	1.2088
CV(%)	8.85	9.20	8.32	8.09

Significant at 5% level of probability.

Table 114. Effect of Rhizobial inoculation on nodule dry weight of soybean in field environment at Satkhira and Noakhali

Treatments	Nodule dry weight (mg/plant)			
	Satkhira		Noakhali	
	40 DAS	70 DAS	40 DAS	70 DAS
T1: Control	3.03d	3.57d	3.500c	6.57d
T2: STR-1	34.57b	79.33b	37.00b	89.17b
T3 : STR-2	29.50c	71.67c	49.33a	81.73c
T4: STR-3	36.00b	74.00bc	47.67a	86.73b
T5: STR-4	41.00a	86.67a	51.00a	98.13a
T6: N15	2.67d	4.00d	3.467c	7.10d
T7: N30	2.90d	4.00d	3.600c	7.53d
T8: N45	2.33d	4.00d	4.033c	7.2 d
Lsd	2.0098	5.4170	5.6170	4.9095
CV(%)	9.23	7.56	12.86	5.84

Significant at 5% level of probability.

Table 115. Effect of Rhizobial inoculants on yield attributes of soybean in field environment at Satkhira and Noakhali

Treatments	Satkhira			Noakhali		
	Pod/plant	Grains/pod	100 seed wt.	Pod/plant	Grains/pod	100 seed wt.
T1: Control	12.33 e	2.90 e	10.30d	17.30 e	2.67c	10.50 d
T2: STR-1	23.44 c	3.63 cd	10.73abc	26.88 b	3.03abc	11.10 abc
T3 : STR-2	27.02 b	3.93 bc	10.67a-d	26.98 b	3.27ab	11.07abc
T4: STR-3	22.00 c	4.13 b	10.87ab	30.08 a	3.43a	11.17 ab
T5: STR-4	29.00 a	4.63 a	10.93a	30.26a	3.40a	11.27 a
T6: N15	13.00 de	3.20 de	10.40cd	17.86 e	2.87bc	10.73 bcd
T7: N30	15.53 de	3.33 de	10.47bcd	20.12 d	3.07abc	10.93 a-d
T8: N45	16.80 d	3.63 cd	10.60a-d	22.56 c	3.20ab	10.60 cd
Lsd	2.4296	0.4975	0.4033	2.2751	0.42	0.5057
CV(%)	9.57	7.73	2.17	5.07	7.71	8.21

Significant at 5% level of probability.

Table 116. Effect of Rhizobial inoculants on nodule dry weight of soybean in field environment at Satkhira and Noakhali

Treatments	Grain yield (kg/ha)		Stover yield kg/ha)	
	Satkhira	Noakhali	Satkhira	Noakhali
T1: Control	848e	962 e	1028 e	1156 e
T2: STR-1	1253 bc	1351bc	1441 cd	1482bc
T3 : STR-2	1285 abc	1402b	1541 bc	1536b
T4: STR-3	1342 ab	1612a	1711 ab	1768a
T5: STR-4	1543 a	1702a	1881 a	1863a
T6: N15	954 de	1060de	1075 e	1163e
T7: N30	1050 cde	1171cd	1244 de	1291d
T8: N45	1121 bcd	1288 bc	1382 cd	1402cd
Lsd	269.88	189.60	217.28	117.17
CV(%)	13.12	8.21	8.78	4.59

Significant at 5% level of probability.

Table 117. Effect of Rhizobial inoculants on organic matter status of post harvest Soil of soybean field at Satkhira and Noakhali

Treatments	Organic matter status of Post harvest Soil (%)	
	Satkhira	Noakhali
T1: Control	2.27 c	1.84c
T2: STR-1	2.45 ab	1.98 a
T3 : STR-2	2.46 ab	1.97 a
T4: STR-3	2.49 a	2.02 a
T5: STR-4	2.50 a	2.03 a
T6: N15	2.31 c	1.84 b
T7: N30	2.32 c	1.87 b
T8: N45	2.33 c	1.87 b
CV(%)	2.01	2.42

Significant at 5% level of probability

Fig. 65. Effect of Salinity tolerant biofertilizer on soybean

Fig. 66. Without Biofertilizer (Soybean plot) and with biofertilizer (Soybean plot)

Conclusion: From the above discussion it can be concluded that salinity tolerant inoculant STR-4 may be suitable for production of soybean in saline area of Satkhira and Noakhali.

Survival of Rhizobia strain in peat inoculant at different temperature conditions

The rhizobial peat inoculant strains were evaluated for survival in different temperature conditions, up to 12 months of survival was observed in Refrigerator condition, 11 nonths at air cooler room while nine months in room temperature condition. Inoculant strain STR-4 was found storage duration of 9 months which was quite suitable as biofertilizer.

Table 118. Survival of Rhizobia strain in peat inoculant at different temperature conditions

Temp. conditions	Peat Inoculant Strains	Initial population (cfu g $^{-1}$)	Duration of survival of inoculant strains (cfu g $^{-1}$ peat inoculant)											
			1 M	2 M	3M	4 M	5 M	6 M	7 M	8 M	9 M	10 Mh	11 M	12M
Room temp. 16-35^{0}C	STR-1	$2.5x10^9$	$2.6x10^9$	$2.5x10^9$	$2.2x10^9$	2.1×10^9	2.0×10^9	1.1×10^9	7×10^8	3×10^8	1×10^8	3×10^7	8×10^6	3×10^6
	STR-2	$2.1\times\times10^9$	2.9×10^9	2.1×10^9	1.5×10^9	1.0×10^9	8.5×10^8	7×10^8	6×10^8	3×10^8	2×10^8	5×10^7	9×10^6	1×10^7
	STR-3	2.4×10^9	2.4×10^9	2.3×10^9	2.2×10^9	2.0×10^9	1.8×10^9	8×10^8	7×10^8	6×10^8	4×10^8	2×10^8	7×10^7	1×10^7
	STR-4	$2.6\times\times10^9$	2.5×10^9	2.3×10^9	2.3×10^9	2.2×10^9	1.5×10^9	9×10^8	8×10^8	6×10^8	5×10^8	3×10^8	7×10^7	2×10^7
Air cooler (18-22^{0}C)	STR-1	2.0×10^9	2.1×10^9	2.0×10^9	2.0×10^9	2.0×10^9	1.6×10^9	1.2×10^9	9×10^8	8×10^8	7×10^8	5×10^8	4×10^8	1×10^8
	STR-2	2.3×10^9	2.3×10^9	2.0×10^9	2.0×10^9	1.9×10^9	1×10^9	9×10^8	8×10^8	7×10^8	7×10^8	6×10^8	2×10^8	1×10^8
	STR-3	2.5×10^9	2.5×10^9	2.1×10^9	2.0×10^9	2.0×10^9	1×10^9	9×10^8	8×10^8	7.5×10^8	7×10^8	6×10^8	2×10^8	1×10^8
	STR-4	2.2×10^9	2.2×10^9	2.1×10^9	2.1×10^9	2×10^9	1.5×10^9	1×10^9	8.5×10^8	7.5×10^8	7×10^8	6.5×10^8	4×10^8	2×10^8
Refrige rator (4-10^{0}C)	STR-1	2.5×10^9	2.2×10^9	2.1×10^9	2.0×10^9	9×10^8	8×10^9	1×10^9	9×10^8	8×10^8	7×10^8	7×10^8	5×10^8	1×10^8
	STR-2	$2.6\times\times10^9$	2.5×10^9	2.4×10^9	2.2×10^9	2.1×10^9	2.0×10^9	1×10^9	8×10^8	6×10^8	5×10^8	4×10^8	3×10^8	1×10^8
	STR-3	2.2×10^9	2.2×10^9	2.2×10^9	2.1×10^9	2.0×10^9	1.5×10^9	1×10^9	9×10^8	8×10^8	7×10^8	6×10^8	5×10^8	2×10^8
	STR-4	2.6×10^9	2.5×10^9	2.4×10^9	2.3×10^9	2.2×10^9	2.1×10^9	2.0×10^9	1.5×10^9	9×10^8	8×10^8	6.5×10^8	5×10^8	2×10^8

M= Month

BSRI Component

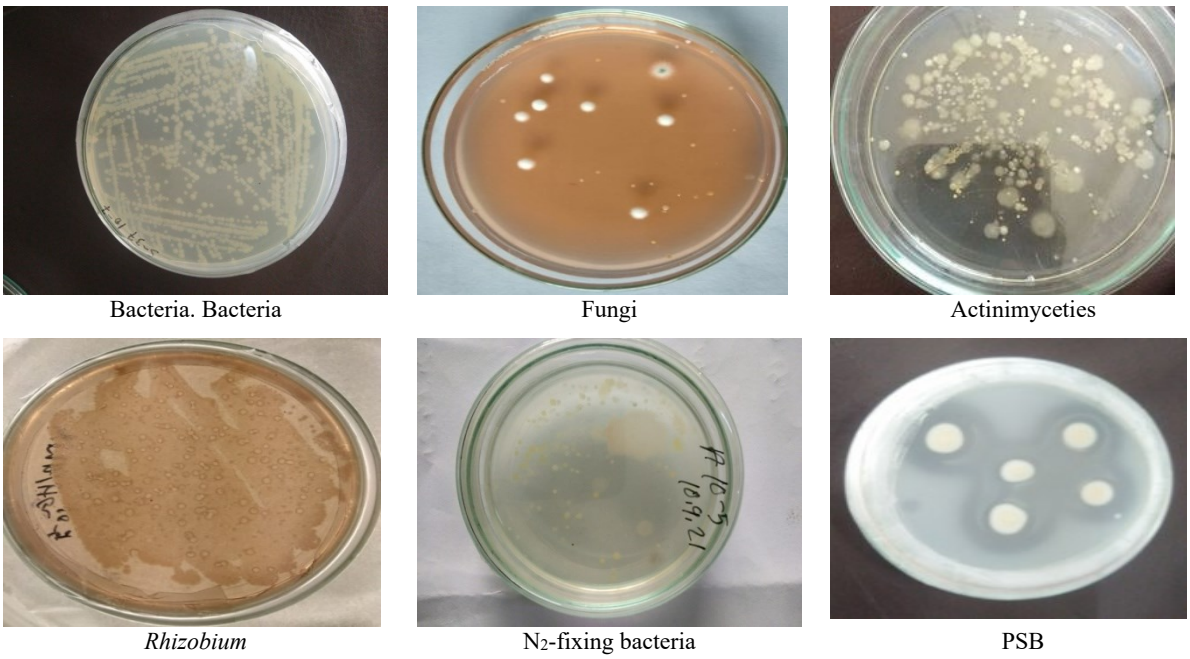
Population of beneficial microorganisms in different AEZs with physiochemical properties of soils

Soil biology of AEZ 1

The biological properties of AEZ 1 soils were described in Table 119. In the AEZ 1, the highest total bacteria population range was found in 2 no. Sundorban union (11×10^6 to 7.25×10^9) at Dinajpur sadar upazila under Dinajpur district while the lowest range was found in 10 no. Jamalpur union (2.26×10^5 to 5×10^8) at Thakurgaon sadar upazila under Thakurgaon district. The highest fungi population range was found in 2 no. Sojalpur union (9.9×10^5 to 7.6×10^7) at Birgonj upazila under Dinajpur district while the lowest range was found in 8 no. Rahimapur union (2.1×10^5 to 2.7×10^7) at Thakurgaon sadar upazila under Thakurgaon district. The highest actinomycetes population range was found in 5 no. Dohosoho union (2.96×10^7 to 5.9×10^7) at Baliadangi upazila under Thakurgaon district while the lowest range was found in 2 no. Sundorban union (2×10^5 to 1.75×10^7) at Dinajpur sadar upazila under Dinajpur district.

The highest *Rhizobium* and the lowest nitrogen fixing bacteria population range were found in 3 no. Fazilpur union (2.65×10^5 to 5.1×10^7 and 5.8×10^5 to 8.95×10^5) at Dinajpur sadar upazila under Dinajpur district while the lowest *Rhizobium* range was found in 8 no. Rahimapur union (3.15×10^5 to 2.4×10^7) at Thakurgaon sadar upazila under Thakurgaon district and the highest nitrogen fixing bacteria population range was found in 8 no. Borobari union (2.24×10^7 to 4.95×10^7) at Baliadangi upazila under Thakurgaon district.

The highest and lowest phosphate solubilizing bacteria population range were found in 4 no. Paltapur union (3.5×10^5 to 6×10^7) and Sojalpur union (4.5×10^4 to 4×10^5) at Birgonj upazila under Dinajpur district.



Bacteria. Bacteria | Fungi | Actinimyceties

Rhizobium | N_2-fixing bacteria | PSB

Fig. 67. Microorganisms were grown in different media

Table 119. Soil biology of AEZ 1 (Thakurgaon)

District	Upazila	Union	Microbial population (Cfu/g soil)					
			TB	Fungi	Act	Rhizobium	NFB	PSB
Thakurgaon	Baliadangi	5 no. Dohosoho	9.16×10^5-6.83×10^9	6.33×10^5-5.16×10^7	2.96×10^7 -5.9×10^7	2.9×10^7-4.2×10^7	5.1×10^6-4.9×10^7	1×10^6 -2.25×10^6
		8 no. Borobari	9.0×10^6-7.0×10^8	4.5×10^5 -6.23×10^6	2.25×10^7-4.03×10^7	2.25×10^7-3.35×10^7	2.24×1^7-4.95×10^7	2.0×10^6-3.5×10^6
	Thakurgaon sadar	10 no. Jamalpur	2.26×10^5-5.0×10^8	5.3×10^5-3.0×10^7	2.4×10^6-3.06×10^7	2.35×10^7-3.75×10^7	6.6×10^5-5.75×10^6	1×10^6 -2.25×10^6
		8 no. Rahimapur	2.29×10^7-3.36×10^8	2.1×10^5 -2.7×10^7	2.1×10^5-3.4×10^7	3.15×10^5-2.4×10^7	2.4×1^7-4.9×10^7	2.0×10^6-3.5×10^6
Dinajpur	Dinajpur Sadar	2 no. Sundorban	11×10^6-7.25×10^9	8.5×10^5-6.5×10^7	2×10^5-1.75×10^7	4.1×10^6-4.5×10^7	5.85×10^6-5.05×10^7	2×10^5 -3×10^6
		3 no. Fazilpur	14×10^5-13.5×10^8	9.45×10^5 -4.5×10^7	2.75×10^6-3.6×10^7	3.65×10^5-5.1×10^7	5.8×10^5-8.95×10^5	1.5×10^5-2.5×10^7
	Birgonj	Sojalpur	7.16×10^5-4.03×10^9	9.9×10^5-7.6×10^7	2.63×10^5-2.56×10^7	3.5×10^7-4.5×10^7	5×10^5-4.9×10^7	4.5×10^4 -4×10^5
		4 no. Paltapur	4.83×10^6-6.0×10^8	6.63×10^5 -4.0×10^7	2.9×10^6-3.4×10^7	4.8×10^6-5.4×10^7	3.15×10^7-4.85×10^7	3.5×10^5-6×10^7

Here, TB: total bacteria, NFB: Free-living N_2 fixing bacteria, PSB: phosphate solubilizing bacteria and Act: Actinomycetes.

Soil physico-chemical properties:

The soils of AEZ 1 were sandy loam to sandy clay loam in nature (Table 120). The higher value of soil pH was ranged from 5.63 to 6.33 in sandy loam soil at 2 no. Sundorban union in Dinajpur sadar upazila under Dinajpur district and the lower value of soil pH was ranged from 4.65 to 5.02 in sandy loam soil at 10 no. Jamalpur union in Thakurgaon sadar upazila under Thakurgaon district. The soils under study were strongly acidic to slightly acidic.

The higher value of organic matter (%) was ranged from 1.03 to 1.55% in sandy clay loam soil at 4 no. Paltapur union of Birgonj upazila under Dinajpur district and the lower value of soil organic matter was ranged from 0.99 to 1.18 in sandy loam soil at 8 no. Rahimapur union at Thakurgaon sadar upazila under Thakurgaon district. The organic matter statuses of soils were low.

The higher value of nitrogen (%) was ranged from 0.08 to 0.14 % in sandy clay loam soil at at 8 no. Rahimapur union at Thakurgaon sadar upazila under Thakurgaon district and the lower value of nitrogen (%) was ranged from 0.07 to 0.10% in sandy loam soil at in 4 no. Paltapur union at Birgonj upazila under Dinajpur district. The nitrogen content of studied area is very low to low.

