CONSERVATION AGRICULTURE includes minimum tillage, previous crop residue retention and crop rotation. Minimum tillage is the first option to establish crops. It is well established that crops other than rice can be grown under minimum tillage practices. CA based machinery are developed and operated in the different parts of the country to establish wheat, maize, pulses, etc. Now it is crucial to fit the CA technology in transplanted rice based cropping sequence. Dr AKM Saiful Islam has written a demand driven book. He strives hard to succinctly present the research findings on the application of conservation agriculture concept in rice farming systems in our soil type and agro-climatic condition. Dr Islam describes and analyses the establishment of various crops under minimum tillage, improvement of soil health and energy consumption pattern.The findings of the CA based investigation will be helpful to the researchers, academics, extension agents and policy makers to move forward the technology and to fit into rice based cropping systems.

BRRI

CONSERVATION AGRICULTURE IN RICE FARMING SYSTEMS

AKM Saiful Islam, *PhD*

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Content

Preface

Conservation agriculture (CA) based crop production technologies are of growing concern to the farmers as they save resources and improve soil health without sacrificing crop yield. CA technologies are proven in the establishment of the non-rice crops elsewhere in the world, whereas researchers are trying to accommodate these technologies in transplanted rice based cropping system. Rice-rice, rice-wheat and rice-maize are the major cereal based cropping sequence in Bangladesh and rice seedling are transplanted manually in puddled land, which requires lot of water, fuel, energy and time. Rice is water loving plants and non-rice crops need little or less water during crop cultivation. Land gets soft if rice is grown in puddled condition and difficult to grow next crop especially wheat. Soft land hinders the movement of seeder machine. The researchers are trying to fit the CA technologies in two opposite situations. There is a dearth on the CA related research books based on the soil type and agro-climatic condition of Bangladesh. The book summarizes the research findings of CA based activities and establishment of different crops under minimum tillage practices. It is divided into six chapters, which describe different CA methods, machinery development, field operation, possibilities of unpuddled rice establishment, soil health improvement and energy consumption. It also discusses the constraints in the establishment of crops under minimum tillage practices. The book has written based on the research results conducted in Bangladesh and some of the research findings published elsewhere in the world. The book will be useful to the readers to understand the CA practices and will serve as a reference to the policymakers, researchers and extension agents in the national and international arena. This book may also be helpful to academics and post-graduate students of the relevant fields. The readers are encouraged to provide opinion for further improvement of the book.

Foreword

Conservation Agriculture (CA) implies the judicial integration of minimum tillage, crop residue retention and crop rotation to get maximum benefit of sustainable agriculture. It is a well established technology in many countries for the crops other than rice. Ours is a country of agriculture dominating rice and we have, still, a few relevant technologies related to this crop. But we are sure that CA might be a good option for establishing transplanted rice in an eco-friendly sustainable agriculture. So we should have the practice in our country in our modern day agriculture. Scientists are in progress to revive the technology with some innovative ideas. That is why they are in progress to develop some tools and techniques very relevant a specific area. Some of the scientists from BRRI had a considerable works on CA. Dr AKM Saiful Islam, an Agricultural Engineer by profession, is one of them. I am glad to see that Dr Saiful has accumulated all the issues related to CA with respect to different agro-climatic conditions and soil types in a book. It is indeed a hard work and he deserves a bunch of felicitations from me.

I hope this would be a reference work for the scientists, academics and policy makers as well.