Table 120. Soils physio-chemical properties of AEZ 1 (Thakurgaon)

District	Upazila	Union	Physical properties	Chemical properties		
			Texture	Soil pH	OM (%)	TN (%)
Thakurgaon	Baliadangi	5 no. Dohosoho	Sandy loam to sandy clay loam	5.33-5.62	1.35-1.42	0.076-0.14
		8 no. Borobari	Sandy loam to sandy clay loam	5.15-5.35	1.68-1.21	0.08-0.14
	Thakurgaon sadar	10 no. Jamalpur	Sandy loam	4.65-5.02	1.18-1.38	0.12-0.14
		8 no. Rahimapu	Sandy loam	5.15-5.46	0.99-1.18	0.10-0.12
Dinajpur	Dinajpur Sadar	2 no. Sundorban	Sandy loam	5.63-6.33	1.20-1.53	0.04-0.17
		3 no. Fazilpur	Sandy loam	5.60-6.10	1.07-1.55	0.05-0.13
	Birgonj	Sojalpur	Sandy clay loam	4.70-5.05	1.23-1.42	0.08-0.13
		4 no. Paltapur	Sandy clay loam	5.13-5.49	1.03-1.55	0.07-0.10

Here, OM: Organic matter, TN: Total nitrogen

Soil biology of AEZ 8:

The biological properties soils of AEZ 8 were described in Table 121. In the AEZ 8, the higher total bacteria population range was found at Meherpara union (23.57×10^5 to 18.92×10^9) at Madhobdi upazila under Narsindhi district while the lower range was found at Vatshala union (12.5×10^6 to 7×10^8) at Sherpur sadar upazila under Sherpur district. The higher fungi and actinomycetes population range were found at Kamariya union (10×10^7 to 18×10^7 and 9.15×10^5 to 10×10^7) at Sherpur sadar upazila under Sherpur district while the lower range of fungi population was found at 9 no. ward union (4.1×10^7 to 6.26×10^7) and actinimycetes population was found at Nojorpur at Narsindhi sadar upazila under Narsindhi district.

The higher and lower Rhizobium population range were found at Chondrokona and Vatshala union (8.6×10^7 to 8.9×10^8 and 10.9×10^4 to 2.55×10^5) at Nakla and Sherpur sadar upazila, respectively under Sherpur. The higher nitrogen fixing bacteria population range was found at Meherpara union (4.71×10^7 to 7×10^7) at Madhobdi upazila under Narsindhi district and the lower nitrogen fixing bacteria population range was found at Nojorpur union (6.28×10^5 to 8.78×10^6) at Narsindhi sadar upazila under Narsindhi district. The higher and lower phosphate solubilizing

bacteria population range were found in Char ostodhaor union (9.5×10^4 to 8.5×10^7) and Vatshala union (1.2×10^5 to 1.18×10^6) at Nakla and Sherpur sadar upazila under Sherpur district.

Table 121. Soil biology of AEZ 8 (Sherpur)

District	Upazila	Union	Microbial population (Cfu/g soil)					
			TB	Fungi	Act	Rhizobium	NFB	PSB
Sherpur	Sherpur Sadar	Kamariya	8.75×10^7-15×10^9	10×10^7-18×10^7	9.15×10^5-10×10^7	10.95×10^5-9×10^6	5.1×10^5-4.5×10^7	1.1×10^5 - 1.5×10^7
		Vatshala	12.5×10^6-7×10^8	17.25×10^5 - 16.4×10^7	5.95×10^5-8.75×10^7	10.9×10^4-2.55×10^5	2.55×10^7-4.2×10^7	1.2×10^5-1.18×10^6
	Nakla	Chondrokona	12.95×10^5-14.95×10^8	10.35×10^5 -7.95×10^7	2.55×10^7-5.10×10^7	8.6×10^7-8.9×10^8	2.95×10^7-4.04×10^7	9×10^5 - 8.5×10^7
		Char ostodaor	15.05×10^5-4.95×10^9	7.4×10^6 - 8×10^7	5.95×10^5-8.75×10^7	11.35×10^5-11.6×10^7	3.95×10^7-5.1×10^7	9.5×10^4-8.5×10^7
Narsindhi	Narsindhi Sadar	Nojorpur	10×10^5-9×10^9	6.66×10^5 -6.6×10^7	1.8×10^7-2.9×10^7	4.35×10^7-7.21×10^7	6.28×10^5-8.78×10^6	1.4×10^6 - 3.5×10^6
		9 no ward	11.93×10^6-11.3×10^8	4.1×10^7-6.26×10^7	3.26×10^5-2.26×10^7	5×10^6-5.07×10^7	8.57×10^5-5.5×10^7	7×10^5-2.1×10^6
	Madhobdi	Meherpara	23.57×10^5-18.92×10^9	14.14×10^5 -14×10^7	6.42×10^5-6.14×10^7	4.57×10^7-7.28×10^7	4.71×10^7-7×10^7	7×10^5 - 2.8×10^6
		Pachdona	23.35×10^7-25×10^8	12.85×10^7-13.85×10^7	3.07×10^7-6.78×10^7	4.28×10^7-5.57×10^7	3.42×10^7-5.57×10^7	1.4×10^6-2.1×10^6

Here, TB: total bacteria, NFB: Free-living N_2 fixing bacteria, PSB: phosphate solubilizing bacteria and Act: Actinimycetes.

Soil physico-chemical properties:

The soils of studied area of AEZ 8 were silt loam in nature (Table 122). The higher value of soil pH was ranged from 5.55 to 6.15 at Patchdona union at Madhobdi upazila under Narsindhi district and the lower value of soil pH was ranged from 5.12 to 5.80 at Nojorpur union in Narsindhi sadar upazila under Narsindhi district. The soils under studied were strongly acidic to slightly acidic.

The higher value of organic matter (%) was ranged from 1.41 to 1.89% at Meherpara union at Madhobdi upazila under Narsindhi district and the lower value of soil organic matter was ranged from 0.88 to 1.14 at Kamariya union at Sherpur sadar upazila under Sherpur district. The organic matter contents of soils were very low to medium.

The higher value of nitrogen (%) was ranged from 0.10 to 0.15 % at Meherpara union at Madhobdi upazila under Narsindhi district and the lower value of nitrogen (%) was ranged from 0.08 to 0.11 at Char ostodaor union at Nakla upazila under Sherpur district. The nitrogen contents of studied area were low.

Table 122. Soils physio-chemical properties of AEZ8 (Sherpur)

District	Upazila	Union	Physical properties	Chemical properties		
			Texture	Soil pH	OM (%)	TN (%)
Sherpur	Sherpur Sadar	Kamariya	Sitl loam	5.15-6.00	0.88-1.14	0.10-0.12
		Vatshala	Silt loam	5.15-6.02	1.09-1.19	0.10-0.13
	Nakla	Chondrokona	Silt loam	5.18-6.05	1.02-1.41	0.10-0.12
		Char ostodaor	Silt loam	5.19-6.00	0.95-1.41	0.08-0.11
Narsindhi	Narsindhi Sadar	Nojorpur	Silt loam	5.12-5.80	1.48-1.63	0.10-0.15
		9 no ward	Silt loam	5.05-6.05	1.51-1.63	0.10-0.12
	Madhobdi	Meherpara	Silt loam	5.22-5.80	1.48-1.89	0.10-0.15
		Pachdona	Silt loam	5.55-6.15	1.61-1.84	0.10-0.13

Here, OM: Organic matter, TN: Total nitrogen

Soil biology of AEZ 28:

The biological properties soils of AEZ 28 were described in Table 123. In the AEZ 28, the higher total bacteria and fungi population range were found at Jodunathpur union (9.9×10^7 to 14.35×10^8) and 5.2×10^7 to 10.35×10^7) at Dhanbari upazila under Tangail district while the lower range was found at 7 no. ward union (9.96×10^5 to 8.9×10^7) and 2 no. Chapayeir union (5.7×10^5 to 5.5×10^7) at Kaliakoir upazila under Gazipur district.

The higher actinomycetes and Rhizobium population range were found at Oronkhola union ($3.35\times10^{5\text{ to}}$ 5.15×10^7 and 9.95×10^7 to 14.35×10^5) at Madhupur upazila under Tangail district while the lower range were found at 32 no. word union (2.1×10^7 to 2.93×10^7) and 17 no. ward union ($5.5\times10^{5}$to 2.42×10^7) at Gazipur sadar upazila under Gazipur district. The higher nitrogen fixing bacteria population range was found at 2 no. Chapayeir union (5×10^7 to 10.35×10^7) at Kaliakoi upazila under Gazipur district while the lower nitrogen fixing bacteria population range was found oronkhola union (1.7×10^7 to 2.55×10^7) at Madhupur upazila under Tangail district.

The higher phosphate solubilizing bacteria population range was found at 6 no. Sutrapur union (2.8×10^6 to 9.2×10^6) at Kaliakoir upazila under Gazipur district while the lower population range was found at 17 and 32 no. ward union (1.4×10^6 to 5×10^6) at Gazipur sadar upazila under Gazipur district.

Table 123. Soil biology of AEZ28 (Tangail)

District	Upazila	Union	Microbial population (Cfu/g soil)					
			TB	Fungi	Act	Rhizobium	NFB	PSB
Tangail	Dhanbari	Jodunathpur	9.9×10^7-14.35×10^8	5.2×10^7-10.35×10^7	3.3×10^7-5.05×10^7	4.85×10^7-9.95×10^7	2.45×10^7-4.9×10^7	2.5×10^6 -8.5×10^6
	Madhupur	Oronkhola	12.9×10^7-12.35×10^8	5.4×10^7 -9.45×10^7	3.35×10^5-5.15×10^7	9.95×10^7-14.45×10^7	1.7×10^7-2.55×10^7	1.5×10^6 -5.5×10^6
		Kuragacha	12.7×10^7-15.35×10^7	7.85×10^7-9.45×10^7	4.20×10^7-5.10×10^7	9.05×10^7-12.55×10^7	1.2×10^7-4.15×10^7	2.5×10^6-8.5×10^6
Gazipur	Kaliakoir	2 no. Chapayeir	10×10^5-6.26×10^8	5.7×10^5-5.5×10^7	3.4×10^6-3.3×10^7	4.5×10^7-5.78×10^7	5×10^7-10.35×10^7	2.1×10^6 -5.7×10^6
		6 no. Sutrapur	8×10^6-3.4×10^8	5.46×10^6-6.63×10^7	1.56×10^7-3.36×10^7	5.07×10^6-5×10^7	3.14×10^7-6.28×10^7	2.8×10^6-9.2×10^6
	Gazipur Sadar	32 no. ward	4.66×10^7-8.23×10^8	5.6×10^6-6.10×10^7	2.1×10^7-2.93×10^7	4.78×10^6-3.85×10^7	8×10^6-6.21×10^7	1.4×10^6 -5×10^6
		17 no. ward	9.96×10^5-8.9×10^7	6.56×10^6-6.64×10^7	1.56×10^7-3.36×10^7	5.5×10^5-2.42×10^7	8.07×10^5-4.42×10^7	1.4×10^6-5×10^6

Here, TB: total bacteria, NFB: Free-living N_2 fixing bacteria, PSB: phosphate solubilizing bacteria and Act: Actinimycetes.

Soil physico-chemical properties:

The soils of studied area of AEZ 28 were clay to clay loam in nature (Table 124). The higher value of soil pH was ranged from 6.55 to 6.99 at Sutrapur union at Kaliakoir upazila under Gazipur district and the lower value of soil pH was ranged from 5.15 to 6.10 at Jodunathpur union at Dhanbari upazila under Tangail district.

The higher value of organic matter (%) was ranged from 1.40 to 1.80% at 2 no. Chapayeir union at Kaliakoir upazila under Gazipur district and the lower value of soil organic matter was ranged from 1.10 to 1.25 at Oronkhola union at Madhupur upazila under Tangail district. The nitrogen content of studied area is very low to low.

The higher value of nitrogen (%) was ranged from 0.09 to 0.15 % at Jodunathpur union at Dhanbari upazila under Tangail district and the lower value of nitrogen (%) was ranged from 0.09 to 0.12 at Kuragacha union at Madhupur upazila under Tangail district.

Table 124. Soils physio-chemical properties of AEZ28 (Tangail)

District	Upazila	Union	Physical properties	Chemical properties		
			Texture	Soil pH	OM (%)	TN (%)
Tangail	Dhanbari	Jodunathpur	Clay loam	5.15-6.10	1.21-1.45	0.09-0.15
	Madhupur	Oronkhola	Clay loam	5.09-5.89	1.10-1.25	0.10-0.12
		Kuragacha	Clay loam	5.22-5.99	1.13-1.26	0.09-0.12
Gazipur	Kaliakoir	2 no. Chapayeir	Clay	6.00-6.88	1.40-1.80	0.10-0.14
		6 no. Sutrapur	Clay loam	6.55-6.99	1.44-1.59	0.10-0.13
	Gazipur Sadar	32 no. ward	Clay loam	6.12-6.33	1.42-1.59	0.10-0.12
		17 no. ward	Clay loam	6.05-6.75	1.41-1.61	0.10-0.13

Here, OM: Organic matter, TN: Total nitrogen

Soil biology of AEZ 5:

The biological properties soils of AEZ 5 were described in Table 125. In the AEZ 5, the higher total bacteria population range was found at Lalor union (20.57×10^7 to 21.14×10^8) at Singra upazila under Natore district while the lower range was found at Gona union (15.64×10^7 to 12.64×10^8) at Raninagar upazila under Naogaon district.

The higher fungi population range was found at Naogaon pourashava ward no. 7 union (19×10^7 to 20.21×10^7) at Naogaon sadar upazila under Naogaon district while the lower range was found at Gona union (14.35×10^7 to 18.57×10^7) at Raninagar upazila under Naogaon district.

The higher actinomycetes population range was found at 7 no. Laxmipur kholabaria union (3.92×10^7 to 7.07×10^7) at Natore sadar upazila under Natore district while the lower range were found at Naogaon pourashava ward no. 7 union (3.01×10^7 to 4.57×10^7) at Naogaon sadar upazila under Naogaon district. The higher Rhizobium population range was found at Raninagar union (6.07×10^7 to 9.07×10^7) at Raninagar upazila under Naogaon district while the lower range was found at Lalor union (5.9×10^7 to 7.07×10^7) at Singra upazila under Natore district. The higher nitrogen fixing bacteria population range was found at 4 no. Laxmipur kholabaria union (5.58×10^7 to 10.10×10^7) at Natore sadar upazila under Natore district while the lower nitrogen fixing bacteria population range was found at Naogaon pourashava ward no. 7 union (5×10^7 to 8.6×10^7) at Naogaon sadar upazila under Naogaon district.The higher phosphate solubilizing bacteria population range was found at4 no. Laxmipur kholabaria union (3.7×10^6 to 4.5×10^6) at Natore sadar upazila under Natore district while the lower population range was found at Singra union (3.2×10^6 to 3.6×10^6) at Singra upazila under Natore district.

Table 125. Soil biology of AEZ5 (Natore)

District	Upazila	Union	Microbial population (Cfu/g soil)					
			TB	Fungi	Act	Rhizobium	NFB	PSB
Natore	Singra	Singra	20.14×10^7-19.57×10^8	16.50×10^7-19.64×10^7	3.20×10^7-5.92×10^7	6×10^7-7.8×10^7	6.64×10^7-8.78×10^7	3.2×10^6 - 3.6×10^6
		Lalor	20.57×10^7-21.14×10^8	16.50×10^7-18.64×10^7	3.07×10^7-5.90×10^7	5.9×10^7-7.07×10^7	6.64×10^7-8.78×10^7	3.1×10^6-3.9×10^6
	Natore Sadar	7 no. Laxmipur Kholabaria	19.28×10^7-18.71×10^8	16.71×10^7-19.28×10^7	3.92×10^7-7.07×10^7	6.64×10^7-8.78×10^7	5.50×10^7-10×10^7	3.2×10^6 - 4.2×10^6
		4 no. Laxmipur Kholabaria	19.08×10^7-18.71×10^8	15.71×10^7-19.28×10^7	4.92×10^7-7.07×10^7	5.78×10^7-7.64×10^7	5.58×10^7-10.10×10^7	3.7×10^6-4.5×10^6
Naogaon	Raninagar	Gona	15.64×10^7-12.64×10^8	14.35×10^7-18.57×10^7	4.5×10^7-5.5×10^7	7.07×10^7-9.07×10^7	7.85×10^7-9.64×10^7	2.8×10^6 - 4.2×10^6
		Raninagar	18.52×10^7-12.64×10^8	14.35×10^7-18.77×10^7	3.7×10^7-5.51×10^7	6.07×10^7-9.07×10^7	8.35×10^7-9.60×10^7	2.78×10^6-4.2×10^6
	Naogaon Sadar	Naogaon pourashava	17.64×10^7-17.78×10^9	15.21×10^7-20.21×10^7	3×10^7-4.57×10^7	5.99×10^7-7.78×10^7	6.78×10^7-8.78×10^7	3.91×10^6 - 4.3×10^6
		Naogaon pourashava ward no. 9	15.71×10^7-15.63×10^8	19×10^7-20.21×10^7	3.01×10^7-4.57×10^7	6.22×10^7-7.75×10^7	5×10^7-8.60×10^7	4.1×10^6-4.2×10^6

Here, TB: total bacteria, NFB: Free-living N_2 fixing bacteria, PSB: phosphate solubilizing bacteria and Act: Actinomycetes.

Soil physico-chemical properties:

The soils of studied area of AEZ 5 were silt clay in nature (Table 126). The higher value of soil pH was ranged from 5.80 to 6.52 at Naogaon pourashava union at Naogaon sadar upazila under Naogaon district and the lower value of soil pH was ranged from 5.00 to 6.68 at 4 no. Laxmipur kholabaria union at Natore sadar upazila under Natore district.

The higher value of organic matter (%) was ranged from 1.43 to 1.69 % at Singra union at Singra upazila under Natore district and the lower value of soil organic matter was ranged from 1.51 to 1.60 at Naogaon pourashava ward no. 9 union at Naogaon sadar upazila under Naogaon district. The nitrogen content of studied area is very low to low. The higher value of nitrogen (%) was ranged from 0.07 to 0.10 % at 7 no. Laxmipur kholabaria union at Natore sadar upazila under Natore district and the lower value of nitrogen (%) was ranged from 0.06 to 0.08 at Lalor union at Sngra upazila under Natore district.

Table 126. Soils physio-chemical properties of AEZ5 (Natore)

District	Upazila	Union	Physical properties	Chemical properties		
			Texture	Soil pH	OM (%)	TN (%)
Natore	Singra	Singra	Silt clay	5.69-5.90	1.43-1.69	0.07-0.09
		Lalor	Silt clay	5.83-5.85	1.50-1.68	0.06-0.08
	Natore Sadar	7 no. Laxmipur Kholabaria	Silt clay	5.05-5.98	1.13-1.56	0.07-0.10
		4 no. Laxmipur Kholabaria	Silt clay	5.00-5.68	1.20-1.58	0.07-0.09
Naogaon	Raninagar	Gona	Silt clay	5.66-5.99	1.52-1.67	0.06-0.09
		Raninagar	Silt clay	5.56-5.93	1.53-1.67	0.07-0.09
	Naogaon Sadar	Naogaon pourashava	Silt clay	5.80-6.52	1.44-1.64	0.06-0.08
		Naogaon pourashava ward no. 9	Silt clay	5.70-6.43	1.51-1.60	0.07-0.08

Here, OM: Organic matter, TN: Total nitrogen

Soil biology of AEZ 21:

The biological properties soils of AEZ 21 were described in Table 127. In the AEZ 21, the higher and lower total bacteria population range was found at Karimpur union (9.07×10^7 to 18.21×10^9) and 9 no. ward Dhirai (14.35×10^7 to 9.07×10^8) at Dhirai upazila under Snumgonj district. The higher fungi population range was found at Pathariya union (5.21×10^7 to 11.78×10^7) at South sunamgonj upazila under Sunamgonj district while the lower range was found at Kaimpur union (2.64×10^7 to 5.30×10^7) at Dhirai upazila under Sunamgonj district.

The lower actinomycetes, nitrogen fixing bacteria and Rhizobium population range were found at Pathariya union (3.10×10^7 to 5.78×10^7), (1.44×10^7 to 4.30×10^7) and (6.5×10^6 to 5.14×10^7) at South sunamgonj upazila under Sunamgonj district while the higher range of actinomycetes and nitrogen fixing bacteria were found at 9 ward Dhirai union (3×10^7 to 6.78×10^7) and (1.5×10^7 to 6.07×10^7) at Dhirai upazila and Rhizobium at Joykolos union (5.30×10^6 to 6.60×10^7) at South sunamgonj upazillz under Sunamgonj district.

The higher phosphate solubilizing bacteria population range was found at Pathariya union (8.5×10^6 to 2.52×10^7) at South sunamgonj upazila while the lower population range was found at 9 ward Dhirai union (1.35×10^7 to 1.92×10^7) at Dhirai upazila under Sunamgonj district.

Table 127. Soil biology of AEZ21 (Sunamgonj)

District	Upazila	Union	Microbial population (Cfu/g soil)					
			TB	Fungi	Act	Rhizobium	NFB	PSB
Sunamgonj	Dhirai	Korimpur	9.07×10^{7}-18.21×10^{9}	2.64×10^{7}-5.30×10^{7}	2.14×10^{7}-6.62×10^{7}	8.5×10^{6}-6.14×10^{7}	1.35×10^{7}-6.07×10^{7}	8.5×10^{6} -2.28×10^{7}
		9 no. ward Dhirai	14.35×10^{7}-9.07×10^{8}	6.21×10^{7}-10.42×10^{7}	3.0×10^{7}-6.78×10^{7}	1.28×10^{7}-5.42×10^{7}	1.5×10^{7}-6.07×10^{7}	1.35×10^{7}-1.92×10^{7}
	South Sunamgonj	Joykolos	9.07×10^{7}-13.70×10^{8}	2.44×10^{7}-5.35×10^{7}	1.14×10^{7}-6.52×10^{7}	5.30×10^{6}-6.60×10^{7}	2.35×10^{7}-5.07×10^{7}	6.5×10^{6} -2.63×10^{7}
		Pathariya	14.0×10^{7}-14.9×10^{8}	5.21×10^{7}-11.78×10^{7}	3.10×10^{7}-5.78×10^{7}	6.5×10^{6}-5.14×10^{7}	1.44×10^{7}-4.30×10^{7}	8.5×10^{6}-2.82×10^{7}

Here, TB: total bacteria, NFB: Free-living N_2 fixing bacteria, PSB: phosphate solubilizing bacteria and Act: Actinomycetes.

Soil physico-chemical properties

The soils of studied area of AEZ 21 were clay loam in nature (Table 128). The higher and lower value of soil pH was ranged from 4.85 to 6.51 and 5.51 to 6.12 at Karimpur and 9 no. ward Dhirai union at Dhirai upazila under Sunamgonj district.

The higher value of organic matter (%) was same, ranged from 1.07 to 1.45 % at 9 no ward Dhirai union at Dhirai upazila and Joykolos union at South sunamgonj upazila under Sunamgonj district and the lower value of soil organic matter was ranged from 1.0 to 1.23 at Pathariya union at South sunamgonj upazila under Sunamgonj district. The nitrogen content of studied area is very low to low.

The higher and lower value of nitrogen (%) was ranged from 0.12 to 0.14 % and 0.09 to 0.10 at 9 no. ward Dhirai and Karimpur union at Dhirai upazila under Sunamgonj district.

Table 128. Soils physio-chemical properties of AEZ21 (Sunamganj)

District	Upazila	Union	Physical properties	Chemical properties		
			Texture	Soil pH	OM (%)	TN (%)
Sunamgonj	Dhirai	Korimpur	Clay loam	4.85-6.51	1.0-1.39	0.09-0.10
		9 no. ward Dhirai	Clay loam	5.51-6.12	1.07-1.45	0.12-0.14
	South Sunamgonj	Joykolos	Clay loam	4.85-6.54	1.07-1.45	0.09-0.12
		Pathariya	Clay loam	5.04-6.23	1.0-1.23	0.11-0.13

Here, OM: Organic matter, TN: Total nitrogen

Soil biology of AEZ 20

The biological properties soils of AEZ 20 were described in Table 129. In the AEZ 20, the higher total bacteria population range was found at Goiyanghat sadar union (9.35×10^7 to 12.35×10^9) at Goiyanghat upazila under Sylhet district while the lower range was found at 9 no, ward Nabigonj union (10.10×10^7 to 9.07×10^8) at Nabigonj sadar upazila under Habigonj district.

The higher fungi population range was found at 8 no ward Nanigonj union (2.65×10^7 to 11.78×10^7) at Nabigonj sadar upazila under Habigonj district while the lower range was found at Mogolgao union (1×10^7 to 3.42×10^7) at Sylhate sadar upazila under Sylhate district. The higher actinomycetes population range was found at Richi union (3.71×10^7 to 6.78×10^7) at Habigonj sadar upazila while the lower range was found at 9 no ward Nabigonj union (2.14×10^7 to 3.99×10^7) at Nabigonj sadar upazila under Habigonj district.

The higher Rhizobium population range was found at Kandigao union (2.86×10^7 to 8.5×10^7) at Sylhate sadar upazila under Sylhate district while the lower range was found at 8 no ward Nabigonj union (2.39×10^7 to 4.35×10^7) at Nabigonj sadar upazila under Habigonj district. The higher nitrogen fixing bacteria population range was found at 8 no ward Nabigonj union (1.55×10^7 to 6.17×10^7) at Nabigonj sadar upazila under Habigonj district while the lower nitrogen fixing bacteria population range was found at Purbo jaflong union (5.5×10^7 to 6.9×10^7) at Goiyanghat upazila under Sylhat district.

The higher phosphate solubilizing bacteria population range was found at Richi union (7.5×10^6 to 3.9×10^7) at Habigonj sadar upazila under Habigonj district while the lower population range was found at Purbo jaflong union (2.1×10^5 to 3.5×10^5) at Goiyanghat upazila under Sylhat district.

Table 129. Soil biology of AEZ20 (Sylhet)

District	Upazila	Union	Microbial population (Cfu/g soil)					
			TB	Fungi	Act	Rhizobium	NFB	PSB
Sylhet	Sylhet Sadar	Kandigao	3.21×10^7-10×10^9	1.57×10^7-5.85×10^7	1.5×10^7-4×10^7	2.86×10^7-8.5×10^7	1.42×10^7-6.07×10^7	1.4×10^6 -4×10^6
		Mogolgao	4.35×10^7-12.57×10^8	1×10^7-3.42×10^7	4.07×10^7-6.35×10^7	2.33×10^7-5.86×10^7	1.14×10^7-4.71×10^7	1.4×10^6-4.2×10^6
	Goiyanghat	PurboJaflong	6.15×10^7-12.10×10^9	2.42×10^7-4.78×10^7	2.45×10^7-4.9×10^7	2.42×10^7-5.42×10^7	5.50×10^5-6.90×10^5	2.1×10^5-3.5×10^5
		Goiyanghat Sadar	9.35×10^7-12.35×10^9	1.88×10^7-3.55×10^7	3.64×10^7-4.6×10^7	3.35×10^7-4.71×10^7	2.33×10^5-7.86×10^5	2.4×10^5-4.2×10^5
Habigonj	Habigonj Sadar	Gopaya	9.07×10^7-16.21×10^8	2.64×10^7-9.08×10^7	3×10^7-6.42×10^7	3.28×10^7-6.5×10^7	1.35×10^7-3.71×10^7	5.5×10^6-2.82×10^7
		Richi	9.07×10^7-15.27×10^8	3.64×10^7-10.42×10^7	3.71×10^7-6.78×10^7	2.28×10^7-6.5×10^7	2.35×10^7-5.07×10^7	7.5×10^6-3.9×10^7
	Nabigonj Sadar	9 no. ward Nabigonj	14.10×10^7-9.07×10^8	2.80×10^7-9.78×10^7	2.14×10^7-3.99×10^7	7.5×10^6-6.4×10^7	2.35×10^7-5.07×10^7	7.5×10^6-$2.82.\times10^7$
		8 no. ward Nabigonj	7.08×10^7-18.27×10^8	2.65×10^7-11.78×10^7	3.40×10^7-6.78×10^7	2.39×10^7-4.35×10^7	1.55×10^7-6.17×10^7	1.8×10^7-1.9×10^7

Here, TB: total bacteria, NFB: Free-living N_2 fixing bacteria, PSB: phosphate solubilizing bacteria and Act: Actinomycetes.

Soil physico-chemical properties:

The soils of studied area of AEZ 20 were silty clay to silty clay loam in nature (Table 130). The higher and lower value of soil pH was ranged from 5.21 to 6.45 and 5.10 to 5.65 at Purbo jaflong and Goiyanghat sadar union at Goiyanghat upazila under Sylhat district.

The lower value of organic matter (%) was same, ranged from 1.0 to 1.33 % at Richi and 9 no ward Nabigonj union at Habigonj sadar and Nabigonj sadar upazila under Habigonj district and the higher value of soil organic matter was ranged from 1.21 to 1.99 at Goiyanghat sadr union at Goiyanghat upazila under Sylhet district. The nitrogen content of studied area is very low to low.

The higher value of nitrogen (%) was ranged from 0.10 to 0.18 % at Gopaya union at Habigonj sadar upazila and lower value was ranged from 0.09 to 0.13 at 9 no. ward Nabigonj union at Nabigonj upazila under Habigonj district.

Table 130. Soils physio-chemical properties of AEZ20 (Sylhet)

District	Upazila	Union	Physical properties	Chemical properties		
			Texture	Soil pH	OM (%)	TN (%)
Sylhet	Sylhet Sadar	Kandigao	Silty clay loam	5.01-5.70	1.11-1.94	0.11-0.13
		Mogolgao	Silty clay loam	5.05-6.51	1.26-1.96	0.08-0.18
	Goiyanghat	PurboJaflong	Silty clay	5.21-6.45	1.26-1.94	0.08-0.18
		Goiyanghat Sadar	Silty clay	5.10-5.65	1.21-1.99	0.11-0.13
Habigonj	Habigonj Sadar	Gopaya	Silty clay	5.32-6.12	1.16-1.86	0.10-0.18
		Richi	Silty clay	5.14-5.89	1.0-1.33	0.12-0.17
	Nabigonj Sadar	9 no. ward Nabigonj	Silty clay	5.14-5.71	1.0-1.33	0.09-0.13
		8 no. ward Nabigonj	Silty clay	5.28-5.78	1.16-1.56	0.10-0.17

Here, OM: Organic matter, TN: Total nitrogen

Soil biology of AEZ 4

The biological properties soils of AEZ 4 were described in Table 131. In the AEZ 4, the higher total bacteria, fungi, actinomycetes, Rhizobium and nitrogen fixing bacteria population range were found at Bera sadar ward no. 10 union (16.78×10^7 to 17.28×10^9, 14.28×10^7 to 18.57×10^7, 5.21×10^7 to 8.07×10^7, 3.42×10^7 to 7.07×10^7 and 7.07×10^5 to 13.21×10^5) at Bera upazila under Pabna district while the lower range of bacteria, actinimycetes and nitrogen fixing bacteria were found at Bhadraghat union (14.71×10^7, 4.92×10^7 and 4.86×10^5) at Kamarkhand upazila under Sirajgonj district and fungi and Rhizobium were found at Bagbati union (13.28×10^7 and 2.42×10^7) at Sirajgonj sadar under Sirajgonj district.

The higher phosphate solubilizing bacteria population range was found at Tarash union (3.1×10^5 to 5.13×10^5) at Tarash upazila while the lower population range was found at Chakla union (2.8×10^5 to 3.4×10^5) at Ullapara upazila under Sirajgonj district.

Table 131. Soil biology of AEZ4 (Sirajgonj)

District	Upazila	Union	Microbial population (Cfu/g soil)					
			TB	Fungi	Act	Rhizobium	NFB	PSB
Sirajgonj	Raigonj	Pangashi	16.78×10^7-18.71×10^8	13.28×10^7-17.14×10^7	4.92×10^7-7.07×10^7	4.37×10^7-6.06×10^7	4.50×10^5-6.90×10^5	4.0×10^5-5.1×10^5
	Tarash	Tarash	15.5×10^7-19.20×10^8	12.14×10^7-18.17×10^7	5.21×10^7-6.21×10^7	4.07×10^7-5.42×10^7	4.53×10^5-6.56×10^5	3.1×10^5-$5.13.5\times10^5$
	Ullahpara	Chakla	19.08×10^7-17.5×10^8	15.57×10^7-17.14×10^7	5.71×10^7-6.01×10^7	3.14×10^7-3.35×10^7	3.56×10^5-4.96×10^5	2.8×10^5-3.4×10^5
		Ullahpara	15.78×10^7	14.28×10^7	6.07×10^7	4.35×10^7	5.33×10^5	4.2×10^5
	Sirajgonj Sadar	Bagbati	18.5×10^7	13.28×10^7	6.21×10^7	2.42×10^7	6.21×10^5	3.7×10^5
	Kamarhkand	Bhadraghat	14.71×10^7	10.71×10^7	4.92×10^7	4.71×10^7	4.86×10^5	4.0×10^5
Pabna	Bera	Bera Sadar ward no. 01	16.78×10^7-17.28×10^9	14.28×10^7-18.57×10^7	5.21×10^7-8.07×10^7	3.42×10^7-7.07×10^7	7.07×10^5-13.21×10^5	2.4×10^5-5.1×10^5
		Bera Sadar ward no. 10	17.5×10^7-20.78×10^8	13.14×10^7-17.14×10^7	4.92×10^7-7.01×10^7	3.35×10^7-4.75×10^7	4.06×10^5-8.86×10^5	2.8×10^5-4.0×10^5

Here, TB: total bacteria, NFB: Free-living N_2 fixing bacteria, PSB: phosphate solubilizing bacteria and Act: Actinomycetes.

Soil physico-chemical properties:

The soils of studied area of AEZ 4 were silt loam in nature (Table 132). The higher and lower value of soil pH was found at 7.51 at Ullapara union Ullapara upazila under Sirajgonj district and the lower value range was found from 5.46 to 6.19 at Bera sadar ward no. 10 union at Bera upazila under Pabna district.

The higher value of organic matter (%) was found at 1.69 % at Bhadraghat union at Kamarkhand upazila under Sirajgonj district and the lower value of soil organic matter was ranged from 1.07 to 1.23 at Bera sadar ward no. 10 union at Bera upazila under Pabna district. The nitrogen content of studied area is very low to low.

The higher value of nitrogen (%) was ranged from 0.09 to 0.13 % at Bera sadar ward no. 10 union at Bera upazila under Pabna district and lower value was found 0.07 at Ullapara union at Ullapara upazila under Sirajgonj district.

Table 132. Soils physio-chemical properties of AEZ4 (Sirajgonj)

District	Upazila	Union	Physical properties	Chemical properties		
			Texture	Soil pH	OM (%)	TN (%)
Sirajgonj	Raigonj	Pangashi	Silt loam	6.20-6.47	1.38-1.49	0.09-0.12
	Tarash	Tarash	Silt loam	6.02-6.10	1.50-1.65	0.07-0.08
	Ullahpara	Chakla	Silt loam	6.94-7.45	1.40-1.49	0.08-0.09
		Ullahpara	Silt loam	7.51	1.65	0.07
	Sirajgonj Sadar	Bagbati	Silt loam	6.21	1.56	0.08
	Kamarhkand	Bhadraghat	Silt loam	6.31	1.69	0.10
Pabna	Bera	Bera Sadar ward no. 01	Silty loam	5.47-6.42	1.18-1.55	0.09-0.12
		Bera Sadar ward no. 10	Silty loam	5.46-6.19	1.07-1.23	0.09-0.13

Here, OM: Organic matter, TN: Total nitrogen

From the above results it reveled that the higher total range of bacteria (23.57×10^5-18.92×10^9) , the actinomycetes (9.15×10^5-10×10^7), Rhizobium (8.6×10^7-8.9×10^8) and the phosphate solubilizing bacteria (9.5×10^4-8.5×10^7) were found in AEZ 8 where the Tomato-Brinjal-T.Aman major cropping pattern followed high land (Annex-1). The soil texture was silt loam containing higher range of organic matter (1.48-1.89%), total nitrogen (0.10-0.15%) and soil pH (5.55-6.15) (table 132). But the higher range of fungus (19×10^7-20.20×10^7) was found in AEZ 5 where the cropping pattern followed Garlic-B.Aman in medium high land. The soil texture was silt clay containing higher range of organic matter (1.43-1.69%), total nitrogen (0.07-0.10%) and soil pH (5.80-6.52). The higher range of Nitrogen fixing bacteria (5×10^7-10.35×10^7) was found in AEZ 28 where the cropping pattern occupied sugarcane in high land. The soil texture was clay containing higher range of organic matter (1.40-1.80%), total nitrogen (0.09-0.15%) and soil pH (6.55-6.99) (table 132).

Activities of Objective-2

Isolation of Nitrogen bacteria fixing and phosphate solubilizing bacteria from sugarcane rhizosphere soils and roots

Four (4) nitrogen fixing and two (2) phosphate solubilizing bacteria were isolated from rhizosphere soils and roots of sugarcane fig. 68. The diazotrophic bacteria count (MPN) was carried out.

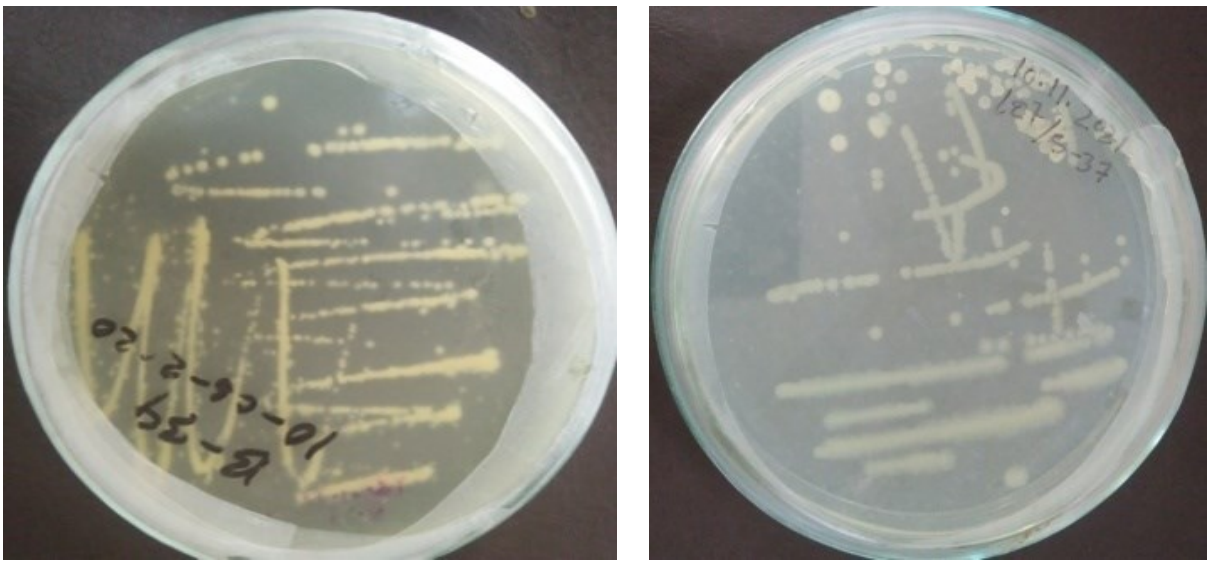


Fig. 68. Isolation of N_2-fixing and phosphate solubilizng bacteria from rhizosphere soil and plant samples

Gram staining and cell morphology

After incubation of the N_2-fixing bacteria found that colonies on LGIM agar plates were large, translucent, pink, white to creamy, and round to irregular (fig. 69).

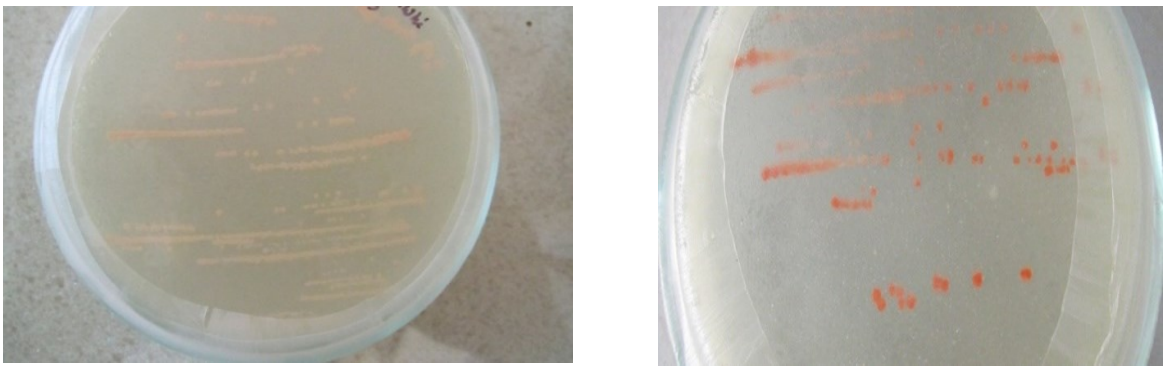


Fig. 69. Growth of individual colonies of isolate on LB agar plate.

In microscopic observation, strains were Gram negative and Gram positive and rod shaped (fig. 70). The diazotrophic bacteria count (MPN) was carried out. The numbers of bacteria in the rhizosphere soil were of 1.5-4.2×10^3 CFU/g of dry weight and then the values found roots sample were of 0.1-2.5×10^3 CFU/g of dry weight.

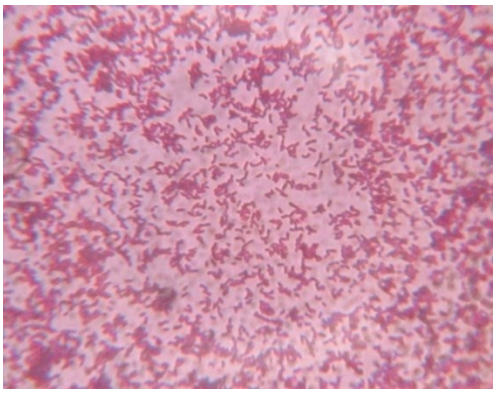


Fig. 70. Isolate BSRI 1 under light microscope after Gram staining.

The diazotroph isolated from sugarcane rhizosphere and roots were tested for Gram reaction. Among the 9 isolated strains 6 of them were found as Gram negative and 3 were Gram positive.

Cellulase activity

Jensen-CMC plate assayed to determine cellulose activity. The plates spoted with diazotrophic broth showed a clear halo zone after stained with 0.1% Congo red indicating cellulose activity. All of the isolates were positive for cellulose activity.

Phosphate solubilizing activity

Pikovskaya plates were assayed to determine phosphate solubilizing activity. The cultures of diazotroph isolates were spot inoculated on the plates and incubated in an incubator at 28°C for 3-5 days. Formation of clear zone around the microbial colonies indicated phosphate solubilization. Two of the diazotroph isolates BSBR1 and BSBR2 were found as positive for phosphate solubilization activity.

Indoleacetic acid (IAA) production

Isolated bacteria were able to produce high amount of IAA (Table 133, Fig. 71). In the presence of tryptophan, the bacterial isolates produced higher IAA which varied from 65 to 162 µg mL^{-1}. The highest IAA was recorded in strain BS37a (162 µg mL^{-1}) and lowest was recored in strain 8 (65 µg mL^{-1}).

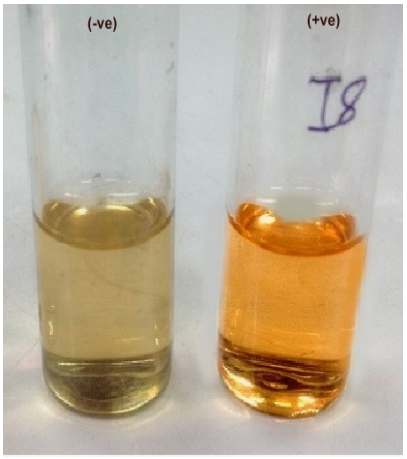


Fig. 71. Indoleacetic acid production (+ve) positive and (-ve) negative

Table 133. IAA production of the isolated diazotroph from sugarcane soil-plant system

Isolates	IAA production (mg mL^{-1})
BSBR1	125
BSBR2	155
BS 37a	160
BS 37b	150
BS 34a	162
BS 34b	155
BS 37c	90
BS 34c	65
BS 34d	-

Identification of isolates using universal method:

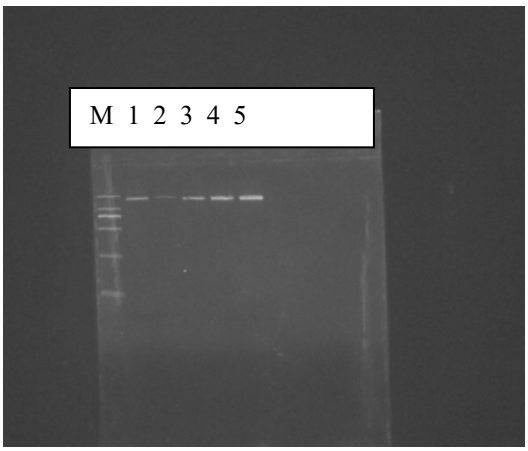


Fig. 72. PCR product of the 16S rRNA bacterial strains (Product size is ~1400bp, Left 100bp DNA Marker (M) (2000, 1000, 750, 500, 250, 100)

The results of the BLAST analysis of amplified 16S rRNA gene product of the isolates were shown in Table 134. The table showed the name of the bacteria, 16S ribosomal RNA sequence of which microorganism shows the highest score in identity with the test isolates' 16S rRNA gene sequences (Fig. 73).

Table 134. Bacterial strains isolated from rhizosphere soils and roots of sugarcane

Strains	Isolated parts	Type strains	Highest mach (%)
BSBR1	Root	*Kocuria rosea*	99
BSBR2	Root	*Kocuria rosea*	99
BS 37a	Rhizosphere soil	*Bacillus pumilus*	99
BS 37b	Rhizosphere soil	*Bacillus pumilus*	99
BS 34a	Rhizosphere soil	*Bacillus pumilus*	99
BS 34b	Rhizosphere soil	*Bacillus pumilus*	99

Based on the 16S rRNA gene sequencing and blast analyses the isolated strains *Bacillus pumilus* BS37a, *Bacillus pumilus* BS37b, *Bacillus pumilus* BS34a and *Bacillus pumilus* BS34b had the highest similarity 99% type strain *Bacillus pumilus* and *Kocuria rosea* BSBR1 and *Kocuria rosea* BSBR2 had the highest similarity 99% type strain *Kocuria rosea* (Table 134). *B. pumilus* is

significant to ecosystem biochemistry because it functions as a nitrogen fixing bacteria capable of metabolically transforming molecular nitrogen (N_2) into ammonia (NH_3) [Hernandez *et al*., 2009.

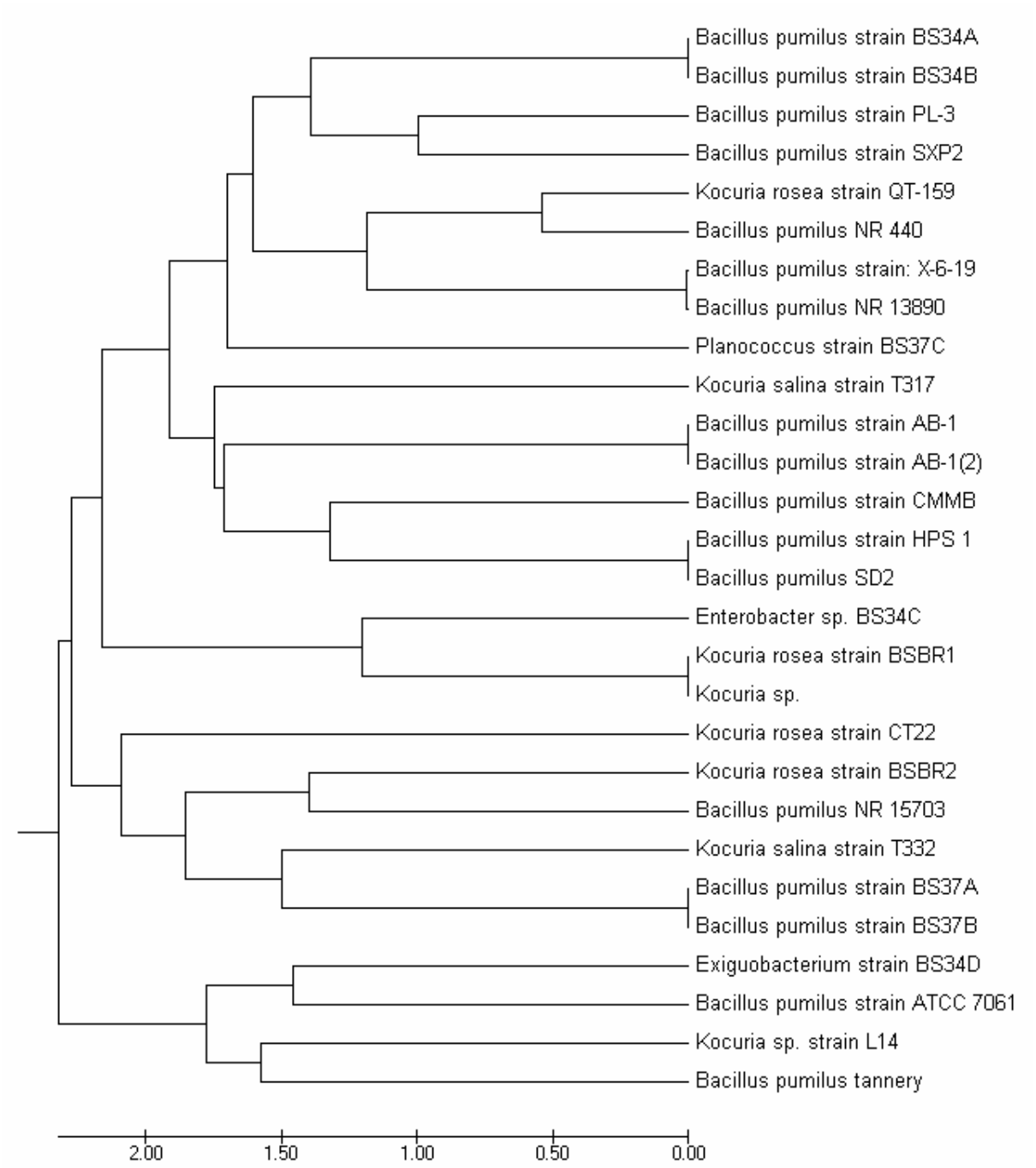


Fig. 73. A phyllogenetic tree based on the 16S rRNA gene sequence.

The phylogenetic position based on the 16S rRNA gene sequences of the isolates was shown in fig. 73. Among the isolated strains, six of them were included into two genera such as *Bacillus* and *Kocuria*. The 16S rRNA gene nucleotide sequences of four isolates (BS37a, BS34b, BS34a and BS34b) were showed high similarity (99%) to the 16S rRNA gene sequences of type strain *Bacillus*

pumilus (Table 134) but other two (BSBR1 and BSBR2) showed high similarity (99%) to the type strain *Kocuria rocea* (Table 134).

Objectives 3

Preparation of N_2-fixing inoculants and its application

The LB liquid media and 3 to 8% molasses (Chetagur) were used for preparation of liquid biofertilizer. The strains (nitrogen fixing) were grown in LB and 3 to 8% molasses broth culture for two days. Then the broth was centrifuged at 6000 rpm for 5 minutes. After that supernatant was discarded and cell pellets were washed in to two times with sterile water and were collected in a 30 ml bottle. This solution was centrifuged by vortex mixture to homogenize the strains in sterile water. Bacterial concentration was adjusted using a spectrophotometer at 540 nm and 0.1 ml of suspension containing 10^8 cells was inoculated into liquid LB media. Initially, two eyed sugarcane setts were soaked in bacterial suspension. 13 L bacterial suspension was prepared with 160 ml bacterial culture for inoculating 1 bigha of land. Inoculants were applied at the base of seedling at 120 and 180 DAP (Fig. 74-75).

Fig. 74. N_2-fixing liquid bofertilizer

Fig. 75. Application of N_2-fixing liquid bofertilizer

Objectives 4:

For the efficacy test, the entitled 'combined effect of bio-fertilizer and inorganic fertilizer on growth and yield of sugarcane' study was conducted.

Yield and yield attributing characters:

The highest germination was found of 50.43% in control treatment. The highest tiller was found of 120.24× 10^3 ha^{-1} in T5 treatment but it was statistically similar with all others treatments except control (Table 135).

Table 135. Yield and yield attributing characters

Treatments	Germination (%)	Tiller (×10^3)	Millable cane (×10^3)	Yield (t ha^{-1})	Brix (%)
T_1	50.43 a	88.11 b	70.06 c	38.61 d	21.23
T_2	39.16 ab	112.01 a	97.47 b	102.96 ab	21.74
T_3	48.06 ab	115.77 a	103.85 b	91.68 c	21.33
T_4	39.16 ab	114.13 a	98.95 b	93.27 bc	21.12
T_5	42.72 ab	120.24 a	114.03 a	108.25 a	21.71
T_6	33.82 b	108.69 a	97.34 b	91.21 c	21.37
T_7	36.93 ab	111.89 a	98.34 b	94.57 bc	21.54
T_8	40.70 ab	111.03 a	98.27 b	91.58 c	21.75
$LSD_{0.05}$	7.295	6.194	4.556	5.0107	ns

T_1 = No fertilizers and strains, T_2 = Recommended Dose of Fertilizers (RFD), T_3 = 100% N of RFD+N-fixing inoculants, T_4 = 50 % N of RFD + N-fixing inoculants, T_5= 75 % N of RFD + N-fixing inoculants, T_6 = 50% of RFD+ Nitrogen and phosphate solubulizing inoculants, T_7= 75 % of P and full amount of NKSZn + phosphate solubulizing inoculants and T_8 = 50 % of P and full amount of NKSZn + phosphate solubulizing inoculants.

The highest millable cane of 114.03 × 10^3 ha^{-1} was found in T_5 treatment and second highest of 103.85 × 10^3 ha^{-1} was found in T_3 treatment, it was similar with all others treatments except control. But the highest sugarcane yield of 108.25 tha^{-1} was found in T_5 treatment, it was statistically similar with T_2 treatment. So, 75% RFD along with nitrogen fixing inoculants gave the better performance.

12. Research highlight (title, background, objectives, methodology, key findings, and key words):

BARI Component

Title: Microbial Characterization of Bangladesh Soil and Development of Climate Smart Biofertilizers for Crop Production and Soil Fertility

The study on biological component of soil is very important for soil fertility. Microbial community and their population play an important role in nutrient availability and release as well as soil productivity. Development of climate resilience technology for crop production and soil fertility restoration is key demand for increment of crop productivity. Understanding the microbial community and composition following long-term fertilization may have significant implications for the development of better fertilizer regime in any agro-ecosystems which is the primary requirement of national food security. Hence present study was conducted with the specific objectives:

1. To develop and validate climate smart biofertilizers for high yielding oil seed and pulses varieties.
2. To find out strain's performance and measure nodulation ability of collected effective strains in pulse and oil seed crop.
3. To measure N fixation capacity, growth and yield performance of pulse and oil seed crop
4. To train up farmers' and extension worker for Oil seeds and Pulses like Groundnut and Lentil biofertilizer use

Several studies were conducted with the aim to determine the soil microbial populations from eight AEZ's of Bangladesh and to characterize the and prepared a climate smart biofertilizer using the potential bacteria for higher yield of lentil and groundnut. Soil sampleswere collected from Kurigram and Rangpur under AEZ 02, Naogaon and Chapainawabganj under AEZ 06, Khulna, Satkhira under AEZ 13, and Patuakhali, and Barishal Bhola under AEZ 18, Chattogram and Cox's Bazar under AEZ 23, Saint Martin's Coral Island under AEZ 24, Bandarban and Khagrachari under AEZ 29, Brahmanbaria and Hobiganj under AEZ 30, respectively. Isolation of organisms, characterization and biofertilizer production, laboratory and pot experiments were done in Soil Science Division, BARI and two field experiments on lentil were completed in Gazipur and Pabna, and another two field experiments on groundnut were accomplished in Gazipur and Cox's Bazar, respectively.

Key findings obtained were

1. The range of total bacteria populations was high in soil of Diginala upazila of Khagrachari district under AEZ-29 (6.0×10^5 to 2.2×10^9 cfu/g soil). The lowest total bacteria population range was (3.0×10^5-5.0×10^6 cfu/g soil) in Cox's Bazar Sadar upazila soils under AEZ-23. The lowest total fungus population range was recorded in the collected soils of AEZ-30. On an average, Actinomycetes populations were low in all the tested soils of different AEZs. The populations of free-living N_2 fixing bacteria were higher than the *Rhizobium* and *Bradyrhizobium* populations.
2. The populations of phosphate solubilizing bacteria were higher than free-living N_2 fixing bacteria. The soils of AEZ 18 (mostly Bhola) appeared to be alkaline while the soils of Rangpur under AEZ 3 found to be acidic.
3. Application of biofertilizer resulted in higher crop performance in groundnut and lentil over uninnoculated control in all locations. In case of groundnut, the highest nut yield 27.60 g/plant and 27.31 g/plant were recorded by using *Rhizobium* sp. FAGR241 and *Rhizobium* sp. FAGR102 during 2020-2021 and 2021-2022, respectively under pot study. However, in case of field trial, at Cox's Bazar the higher groundnut yield (2.28 t ha^{-1}) was obtained with *Rhizobium* sp. BARIRAh808 while in Gazipur *Rhizobium* sp. FAGR318 *Rhizobium* sp. FAGR318 gave the higher nut yield (2.10 t/ha) during 2021-2022. In the year 2020-2021, the highest nut yield 1.98 t/ha was obtained with *Rhizobium* sp. FAGR318 at Gazipur location.
4. In case of lentil, the highest seed yield 1.76 g/plant and 0.67 g/plant were recorded by using *Rhizobium* sp. FALR114 and during 2021-2022 and 2020-2021, respectively under pot study. In field experiment, the highest seed yield (1.33 t/ha) in Gazipur was obtained with T_5 (*Rhizobium* sp. FALR328) while at Pabna the highest seed yield (1.81 t/ha) of lentil was recorded from both *Rhizobium* sp. FALR114 and *Rhizobium* sp. FALR317during 2021-2022, which was significantly higher over all other strains except T_6 (Reference strain *Rhizobium* sp. BARIRLc107). In the year 2020-2021, the highest seed yield 1.09 t/ha was obtained from *Rhizobium* sp. FALR319 at Gazipur and 0.74 t/ha by using *Rhizobium* sp. FALR315 at Pabna.

BRRI Component

Title: Microbial Characterization of Bangladesh Soil and Development of Climate Smart Biofertilizers for Crop Production and Soil Fertility.

The study on biological component of rice soil in Bangladesh is new. Understanding the microbial community and composition following long-term fertilization may have significant implications for the development of better fertilizer regime in any agro-ecosystems which is the primary requirement of national food security. In this context, elucidation of rice soil biology and replenish

soil with beneficial microbes using rice based biofertilizer is important to maintain long-term soil fertility, soil health and improve crop productivity. Hence present study was conducted with the specific objectives:

i) To assess soil bio-physico-chemical properties of different AEZ's of Bangladesh and characterization of potential plant growth promoting bacteria (PGPB)

ii) To develop biofertilizer using potential microbes for rice based cropping system

iii) To evaluate efficacy of developed biofertilizer in different AEZ's for the improvement of soil fertility and crop productivity

A number of three studies were conducted with the aim to determine the soil microbial populations from eight AEZ's of Bangladesh and to characterize the potential free-living N_2 fixing, phosphate solubilizing, and indoleacetic acid producing bacteria and finally prepared a climate smart biofertilizer using the potential bacteria for higher rice productivity. Soil samples (0-15 cm depth) were collected using GPS recording from AEZ-10 (Faridpur), AEZ-11 (Jashore- Rajshahi), AEZ-13 (Satkhira), AEZ-15 (Munshiganj), AEZ-16 (Brahmanbaria- Munshiganj), AEZ-19 (Cumilla-Kishoreganj), AEZ-22 (Moulavibazar- Habiganj) and AEZ-27 (Rangpur- Bogura) and tested for microbial properties, texture, soil pH and organic matter. Microbial populations were enumerated on selective media following 'total plate count' method. Potential strains were identified using 16SrRNA partial gene sequence with specific primers. The ability of N_2 fixation, phosphate solubilization and indoleacetic acid production by the strain were determined following standard protocol. A number of 13 mixed potential bacteria (free-living N_2 fixing, phosphate solubilizing and indoleacetic acid producing bacteria) including bacillus spore were coated on urea and TSP and formulated 'Bio-coated urea' and 'Bio-coated TSP' fertilizer for improve rice productivity in the saline and acid soil, respectively. These two climate smart biofertilizer were tested in acid and saline soil at glasshouse condition.

Key findings obtained were

i) The range of total bacteria populations were significantly high in the Decreerchar union of AEZ-10 (2×10^6 to 2×10^9 cfu/g soil), Panisara union of AEZ-11 (2×10^7 to 2×10^9 cfu/g soil), and Deorghachi union of AEZ-22 (7×10^6 to 1×10^9 cfu/g soil). The lowest total bacteria range was in AEZ-13.

ii) Total fungus population range was comparatively lower in the AEZ-10, AEZ-13, AEZ-15, AEZ-16 and AEZ-27. On an average, Actinomycetes populations were low in all the tested AEZ's. The populations of free-living N_2 fixing bacteria were higher than the *Rhizobium* populations. The populations of phosphate solubilizing bacteria were higher than free-living N_2 fixing bacteria.

iii) The dominant potential bacteria from each AEZ's were identified and tested for bio-molecular characteristics. Among the strains, the highest N_2 fixation (28 ppm) NH_4) was recorded by *Bacillus thuringiensis* (B49) isolated from AEZ-27 and *Pseudomonas geniculata* (B61) isolated from AEZ-15.

iv) The highest 3746 ppm P was solubilized by the *Stentrophomonas maltophilia* (B53), isolated from Shahjahanpur upazila of AEZ-27. The highest amount of indoleacetic acid (144 ppm) was produced by the strain B59 isolated from Shyamshiddhi union of Srinagar upazila (AEZ-15).

v) Isolated 15 potential strains were coated with TSP and Urea fertilizer and named as 'Bio-coated urea' and 'Bio-coated TSP' biofertilizer, respectively. In the glasshouse condition, about 36% grain yield increased in BRRI dhan28 and saved 50% TSP fertilizer by the application of 'Bio-coated TSP' in acid soil compared to TSP fertilizer only.

vi) Application of Bio-coated urea improved grain yield 10.53% of BRRI dhan99 over chemical fertilizer in the Saline soil. Nutrient mineralization form Bio-coated fertilizer and survival of the bacteria during the incubation study and plant growth period (glasshouse study) were in satisfactory level.

vii) In conclusion, among tested eight AEZ's, the populations of beneficial bacteria (free-living N_2 fixing, Rhozobium and phosphate solubilizing bacteria), soil organic matter and total N were lower than any healthy agricultural soil.

Key words: Free-living N_2 fixing bacteria, Phosphate solubilizing bacteria, Rhizobium, Bio-coated urea & TSP.

BINA Component

Title: Microbial Characterization of Bangladesh Soil and Development of Climate Smart Biofertilizers for Crop Production and Soil Fertility.

Physico-chemical properties of soils were determined for better use of soil for crop production in Bangladesh earlier. Microbial community and their population play an important role in nutrient availability, release and soil fertility. Study of microbial ecosystem and microbial community is essential for best use of soil for crop production as well as soil fertility management. Development of climate resilience technology for crop production and soil fertility restoration is present demand for increment of crop productivity in stress area like saline areas. With the view in mind present study was conducted with the specific objectives:

i. To assess soil bio-physico-chemical properties of different AEZ's of Bangladesh.

ii) To develop biofertilizer using potential salinity tolerant nodulating bacteria.

iii) To evaluate efficacy of developed biofertilizer in field for the improvement of soil fertility and soybean productivity.

A number of three studies were conducted with the aim to determine the soil microbial populations from eight AEZ's of Bangladesh and prepared a climate smart biofertilizer using the potential bacteria for higher soybean productivity in saline areas. Soil samples (0-15 cm depth) were collected using GPS recording from AEZ-3 (Rangpur-Nilphamary), AEZ-7 (Kurigram-Siraj), Mymensingh-Netrakona (AEZ-9), Faridpur-Pabna (AEZ-12), Gopalganj- Khulna (AEZ-14), Chandpur- Laxmipur (AEZ-17), Bogura- Naogaon (AEZ-25), and Chapainawabganj- Rajshahi (AEZ-26) and tested for microbial properties, texture, soil pH and organic matter. Microbial populations were enumerated on selective media following 'total plate count' method. The ability of N_2 fixation, phosphate solubilization and indoleacetic acid production by the strain were determined following standard protocol. A number of 15 bacteria strains were isolated from where two were found to be promising as biofertilizer for cultivation of soybean in saline areas. These two-climate smart biofertilizer were tested in glass house and saline areas.

Key findings obtained were:

1. AEZ-14 recorded the highest total bacteria, *Rhizobium*, *Bradyrhizobium*, FLNFB and Fungi population among 8 AEZs studied. The total bacteria populations were highest in (AEZ-14) Roghunathpur union (12.6×10^7-15.8×10^7) cfu/g soil) (mean 15.38×10^7 cfu/g soil),, Rangpur union (12.6×10^7-19×10^7 cfu/g soil) (mean 14.82×10^7 cfu/g soil) and Gabindapur union (11.8×10^7-18.5×10^7 cfu/g soil) (mean 14.02×10^7 cfu/g soil).
2. AEZ-25 recorded the highest population of PSB and AEZ-3 as highest population of Fungi.

3. AEZ 26 recorded next to the highest population of total bacteria and PSB.
4. FLNFB population was found higher over Rhizobium, Bradyrhizobium, Fungi and Actinomycetes.
5. Rhizobium and Bradyrhizobium population was found higher over PSB, Fungi and Actinomycetes.
6. PSB population was recorded higher over Fungi and Actinomycetes.
7. Fungi population was found higher over Actinomycetes.
8. Population of Actinomycetes was found the lowest among the microbes studied.
9. Soils of AEZ 3, AEZ 7, AEZ 9, AEZ 17 and AEZ 25 were found acidic in reaction while soils of AEZ 12, AEZ 14 and AEZ 26 showed alkaline. AEZ 17 showed neutral in soil reaction.
10. Soil organic matter was found low (below 2%) in AEZ-7, AEZ-9, AEZ-17, AEZ-25 and AEZ-26 where AEZ-3, AEZ-12 and AEZ-14 contain medium (above 2%) soil organic matter. AEZ-14 showed the highest organic matter in soil among 8 AEZs.
11. Total nitrogen in soils of most AEZ was found low except AEZ 14. AEZ 14 contained the highest soil nitrogen (3.35%) among the agro-ecological regions studied.
12. Soil textures of different AEZs were found sand, loamy sand, sandy loam, loam, clay loam, sandy clay loam and clay where most were sandy loam, sandy clay loam, clay loam and loam.
13. Fifteen salt tolerant Rhizobia strains were isolated and characterized biochemically.
14. Salinity tolerant biofertilizer was developed for production of soybean in saline areas.

Key words: Agro ecological zones, Total bacteria, Free-living N_2 fixing bacteria, Phosphate solubilizing bacteria, Rhizobium, Salinity tolerant biofertilizer for soybean production in saline areas.

BSRI Component

Title: Microbial Characterization of Bangladesh Soil and Development of Climate Smart Biofertilizers for Crop Production and Soil Fertility.

The populations of soil microorganisms played a vital role in the decomposition of organic materials applied to the soil. The status of beneficial microorganisms of soils of Bangladesh was not available. It was needed to study the conditions of beneficial microorganisms and the fertility statuses of soils in different region of Bangladesh. In Bangladesh, the cost of N fertilizer is increasing day by day and P fertilizer is imported from abroad with the exchange of native currency. Besides, unbalanced and injudicious use of chemical N and P fertilizer by our farmers creates economically loses, environmental pollution, damage soil health and hampering crop productivity. Therefore, this project was developed to study the fulfillment of the objectives:

i) To isolate region specific beneficial microorganisms from soils of different agro-ecological zones of Bangladesh

ii) To characterize nitrogen fixing and phosphate solubilizing bacteria isolated from soils, roots, stems and rhizosphere soils of sugarcane

iii) To develop nitrogenous biofertilizers for sugarcane plant

iv) To determine the effect of biofertilizers on growth and biomass production of sugarcane genotypes grown in N and P stressed conditions.

A number of four studies were conducted with the aim to determine the soil microbial populations from seven AEZ's of Bangladesh and to characterize the potential free-living N_2 fixing bacteria from sugarcane rhizosphere and to develop nitrogenousbiofertilzer/inoculants and finally to this biofertilizer for higher sugarcane production.For microbial characterization of soils of BSRI part, 7 agro-ecological zones viz. AEZ 1: Old Himalayan Piedmont Plain, AEZ 4: Karatoya-Bangali Floodplain , AEZ 5: Lower Atrai Basin, AEZ 8: Young Brahmaputra and Jamuna Floodplain, AEZ 20: Eastern Surma Kushiyara Floodplain, AEZ 21: Sylhet Basin and AEZ 28: Madhupur Tract had been selected. A total of 280 (two hundred eighty) soil samples were collected among them 240 (two hundred forty) soil samples were collected from 7 AEZs and 40 (forty) rhizosphere soils, 48 rhizospere root, and 40 leaf sheaths samples were collected from sugarcane fields. The samples were used to study for microbial properties, texture, soil pH and organic matter. Microbial populations were enumerated on selective media following 'total plate count' method. Potential strains were identified using 16SrRNA partial gene sequence with specific primers.

Based on tne 16S rRNA gene sequencing, the isolated strains were identified as *Bacillus pumilus* BS37a, *Bacillus pumilus* BS37b, *Bacillus pumilus* BS34a and *Bacillus pumilus* BS34b in strain *Bacillus pumilus* and *Kocuria rosea* BSBR1 and *Kocuria rosea* BSBR2 in strain *Kocuria rosea*. *B. pumilus* is significant to ecosystem biochemistry because it functions as a nitrogen fixing bacteria capable of metabolically transforming molecular nitrogen (N_2) into ammonia (NH_3) (Hernandez *et al*., 2009).

The identified nitrogenous inoculants were used to test the efficacy of yield performance of sugarcane. An experiment was conducted and it was comprised of eight treatments viz. T_1 = No fertilizers and strains, T_2 = Recommended Dose of Fertilizers (RFD), T_3 = 100% N of RFD+N-fixing inoculants, T_4 = 50 % N of RFD + N-fixing inoculants, T_5= 75 % N of RFD + N-fixing inoculants, T_6 = 50% of RFD+ Nitrogen and phosphate solubulizing inoculants, T_7= 75 % of P and full amount of NKSZn + phosphate solubulizing inoculants and T_8 = 50 % of P and full amount of NKSZn + phosphate solubulizing inoculants. The variety was Isd 39. The highest millable cane was found in T_5 treatment and second highest of 103.85×10^3 ha^{-1} was found in T_5 treatment, it was similar with all others treatments except control. But the highest sugarcane yield of 108.25 was found in T_5 treatment, it was statistically similar with T_2 treatment. So, 75% RFD along with nitrogen fixing inoculants gave the batter performance.

Keywords: Microbial characterization, Bangladesh soil, Climate smart biofertilizers, Sugarcane production, Soil fertility

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) Furniture i.Table ii. Executive Table	2	36463	2	36463	
(b) Office Equipment i. Labtop ii. Printer. iii. Scanner	3	99850	3	99850	
(c) Other capital items	-	-	-	-	
BARI Component					
(a) Office equipment					
1.Desktop Computer	2	120000	2	120000	Good condition
2.UPS (offline)	2	14000	2	14000	Good condition
3.Laser Printer	2	40000	2	40000	Good condition
(b) Lab & field equipment					
1.pH meter(portable)	1	50000	1	50000	Good condition
2.EC meter(portable)	1	50000	1	50000	Good condition
3.Refrigerator(4^0C)	1	90000	1	90000	Good condition
4. Refrigerator(-80^0C)	1	1300000	1	1300000	Good condition
5.Autoclave	1	550000	1	550000	Good condition
6.Hotplate with magnetic stirrer	1	50000	1	50000	Good condition
7.Snowflake Ice making machine	1	300000	1	300000	Good condition
(c) Other capital items					
BRRI Component					
(a) **Lab & field equipment:** **<u>Chemicals</u>** 1.1 Ethyl Alchol (2.5L) 1.2 Percholoric Acid (2.5L) 1.3 Sulfuric Acid (2.5L) 1.4 Nitric Acid (2.5L) 1.5 Hydrochloric Acid (2.5L) 1.6 L-Ascorbic Acid (100g) 1.7 Boric Acid (1 kg) 1.8 Barium Cloride (1kg) 1.9 Sodium bi carbonate (1kg) 1.10 Ammonium venadate (100g) 1. 11 Rectified Spirit (1.5 L) 1.12 Nutrient Agar (500g) 1.13 Nutrient Broth (500g) 1.14 Potato dextrose Agar (500g)	 01 01 01 01 01 01 01 01 01 01 01 01 03 03 03	 Total: 499000 (Year 1)	 01 01 01 01 01 01 01 01 01 01 01 01 03 03 03	 Total: 494500 (Year -1)	100% (Price re-fixed as per BRRI procurement committee)

1.15 Actinimycetes Agar (500g) 1.16 Pseudomonas Agar (500g) 1.17 Typic Soya Agar (500g) 1.18 Pikovaskya Agar (500g) 1.19 Pikovaskya Broth(500g) 1.20 Bacteriology Agar(500g) 1.21 Free living N fixing media (500g) 1.22 Glass Petridishes 1.23 Pipette (10 ml) 1.24 Pipette (1 ml)	03 03 03 03 01 03 02 200 01 01		03 03 03 03 01 03 02 200 01 01		
(b) **Other capital items** 1.1 Refrigerator (4^{oC}) 2.2 Laptop	 1 1	Total: 305000 (Year 1) 245000 60000	 1 1	299500 (Year 1) 242000 57500	100% (Price re-fixed as per BRRI procurement committee)
BINA Component					
(a) Office and Lab equipments					
i.Laptop- 01, ii. Scaner- 01, iii. Digital camera- 01, iv. Excecutive table- 01, v. Excecutive chair- 01 vi.Microscope with monitor and digital camera-01, vii. Deep freezer- 01, viii.PCR machine- 01, ix. pH meter- 01, x. EC meter- 01, xi. Centrifuge machine -01, xii. Vortex machine- 01, xiii.Autodispensor- 01	13	1285000	13	1282600	
(b) Lab &field equipment					
(c) Other capital items					
BSRI Component					
(a) Office equipment i. Laptop-01 ii. Refreezer (20^{0}C)-1 iii. GPS Meter-01 iv. pH Meter-01	4	360000	4	360000	
(b) Lab &field equipment i. Executive table-02 ii. Executive chair-02 iii. File cabinet-02 iv. Steel almira-01	7	124000	7	124000	
(c) Other capital items i. Bicycle	1	15000	1	15000	

2. **Establishment/renovation facilities: N/A**

Description of facilities	Newly established		Upgraded/refurbished		Remarks
	PP Target	Achievement	PP Target	Achievement	
BARC Component					
Repair, renovation and maintenance of Lab of NRM	399500	399500	-	-	

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	45	9	54	1 day	
(c) Others (if any)					
BARI Component					
(a) Training	102	18	120	1 day	4 batch x 30
(b) Workshop					
(c) Others (if any)					
BINA Component					
a) Training-1 (Farmers training)	62	0	62	1 day	
b) Training-1 (Technician training)	29	03	32	3 days	
b)Workshop					
c) Other (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	9920037	9260440	9260440	0	100	
b. Field research/lab expenses and supplies	8960312	8676974	8676974	0	100	
c. Operating expenses	2320439	1920567	1920567	0	100	
d. Vehicle hire and fuel, oil & maintenance	2079610	1874360	1874360	0	100	
e.Training/workshop/ seminar etc.	1059330	983450	983450	0	100	
f. Publications and printing	563500	510500	510500	0	100	
g. Miscellaneous	641302	629312	629312	0	100	
h. Capital expenses	4773813	4773813	4773813	0	100	

Items of expenditure/activities	Total approved budget	Fund received	Actual expenditure	Balance/ unspent	Physical progress (%)	Reasons for deviation
Total	**30318343**	**28629416**	**28629416**	**0**	100	
BARC Component						
a. Contractual staff salary	3736911	3096241	3096241	0	100	
b. Field research/lab expenses and supplies	399500	399500	399500	0	100	
c. Operating expenses	502645	332622	332622	0	100	
d. Vehicle hire and fuel, oil & maintenance	289560	217810	217810	0	100	
e. Training/workshop/ seminar etc.	609330	533450	533450	0	100	
f. Publications and printing	350000	347000	347000	0	100	
g. Miscellaneous	204262	201942	201942	0	100	
h. Capital expenses	136313	136313	136313	0	100	
Total	**6228521**	**5264878**	**5264878**	**0**	100	
BARI Component						
a. Contractual Staff Salary	1900851	1888274	1888274	0	100	
b. Field Research / Lab expenses and supplies	3503045	3303275	3303275	0	100	
c. Operating Expenses	667773	515097	515097	0	100	
d. Vehicle Hire and Fuel, Oil & Maintenance	826650	823250	823250	0	100	
e. Training/ Workshop/ Seminar etc.	300000	300000	300000	0	100	
f. Publications and printing	50000	50000	50000	0	100	
g. Miscellaneous	168551	168419	168419	0	100	
h. Capital Expenses	2556400	2556400	2556400	0	100	
Total	**9973270**	**9604715**	**9604715**	**0**	100	
BRRI Component						
a. Contractual staff salary	1916207	1916207	1916207	0	100	
b. Field research/lab expenses and supplies	1948271	1945365	1945365	0	100	
c. Operating expenses	251922	231761	231761	0	100	
d. Vehicle hire and fuel, oil & maintenance	459500	459500	459500	0	100	
e. Training/workshop/ seminar etc.	0	0	0	0	100	
f. Publications and printing	50000	50000	50000	0	100	
g. Miscellaneous	79000	79000	79000	0	100	
h. Capital expenses	299500	299500	299500	0	100	
Total	5004400	4981333	4981333	0	100	
BINA Component						

Items of expenditure/activities	Total approved budget	Fund received	Actual expenditure	Balance/ unspent	Physical progress (%)	Reasons for deviation
a. Contractual staff salary	1049953	1043603	1043603	0	100	
b. Field research/lab expenses and supplies	1728355	1728355	1728355	0	100	
c. Operating expenses	435203	435203	435203	0	100	
d. Vehicle hire and fuel, oil & maintenance	208900	98900	98900	0	100	
e. Training/workshop/ seminar etc.	150000	150000	150000	0	100	
f. Publications and printing	63500	63500	63500	0	100	
g. Miscellaneous	119489	119489	119489	0	100	
h. Capital expenses	1282600	1282600	1282600	0	100	
Total	**5038000**	**4921650**	**4921650**	**0**	100	
BSRI Component						
a. Contractual staff salary	1316115	1316115	1316115	0	100	
b. Field research/lab expenses and supplies	1381141	1300479	1300479	0	100	
c. Operating expenses	462896	405884	405884	0	100	
d. Vehicle hire and fuel, oil & maintenance	295000	274900	274900	0	100	
e. Training/workshop/ seminar etc.	0	0	0	0	100	
f.Publications and printing	50000	0	0	0	100	
g. Miscellaneous	70000	60462	60462	0	100	
h. Capital expenses	499000	499000	499000	0	100	
Total	**4074152**	**3856840**	**3856840**	**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.To study physical, chemical and microbial properties of soil of different AEZs of Bangladesh	1. 310 soil samples were collected from 02, 06, 13, 18, 23, 24, 29 and 30 AEZs.	1.Generated data regarding Chemical and microbial properties. 2.Texure170 samples were analysed.	1.Microbial properties of eight AEZs were found out 2.Microbial population status assessed

2.To isolate climate smart i.e. saline, acidic and drought tolerant Nitrogen-fixing and plant growth promoting bacteria from root, nodules and rhizosphere soils of Bangladesh	1. Nodules were collected from different AEZs of saline and high temparature area of bangladesh	1.Molecular chatacterization isolated strain were completely	1.Bacterial sequencing was found. 2. Identified salinity and high temperature tolerate bacteria.
3.To develop biofertilizer for pulse, oilseed and test their efficiency for crop productivity and soil fertility	1.10 bacterial strains have been selected for groundnut and 10 bacterial strains have been selected for lentil biofertilizer development.	Prepared promising biofertilizers to be used in harsh environment	Provided better crop yield (Lentil and Groundnut) and improved soil fertility

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 assess soil bio-physico-chemical properties of different AEZ's of Bangladesh and characterization of potential plant growth promoting bacteria (PGPB)	Soil samples were collected from Faridpur (AEZ-10), Jashore- Rajshahi (AEZ-11), Satkhira (AEZ-13), Munshiganj (AEZ-15), Brahmanbaria- Munshiganj (AEZ-16), Cumilla-Kishoreganj (AEZ-19), Moulvibazar- Habiganj (AEZ-22), and Rangpur- Bogura (AEZ-27). Soils were analyzed for: **Physical properties:** Soil texture. **Chemical properties:** pH, total N and organic matter. **Biological Properties:** Population of total bacteria, phosphate solubilizing bacteria, Free-living N_2 fixing bacteria, fungus and actinomycetes. Capability of phosphate solubilizing, N_2 fixing and indole acetic acid production determined for isolatyed bacteria Potential bacteria identified from each AEZ's	• Soil physical chemical and biological properties of the eight AEZ's (AEZ-10, AEZ-11, AEZ-13, AEZ-15, AEZ-16, AEZ-19, AEZ-22 and AEZ-27) was assessed • Output described in: • Annual Report, 2019-20 • Annual Report, 2020-21 • Half yearly Report 2022 • Annual review workshop, 2021 • Annual review workshop, 2022 • PCR	Soil health of the 8 studied AEZ's viz; AEZ-10, AEZ-11, AEZ-13, AEZ-15, AEZ-16, AEZ-19, AEZ-22 and AEZ-27 was assessed. From isolates, capability of phosphate solubilizing, N_2 fixing and indoleacetic acid production determined Potential bacteria identified from each AEZ's

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)
		• Leaflet (8)	
2. To develop biofertilizer using potential microbes for rice based cropping system	'Bio-coated TSP' a climate smart biofertilizer was formulated for rice production in the acid soil. 'Bio-coated urea' a climate smart biofertilizer was developed for rice production in the saline soil	Incubation study was performed to determine mineralization rate of amended nutrients and survival rate of added bacteria. Output described in: Half yearly Report 2022 Annual review workshop, 2022 PCR	• 'Bio-coated TSP' –a climate smart biofertilizer was developed using potential indigenous bacteria to increase rice productivity in acid soil • Bio-coated urea' –a climate smart biofertilizer was developed using potential bacteria identified from AEZ-13 for sustainable rice production in saline soil.
3. To evaluate efficacy of developed biofertilizer in different AEZ's for the improvement of soil fertility and crop productivity	Glasshouse experiments were conducted in AEZ-22 (acid soil) and AEZ-13 (saline soil).	Rice yield, soil analyses data. Output described in: ● Half yearly Report 2022 ● Annual review workshop, 2022 ● PCR	Applied biofertilizers' increased crop yield and improved soil biology in acid and saline soils that collected from AEZ-22 and AEZ-13, respectively

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)
1. To assess soil bio-physico-chemical properties of different AEZ's of Bangladesh	1. Soil samples were collected from AEZ-3, 7, 9, 12, 14, 17, 25 and 26.	1.Generated data regarding physical, chemical and microbiological properties.	1.Chemical, physical and microbial population status were assesed.
2. To isolate, characterized potential microbes (nodulating) and develop climate smart (salinity tolerant) biofertilizer for soybean for saline areas.	2.Nodules were collected from root nodules grown in saline areas and characterized culturally, microscopic, salinity, high temperature and nodulation in glass house condition.	2.From salinity, nodulation, growth and yield increased in pot condition 15 isolates were identified.	2.Salinity tolerant biofertilizer strains were identified.
3. To evaluate efficacy of	3.Four strains were selected for testing	3.Prepared promissing biofertilizer biofertilizer to be used in harsh	3.Proved better crop yield and improved 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. To assess soil bio-physico-chemical properties of different AEZ's of Bangladesh	1. Soil samples were collected from AEZ-3, 7, 9, 12, 14, 17, 25 and 26.	1.Generated data regarding physical, chemical and microbiological properties.	1.Chemical, physical and microbial population status were assesed.
developed biofertilizer in field for oil seed crop soybean productivity.	efficacy in field level in saline areas as biofertilizer quality.	(saline stress) environment for soybean production.	fertility.

BSRI 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)
i. To isolate region specific beneficial microorganisms from soils of different agro-ecological zones of Bangladesh.	240 soils samples collection from 7 AEZs and enumeration of microorganisms.	Generated data regarding chemical and microbial properties.	Microbial population assessed.
ii. To characterize nitrogen fixing and phosphate solubilizing bacteria isolated from soils, roots, stems and rhizosphere soils of sugarcane.	40 rhizospheres soils, 48 rhizosphere roots and 40 lesf sheaths of sugarcane were collected.	Molecular characterization of the isolates was completed	Identified were capable of reduction of nitrogen and phosphatic fertilizers.
iii. To develop nitrogenous biofertilizers for sugarcane plant.	4 bacterial strains were used for nitrogenus and 2 bacterial strains for phosphatic biofertilizer.	Prepared promising biofertilizers to be used in sugarcane.	Provided better crop yield and improved soil fertility.
iv. To determine the effect of biofertilizers on growth and biomass production of sugarcane genotypes grown in N and P stressed conditions.	Field experiment of effect of nitrogen-fixing inoculants and inorganic fertilizes on sugarcane	Identified suitable biofertilizer forbetter sugarcane yield.	Increased crop yield and soil fertility.

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)

1.To study physical, chemical and microbial properties of soil of different AEZs of Bangladesh	1.310 soil samples were collected and analyzed	1.Chemical and microbial population status of eight AEZ soils to be known.	1.Soil Microbial population data were found out
2.To isolate climate smart i.e. saline, acidic and drought tolerant Nitrogen-fixing and plant growth promoting bacteria from root, nodules and rhizosphere soils of Bangladesh	1. Nodules were collected from different AEZs of saline and high temparature area of Bangladesh	1.*Rhizobium* biofertilizer are made from collected strain	1.Yield of lentil and groundnut will be increased.
3.To develop biofertilizer for pulse, oilseed and test their efficiency for crop productivity and soil fertility	10 bacterial strains have been selected for groundnut and 10 bacterial strains have been selected for lentil biofertilizer development.	Siutable *Rhizobium* inoculants for groundnut and lentil developed	Increased lentil and groundnut yield, improved soil fertility and reduced cost of production

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 assess soil bio-physico-chemical properties of different AEZ's of Bangladesh and characterization of potential plant growth promoting bacteria (PGPB)	Soil samples were collected from Faridpur (AEZ-10), Jashore-Rajshahi (AEZ-11), Satkhira (AEZ-13), Munshiganj (AEZ-15), Brahmanbaria- Munshiganj (AEZ-16), Cumilla- Kishoreganj (AEZ-19), Moulavibazar- Habiganj (AEZ-22), Rangpur- Bogura (AEZ-27). Soils were analyzed for: **Physical properties:** Soil texture. **Chemical properties:** pH, total N and organic matter. **Biological Properties:** Population of total bacteria, phosphate solubilizing bacteria, Free-living N_2 fixing bacteria, fungus and actinomycetes. Potentiality of the indigenous bacteria such as free living N_2 fixing, P solubilizing and indoleacetic acid producing capability determined from each tested AEZ. Potential and dominant strains were identified form each AEZ.	Soil bio-physical and chemical properties of the AEZ-10, AEZ-11, AEZ-13, AEZ-15, AEZ-16, AEZ-19, AEZ-22 and AEZ-27) was determined.	Soil health of the 8 studied AEZ's viz; AEZ-10, AEZ-11, AEZ-13, AEZ-15, AEZ-16, AEZ-19, AEZ-22 and AEZ-27 was assessed. • The highest total bacteria found in AEZ-10, AEZ-11 and AEZ-22. • The lowest total bacteria was in AEZ-13. • Potential bacteria from tested AEZ's were identified and biochemical properties of the isolates determined
2. To develop bio-fertilizer using potential microbes	• 'Bio-coated TSP' a climate smart biofertilizer was formulated using potential	Incubation study result proved, mineralization	Using potential bacteria from different AEZ's, climate smart biofertilizer

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)
for rice based cropping system	indigenous bacteria for rice production in the acid soil. • 'Bio-coated urea' a climate smart biofertilizer was developed using potential bacteria isolated from AEZ-13 for rice production in the saline soil • mineralization of respective nutrient from formulated biofertilizer were determined	rate of amended nutrients and survival rate of added bacteria were in sufficient level. Output described in: • Half yearly Report 2022 • Annual review workshop, 2022 • PCR	formulated that improved rice yield and soil biology Formulated biofertilizers are: • 'Bio-coated urea' for saline soil • 'Bio-coated TSP' for acid soil
3. To evaluate efficacy of developed biofertilizer in different AEZ's for the improvement of soil fertility and crop productivity	Glasshouse experiments were conducted with acid (AEZ-22) and saline (AEZ-13) soil.	Rice yield, soil analyses data. Output described in: • Half yearly Report 2022 • Annual review workshop, 2022 • PCR	P fertilizer use efficiency increased in acid soil and simultaneously rice yield improved Rice yield and soil biology improved in saline soil

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)
1. To assess soil bio-physico-chemical properties of different AEZ's of Bangladesh.	1. 320 soil samples were collected and analyzed for physical, chemical and microbial population.	1)Soil bio-physical and chemical properties of the 8 AEZ were obtained.	1.Soil microbial population data were found out. • The highest total bacteria found in AEZ-14, and the lowest total bacteria was in AEZ-17.
2. To isolate, characterized potential microbes (nodulating) and develop climate smart (salinity tolerant) biofertilizer for soybean for saline areas.	2. Nodules were collected from root nodules grown in saline areas and characterized culturally, microscopic, salinity, high temperature and nodulation in glass house condition.	2.Salinity tolerant biofertilizer were formulated from isolated strains.	2.Higher nodulation was found with application of biofertilizer strains.
To develop salinity	Field experiment were	3.Better nodulation and plant	Using salinity

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)
tolerant biofertilizer and test efficacy in saline areas in soybean productivity.	conducted in saline areas.	growth and were found.	tolerant biofertilizer soybean yield was increased by 40-60%.

BSRI 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)
i. To isolate region specific beneficial microorganisms from soils of different agro-ecological zones of Bangladesh.	240 soils samples were collected and analysed.	Chemical and microbial population status of the selelected areas of 7 AEZs would be known.	Populations of microorganisms were found out.
ii. To characterize nitrogen fixing and phosphate solubilizing bacteria isolated from soils, roots, stems and rhizosphere soils of sugarcane.	128 of hizospheres soils, rhizosphere roots and lesf sheaths of sugarcane were collected.	Characterization of the isolates was completed	Capable isolates were used to reduced nitrogen and phosphatic fertilizers.
iii. To develop nitrogenous biofertilizers for sugarcane plant.	4 bacterial strains were used for nitrogenus and 2 bacterial strains for phosphatic biofertilizer.	Developed nitrogen fixing biofertilizers for sugarcane.	Provided better crop yield and improved soil fertility.
iv. To determine the effect of biofertilizers on growth and biomass production of sugarcane genotypes grown in N and P stressed conditions.	Field experiment of effect of nitrogen-fixing inoculants and inorganic fertilizes on sugarcane	Identified suitable biofertilizer forbetter sugarcane yield.	Increased crop yield and soil fertility.

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.	**2**	**-**	
Joumal publication	2		
Video clip/TV program			
News Paper/Popular Article			

Publication	Number of publications		Remarks (e.g. paper title, name of journal, conference name, etc.)
	Under preparation	Completed and published	
Other publications, if any			
BRRI Component			
Technology bulletin/ booklet/leafletlflyer etc.	**Booklet (1):** কৃষি পরিবেশ অঞ্চল-১০, ১১, ১২, ১৩, ১৫, ১৬,১৯,২২, ও ২৭ এর কৃষি জমির মাটির ভৌত, রাসায়নিক ও জৈবিক গুণাবলী	In press	In press Materials will be published soon
Journal publication	Not done	-	-
	Not done	-	-
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.	**Leaflet (2):** ১. লবনাক্ত এলাকায় সয়াবিন চাষে লবনাক্ততা সহনশীল জীবানু সার (লিফলেট, বাংলা) ২. লবনাক্ত এলাকায় সয়াবিন চাষে লবনাক্ততা সহনশীল জীবানু সার (ফ্যাক্টশীট, বাংলা)	published	-
Journal publication	Not done	-	-
Video clip/TV program	Not done	-	-
News Paper/Popular Article	Not done	-	-
Other publications, if any	Not done	-	-
BSRI 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: Use of Biofertilizer for Lentil Production

Introduction

Lentil is very important pulse crop in Bangladesh. Using rhizobium biofertilizer in lentil cultivation is very easy and cheap technology. Biofertilizers contains microorganisms which promote the adequate supply of nutrients to the host plants to ensure their proper development of growth and regulation in their physiology. To prevent the environment pollution from extensive application of chemical fertilizers the biofertilizer could be recommended to farmers to insure the public health and a sustainable agriculture

DESCRIPTION

Developing this biofertilizer

Isolation and purification of bacterial strain

For developing this biofertilizer nodules were collected from lentil plant. Nodules were surface sterilized through washing in running tap water then with distilled water in a wide mouth vial for 5-6 times so that no soil particle was on nodule surface. Then nodules were dipped in to 70% ethyl alcohol solution for 30 seconds. Later washed for 1 minute with mixture solution of 70 percent ethanol solution and 3% hydrogen peroxide solution at 1:1 ratio by volume. After these nodules were cut down at surface with a scalpel blade. Pink coloured nodule sap was taken with inoculation needle and streaked on congored yeast mannitol agar (CRYEMA) plate and incubated in incubator (28^0C) for 7-10 days till well grown iscrete colonies appeared. Colonies typical with rhizobium were selected and restreamed on CRYEMA thrice for purification of strains.

Microscopic observation: Purified bacterial cultures (Strains) were tested for cell shape under microscope.

Salinity tolerance: Salinity tolerance was tested using different concentration of salt containing YEMA plate and growth was observed in incubator for 10 days.

Biochemical test: Indole acetic acid production- Indole acetic acid production was observed by growing bacterial cultures in yeast mannitol broth containing tryptophan and ammonium nitrate.

Pot experiment: Pot experiment was done for studying nodule formation, nitrogen fixation, plant growth and yield in pot.

Field experiment: Field experiments were done in Gazipur and Pabna location to observe nodule formation, nitrogen fixation, plant growth, grain yield due to inoculation of rhizobial biofertilizer.

Application rate of biofertilizer: Biofertilizer is used @ 40-50 g/kg seed. There is no harm if used more than this rate.

APPLICATION METHOD OF BIOFERTILIZER

Bio-fertilizers are usually used in combination with seeds. This fertilizer takes more when applied to the soil. The surface of the seed is first glued by mixing any sticky substance like chitagur or cold rice starch with the seed. Then 40-50 gm of bio-fertilizer per kg of seed should be well mixed

with the seed, so that a black coating is formed on the surface of each seed, as a result the seed is known to have a large number of micro-organisms attached to it and will help in nodule formation. The seeds mixed with this bio-fertilizers should be sown in rows in the ground in a slightly 3/4 cm pitted trance and the trance should be filled with soil. In case of broadcast sowing, a ladder should be provided, so that the seed goes under the soil. The best time for sowing seeds mixed with micro-fertilizers is in the morning or afternoon.

Yield increases due to biodertilizer application: Increases 30-40% lentil yield through application of biofertilizer.

Precautions in collection, transportation and storage of biofertilizer

- This biofertilizer cannot be used other than lentil crop.
- Expiry date written on packet to be seen as no good effect got by using biofertilizer after expiry date.
- At the time of transportation biofertilizer should keep not in direct sun light beside window.
- Biofertilzer should store in dry and cool place at house and shop.

SUITABLE LOCATION/ECOSYSTEM

This biofertilizer technology can be used instead of costly urea fertilizer in the soils of all over Bangladesh for maximizing yield of lentil as well as reduced production cost

BENEFITS OF THIS BIOFERTILIZER

- It fulfills the demand of Nitrogen fertilizer (Urea) for lentil cultivation.
- Enhances vegetative growth and yield of lentil.
- Yield increment of 30-40 percent of lentil.
- Needs less or no nitrogenous fertilizer in subsequent crop by using this biofertilizer.
- It increases soil fertility through decomposing leaves, nodules and other plant parts of lentil.
- It is environmentally friendly.

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Lentil field, Pabna

Lentil pot experiment at Joydebpur

Lentil field at joydebpur

Lentil field at Pabna

Fig. 76. Pot and Field experiment of BARI masur-8

2. **Title of technology: Use of Biofertilizer for Groundnut Production**

Introduction

Groundnut is very important oilseed crop in Bangladesh. Using rhizobium biofertilizer in groundnut cultivation is very easy and cheap technology. Biofertilizers contains microorganisms which promote the adequate supply of nutrients to the host plants to ensure their proper development of growth and regulation in their physiology. To prevent the environment pollution from extensive application of chemical fertilizers the biofertilizer could be recommended to farmers to insure the public health and a sustainable agriculture

DESCRIPTION

Developing this biofertilizer

Isolation and purification of bacterial strain: For developing this biofertilizer nodules were collected from groundnut plant. Nodules were surface sterilized through washing in running tap water then with distilled water in a wide mouth vial for 5-6 times so that no soil particle was on nodule surface. Then nodules were dipped in to 70% ethyl alcohol solution for 30 seconds. Later washed for 1 minute with mixture solution of 70 percent ethanol solution and 3% hydrogen peroxide solution at 1:1 ratio by volume. After these nodules were cut down at surface with a scalpel blade. Pink coloured nodule sap was taken with inoculation needle and streaked on

congored yeast mannitol agar (CRYEMA) plate and incubated in incubator (28^0C) for 7-10 days till well grown iscrete colonies appeared. Colonies typical with Bradyrhizobium were selected and restreamed on CRYEMA thrice for purification of strains.

Microscopic observation: Purified bacterial cultures (Strains) were tested for cell shape under microscope.

Salinity tolerance: Salinity tolerance was tested using different concentration of salt containing YEMA plate and growth was observed in incubator for 10 days.

Biochemical test: Indole acetic acid production- Indole acetic acid production was observed by growing bacterial cultures in yeast mannitol broth containing tryptophan and ammonium nitrate.

Pot experiment: Pot experiment was done for studying nodule formation, nitrogen fixation, plant growth and yield in pot.

Field experiment: Field experiments were done in Gazipur and Cox'sBazar location to observe nodule formation, nitrogen fixation, plant growth, nut yield due to inoculation of rhizobial biofertilizer.

Application rate of biofertilizer: Biofertilizer is used @ 40-50 g/kg seed. There is no harm if used more than this rate.

APPLICATION METHOD OF BIOFERTILIZER

Bio-fertilizers are usually used in combination with seeds. This fertilizer takes more when applied to the soil. The surface of the seed is first glued by mixing any sticky substance like chitagur or cold rice starch with the seed. Then 40-50 gm of bio-fertilizer per kg of seed should be well mixed with the seed, so that a black coating is formed on the surface of each seed, as a result the seed is known to have a large number of micro-organisms attached to it and will help in nodule formation. The seeds mixed with this bio-fertilizers should be sown in rows in the ground in a slightly 3/4 cm pitted trance and the trance should be filled with soil. In case of broadcast sowing, a ladder should be provided, so that the seed goes under the soil. The best time for sowing seeds mixed with micro-fertilizers is in the morning or afternoon.

Yield increases due to biodertilizer application: Increases 40-45% groundnut yield through application of biofertilizer.

Precautions in collection, transportation and storage of biofertilizer

- This biofertilizer cannot be used other than groundnut.
- Expiry date written on packet to be seen as no good effect got by using biofertilizer after expiry date.
- At the time of transportation biofertilizer should keep not in direct sun light beside window.
- Biofertilzer should store in dry and cool place at house and shop.

SUITABLE LOCATION/ECOSYSTEM

This biofertilizer technology can be used instead of costly urea fertilizer in the soils of all over Bangladesh for maximizing yield of lentil as well as reduced production cost

BENEFITS OF THIS BIOFERTILIZER

- It fulfills the demand of Nitrogen fertilizer (Urea) for lentil cultivation.
- Enhances vegetative growth and yield of groundnut.
- Yield increment of 40-45 percent of groundnut.
- Needs less or no nitrogenous fertilizer in subsequent crop by using this biofertilizer.
- It increases soil fertility through decomposing leaves, nodules and other plant parts of groundnut.
- It is environmentally friendly.

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Groudnut field, Cox's bazar

Grounnut field, Joydebpur

Groundnut pot experiment at Joydebpur

Groundnut field, Cox's bazar

Fig. 77. Pot and Field experiment of BARI-Chinabadam-8

ii.) Effectiveness in Policy Support (if applicable): Needed production and distribution of the developed biofertilizer to farmers.

BRRI Component

i. **Technology Fact Sheet (title, introduction, description, suitable location/ecosystem, benefits, name and contact address of author):**

Not applicable

ii. **Effectiveness in policy Support (if any):** Need Field trials of the developed biofertilizers

BINA Component

i) **Technology Fact Sheet (title, introduction, description, suitable location/ecosystem, benefits, name and contact address of author):**

SALINITY TOLERANT BIOFERTILIZER FOR SOYBEN CULTIVATION IN SALINE AREAS

INTRODUCTION

As soybean is high nitrogen fixing and soil fertility increasing crop. It increases soil fertility through dropping leaves and nodules in non-saline as well as saline areas. By using salinity tolerant biofertilizer soybean production can be increased and saline areas will come up under soybean cultivation. With this view in mind this biofertilizer was developed.

DESCRIPTION

Developing this biofertilizer

Isolation and purification of bacterial strain: For developing this biofertilizer nodules were collected from soybean plant grown in Satkhira and Noakhali. Nodules were surface sterilized through washing in running tap water then with distilled water in a wide mouth vial for 5-6 times so that no soil particle was on nodule surface. Then nodules were dipped in to 70% ethyl alcohol solution for 30 seconds. Later washed for 1 minute with mixture solution of 70 percent ethanol solution and 3% hydrogen peroxide solution at 1:1 ratio by volume. After these nodules were cut down at surface with a scalpel blade. Pink coloured nodule sap was taken with inoculation needle and streaked on congored yeast mannitol agar (CRYEMA) plate and incubated in incubator (28^0C) for 7-10 days till well grown discrete colonies appeared. Colonies typical with Bradyrhizobium were selected and restreaked on CRYEMA thrice for purification of strains.

Microscopic observation: Purified bacterial cultures (Strains) were tested for cell shape under microscope.

Salinity tolerance: Salinity tolerance was tested using different concentration of salt containing YEMA plate and growth was observed in incubator for 10 days.

Biochemical test: Indole acetic acid production- Indole acetic acid production was observed by growing bacterial cultures in yeast mannitol broth containing tryptophan and ammonium nitrate.

Phosphate solubilization: Phosphate solubilation was observed through growing bacteria on Pikovskaya agar plate.

Pot experiment: Pot experiment was done for studying nodule formation, nitrogen fixation, plant growth and yield in pot condition in glass house.

Field experiment: Field experiments were done in different locations of saline areas like Satkhira and Noakhali to observe nodule formation, nitrogen fixation, plant growth, grain yield and organic matter increment in soil due to inoculation of salinity tolerant rhizobial biofertilizer.

Application rate of biofertilizer: Biofertilizer is used @ 40-50 g/kg seed. There is no harm if used more than this rate.

APPLICATION METHOD OF BIOFERTILIZER

- An adequate amount of healthy, fresh and dry seeds to be taken in a bowl or bucket or polythene bag. A 20-25 gram of molasses to be mixed with each kg seed in such a way that reddish brown molasses coating is created on each seed surface.
- This molasses coated seeds to be mixed with 50g biofertilizer so that a blakhk coat is created on seed surface.
- Inoculant coated seeds should be sown in field as early as possible. If late then procedure should follow mentioned above.
- Inoculant coated should sow before 9 am and after 4 pm in summer season. But it can be sown day long in winter.
- If seeds are applied with pesticides, then seeds should be washed with water and them

seed should be dried in sun light and then biofertilizer to be used with seed as per procedure mentioned.

Yield increases due to biodertilizer application: Increases 40-70% soybean yield through application of salinity tolerant biofertilizer in saline areas.

Precautions in collection, transportation and storage of biofertilizer

- This biofertilizer cannot be used other than soybean crop.
- Expiry date written on packet to be seen as no good effect got by using biofertilizer after expiry date.
- At the time of transportation biofertilizer should keep not in direct sun light beside window.
- Biofertilzer should store in dry and cool plakhe at house and shop.

SUITABLE LOCATION/ECOSYSTEM

This biofertilizer can be used in Coastal saline areas of country (Satkhira, Khulna, Bagerhat, Noakhali, Chattogram, Cox's Bazar etc. districts) and all over the country.

BENEFITS OF THIS BIOFERTILIZER

- It fulfills the demand of Nitrogen fertilizer (Urea) for soybean cultivation.
- Enhances vegetative growth and yield in saline soil and increase seed quality of soybean.
- Yield increment of 40-70 percent of soybean in saline areas.
- Needs less nitrogenous fertilizer in subsequent crop by using this biofertilizer.
- This biofertilizer can tolerate 8-10 ds/m salinity.
- It increases soil fertility through decomposing leaves, nodules and other plant parts of soybean.
- It is environmentally friendly.

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ii) **Effectiveness in Policy Support (if applicable):** Needed production and distribution of the developed biofertilizer to farmers.

BSRI Component

i) **Technology Fact Sheet (title, introduction, description, suitable location/ecosystem, benefits, name and contact address of author):**

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. Constraints for pulse and oilseed legume production in saline and drought prone soil will be removed.

b. Famer's income will be increased.

c. Employment generation will be increased.

ii. Generation of new knowledge that help in developing more technology in future

Two technologies are developed conducting field experiment on two major pulse and oilseed crop of Lentil and Groundnut. It needs to develop new biofertilizer technology for other pulse and oilseed legume crop.

iii. Technology transferred that help increased agricultural productivity and farmers' income

Two technologies are developed for temperate and saline soil conducting field experiment in two districts (Cox's Bzar and Pabna). Dissemination of the developed technologies are needed for other districts belonging acidic soil, drought prone soil and saline soil.

iv. Policy support

- Biofertilizer need to promote for crop production along with chemical fertilizers.
- Biofertilizer need to be subsidized like Urea, Triple Super Phosphate and Muriate of Potash.
- By Biofertilizer produced crops need higher price for sale

BRRI Component

i. **Immediate impact on generated technology (commodity &non-commodity):**

'Bio-coated urea' and 'Bio-coated TSP' fertilizer developed to increase P fertilizer use efficiency and improve rice growth and yield in the saline and acid soil respectively, However, invented technology need field verification.

ii. **Generation of new knowledge that help in developing more technology in future**

Soil biology, soil texture, soil pH and soil organic matter content assessed in AEZ-
10, AEZ-11, AEZ-13, AEZ-15, AEZ-16, AEZ-19, AEZ-22 and AEZ-27. Based on these informations:

- Soil health determined and can be improved for sustainable crop production.
- Potentiality of the indigenous bacteria such as free living N_2 fixing, P solubilizing and indoleacetic acid producing capability determined from each tested AEZ.
- Potential and dominant strain were identified form each AEZ soil

- Bio-coated urea and Bio-coated TSP fertilizer developed using isolated potential strain for saline and acid soil respectively.
- Based on the information of soil biology of other AEZ's more environmental friendly biofertlizer can be developed

iii. **Technology transferred that help increased agricultural productivity and farmers' income: '**Bio-coated urea' and 'Bio-coated TSP'

iv. **Policy Support**

Need policy support for in-depth study of soil biology and biodiversity to maintain soil health. Results of the present study proved that on an average, the population of free-living N_2 fixing, phosphate solubilizing and indoleacitic acid producing bacteria were low. To booster population of beneficial bacteria and higher crop productivity, biofertilizer application is essential.

BINA Component

i. Immediate impact on generated technology (commodity & non-commodity)
Biofertilizer developed for saline areas to increase soybean yield in saline areas and improve soil health.

ii. Generation of new knowledge that help in developing more technology in future Soil biology, soil texture, soil pH and soil organic matter content assessed in AEZ-3, AEZ-7, AEZ-9, AEZ-12, AEZ-14, AEZ-17, AEZ-25 and AEZ-26.

Based on these informations:

- Soil health determined and can be improved for sustainable crop production.
- Based on the information of soil biology of other AEZ's more environmental friendly biofertlizer can be developed.

iii. Technology transferred that help increased agricultural productivity and farmers' income

'Salinity tolerant biofertilizer for soybean production in saline areas.

iv. Policy Support

Need policy support for in-depth study of soil biology and biodiversity to maintain soil health. Results of the present study proved that on an average, the population of free-living N_2 fixing and phosphate solubilizing bacteria were low. To boost up population of beneficial bacteria and higher crop productivity, biofertilizer application is essential.

BSRI Component

i. **Immediate impact on generated technology (commodity & non-commodity)**
ii. **Generation of new knowledge that help in developing more technology in future**
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 (Lab visit)	A technical team head by Dr. Monowar Karim Khan, Coordinator, visited project activities on 17th December 2020. He visited Microbial analysis, Population data and procurement. A brief presentation was given that time. He was satisfied with the activities
2. Coordination meeting 7th July 2021	A coordination meeting was held headed by coordinator of this project on 7th July 2021. Component wise progress of the laboratory analysis and field experimentation were presented that time. A fruitful discussion was made during this meeting.
3. Coordination meeting 13th September 2021	A coordination meeting was held headed by coordinator of this project on 13th September 2021. Component wise 2nd Annual progress of the project activities were presented that time. A fruitful discussion was made during this meeting.
4.Coordination meeting 26th May 2022	A coordination meeting was held headed by coordinator of this project on 26th May 2022. Component wise progress of the PCR preparation were presented that time. A fruitful discussion was made during this meeting.
5. Inception workshop (29 November, 2019)	Inception workshop held on 29 November, 2019. Brief presentation about objectives, methodology and work plan were discussed in the meeting in presence of prominent soil scientist
6.Annual review workshop (Year 2020)	Annual progress workshop held on 29th September, 2020. Progress of microbial population status of collected soil sample presented at BARC

i) Field Monitoring (date& no. of visit, name and addresses of team visit and output):

Field Monitoring	Name and addresses of team visit and output
1. Monitoring and evaluation by PIU-BARC, NATP-2	A Monitoring team of PIU-BARC, NATP-2 visited project activities on 24th April 2022. The team visited field experiment and prepared video documentation A brief presentation was given that time. The team was satisfied with the activities.
2. Monitoring by CSO, Soil Science Division BARI	A team headed by D. Habib Mohammad Naser, CSO and Head, Soil Science Division, BARI visited project activities on 26th February 2022. The team visited field experiment and prepared video documentation A brief description was given that time. The team was satisfied with the project activities.

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 6th August, 2021. The team visited experiments analytical 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 10th February 2022. The team visited experiments, Laboratory 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 in 4th June 2022 in presence of Director Research 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.
4. Inception workshop (year 2019)	Inception workshop held on 26th December, 2019 at BARC
5.Annual review workshop (Year 2021)	Annual progress workshop held on 24th November, 2021. Progress presented at BARC
6.Annual review workshop (Year 2022)	Annual progress workshop held on 25th May, 2021. Progress presented at BARC (Plenary meeting)

ii. **Field Monitoring:** 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.):

Meeting type	Description & output of consultation meeting
1. Coordination meeting 7th July 2021	A coordination meeting was held headed by coordinator of this project on 7th July 2021. Components wise progress was presented in the meeting. A fruitful discussion was made during this meeting.
2. Coordination meeting 13th September 2021	A coordination meeting was held headed by coordinator of this project on 13th September 2021. Component wise 2nd Annual progress of the project activities were presented that time. A fruitful discussion was made during this meeting.
3.Coordination meeting 26th May 2022	A coordination meeting was held headed by coordinator of this project on 26th May 2022. Components wise progress of the PCR preparation was presented that time. A fruitful discussion was made during this meeting.
4. Inception workshop (29 November, 2019)	Inception workshop held on 29 November, 2019. Brief presentation about objectives, methodology and work plan were discussed in the meeting in presence of prominent soil scientist.

5..Annual review workshop (Year 2020)	Annual progress workshop held on 29th September, 2020. Progress of microbial population status of collected soil sample presented at BARC

ii. Field Monitoring (date& no. of visit, name and addresses of team visit and output):

iii. Weather data, flood/salinity/drought level (if applicable) and natural calamities:

BSRI Component

i. **Desk Monitoring [description & output of consultation meeting, monitoring workshops/seminars etc.)**

Desk monitoring:

Meeting type	Description & output of consultation meeting
1. Coordination meeting 7th July 2021	A coordination meeting was held headed by coordinator of this project on 7th July 2021. Components wise progress was presented that time. A fruitful discussion was made during this meeting.
2. Coordination meeting 13th September 2021	A coordination meeting was held headed by coordinator of this project on 13th September 2021. Component wise 2nd Annual progress of the project activities were presented that time. A fruitful discussion was made during this meeting.
3.Coordination meeting 26th May 2022	A coordination meeting was held headed by coordinator of this project on 26th May 2022. Components wise progress of the PCR preparation was presented that time. A fruitful discussion was made during this meeting.
4. Inception workshop (29 November, 2019)	Inception workshop held on 29 November, 2019. Brief presentation about objectives, methodology and work plan were discussed in the meeting in presence of prominent soil scientist
5. Annual review workshop (Year 2020)	Annual progress workshop held on 29th September, 2020. Progress of microbial population status of collected soil sample presented at BARC

ii. **Field Monitoring (date & no. of visit, name and addresses of team visit and output)**

iii. **Weather data, flood/salinity/drought level (if applicable) and natural calamities**

J. Sub-project auditing (covers all types of audit performed):

Types of Audits	Major observation/ issues/ objections raised; if any	Amount of Audit (Tk.)	Status at the sub-project end	Remarks
BARC Component				
FAPAD Audit	No objection	588070	Satisfactory	-
FAPAD Audit	No objection	1782873	Satisfactory	-
FAPAD Audit	No objection	1159852	Satisfactory	-
BARI Component				
2.11.2020 (FAFAD)	No objection	2453280	Satisfactory	
24.10.2021(FAFAD)	No objection	3868115	Satisfactory	

Types of Audits	Major observation/ issues/ objections raised; if any	Amount of Audit (Tk.)	Status at the sub-project end	Remarks
13.02.2022 (MI Chowdhury & Co.)	No objection	3868115	Satisfactory	
BRRI Component				
FAFAD 30/10/19 to 30/6/2020	No objection	690389	Satisfactory	No objection
FAFAD 01/07/2020 to 30/6/2021	No objection	2189717	Satisfactory	No objection
BINA Component				
FAPAD	No objection	1837930	Satisfactory	-
FAPAD	No objection	1816038	Satisfactory	-
BSRI Component				
FAPAD	No objection	1152550	Satisfactory	-
FAPAD	No objection	1087720	Satisfactory	-

K. Lessons Learned:

Components (Implementation)

BARI:

i) Selected farmers are not cooperative. So before conducting project activity one has to be cautious about farmer selection.

ii) Farmer of coastal 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 famers having smart phone.

iii) Site of field experiment in saline and temparate region 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.

BRRI:

i. Soil biology of AEZ-10, AEZ-11, AEZ-13, AEZ-15, AEZ-16, AEZ-19, AEZ-22 and AEZ-27.
ii. Soil texture, soil organic matter and total nitrogen content of the tested AEZ's
iii. Capability of N_2 fixation, P solubilization and Indoleacitic acid production of the indigenous bacteria were determined
iv. Benefits of 'Bio-coated urea' and 'Bio-coated TSP' biofertilizer for rice production.

BINA:

i. Soil biology of AEZ-3, AEZ-7, AEZ-9, AEZ-12, AEZ-14, AEZ-17, AEZ-25 and AEZ-26.
ii. Soil texture, soil organic matter and total nitrogen content of the tested AEZ's
iii. Benefits of Salinity tolerant biofertilizer for soybean production in saline areas.

BSRI:

i) Status of beneficial microorganisms of different AEZs
ii) Developed and studied of Nitrogenous biofertilizers
iii) Institutional capacity of all component's

L. Challenges (if any):

Component (All)

- Natural problems especially salinity and high temparature are major challenges for field trial conduction. Pandemic disease COVID-19 hampered the frequent visit of scientists in the experimental field. Crop production 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 these problem soil area. More training and media coverage are needed to popularize these technologies.
- Need to increase soil organic matter and replenish population of beneficial bacteria such as Free-living N_2 fixing, Rhizobium, Phosphate solubilizing bacteria, and Indoleacetic acid producing bacteria to booster rice yield.
- Need to increase soil organic matter and replenish population of beneficial bacteria such as Free-living N_2 fixing, Rhizobium and Phosphate solubilizing bacteria to boost up crop production.
- COVID 19 hampered regular activities

M. Suggestions for future planning (if any):

Components (All)

- 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.
- Research facility of existing research stations of these area should be strengthening.
- Need to increase population of free living N_2 fixing, phosphate solubilizing and indoleacetic acid producing bacteria by applying biofertilizer and increasing soil organic matter.
- Need to increase population of free living N_2 fixing, Rhizobium/Bradyrhizobium and phosphate solubilizing bacteria by applying biofertilizer and increasing soil organic matter. Biofertilizer to be used for production of soybean in saline areas.
- These were the partial work among four components. The results of beneficial microorganisms would not be reflected the status of beneficial microorganisms for the whole country. If it has any scope, the project should be continued.

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