Dr Jiban Krishna Biswas
Director General, BRRI

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About the author

Dr AKM Saiful Islam was born in Savar, Dhaka in 1968. He passed SSC examination from Moyez Uddin High School, Faridpur in 1984 and secured first division. He passed HSC examination from Govt. Rajendra University College, Faridpur in 1986 and obtained first division. DrIslam graduated from the Department of Farm Power and Machinery, Bangladesh Agricultural University, Mymensingh and received chancellor award for achieving first position in graduate course. Dr Islam obtained MS degree from the same university in 1996. He completed postgraduate diploma course from Silsoe College, UK in 1997. The author obtained PhD in Agricultural Engineering from the Department of Farm Power and Machinery, Bangladesh Agricultural University, Mymensingh in 2012. He started his career as a Scientific Officer in Farm Machinery and Postharvest Technology Division of Bangladesh Rice Research Institute in 1998. Dr Islam has 40 scientific papers published in national and international journals. He got professional training from India, China and Japan. At present, he is working as a Principal Scientific Officer in the same division.

Acronyms and Abbreviations

2WT	Two wheel tractor
ACIAR	Austrian Center for Agricultural Research
Aman	Paddy/Rice cultivated in rainy season (July to November)
Aus	Paddy/Rice cultivated in Summer season (May to August)
BARC	Bangladesh Agricultural Research Council
BARI	Bangladesh Agricultural Research Institute
BAU	Bangladesh Agricultural University
BCR	Benefit cost ratio
Boro	Paddy/Rice cultivated in winter season (January to May)
BP	Bed planting
BRRI	Bangladesh Rice Research Institute
CA	Conservation agriculture
CIMMYT	International Maize and Wheat Improvement Centre
CR	Previous crop residue retention
CT	Conventional tillage
DAE	Department of Agricultural Extension
DAS	Days after seeding
DAT	Days after transplanting
DPDT	Double pass dry tillage
DSR	Direct seeded rice
GJ	Giga joule
HYV	High yielding variety
LSD	Least significant difference
m	Meter
MJ	Mega joule
mm	Millimeter
MoP	Muriate of potash
MPa	Mega Pascal
PR	Penetration resistance
Rabi	Crop cultivated in winter season (November-March)
SOC	Soil organic carbon
SOM	Soil organic matter
SPST	Single pass shallow tillage
SPWT	Single pass wet tillage
ST	Strip tillage
TSP	Triple super phosphate
VMP	Versatile multi-crop planter
ZT	Zero tillage

CHAPTER I

MACHINE DEVELOPMENT
Improvement of planter

Abstract

Suitable planting machine is one of the important factors for timely sowing and successful crop establishment. Versatile multi-crop planter (VMP) was modified to improve its performance for crop establishment during 2010. The development in VMP involved the replacement of round rotary tillage shaft with square shaft on which tynes can be flexibly attached at variable row spacing and tillage modes, replacement of press wheel with roller, option for appending vertical seed meter in addition to flute seeder meters and replacement of traditional hexagonal bolts with allen socket. The planter has very good options for closing the slit of strip and zero tillage seeding systems. Seed and fertilizer delivery was separated on the back of the furrow opener to minimize seed and fertilizer contact after placement. The spare parts are locally available and any kind of repair can be done at the village/upazila level. Locally made flute type (4, 8 and 16 flute) seed and fertilizer meters are available for seeding rice, wheat, lentil, chickpea, blackgram, mungbean, etc.; and also for applying non-hydroscopic fertilizers. Vertical seed metering device can be dispensed seed precisely in hill configuration. Chinese made Dongfeng or Sifeng models (12 HP) 2-WT have suitable hitching point to attach the planter.

Keywords: Furrow opener, seed meter, hill dispensing, press wheel, seedling emergence

Introduction

The application of machines to agricultural production has been one of the outstanding developments in the developed countries (Osunbitana *et al.*, 2005). Farm machinery plays an important role to reduce drudgery of farm work and sustain crop production at more economic levels. The use of two wheel tractors (2WT) has become widespread in Bangladesh, but originally used primarily for full rotary tillage. These are ideal for use in the small fields of the country and there are estimated to be about 7,00,000 2WT in Bangladesh (Rahman, 2015) and performed 80% of agricultural activities (Rashid, 2007) even though the average land holding size is only 0.05 ha (DAE, 2004). Light tillage implement like power tiller, prepare land swiftly and timely for the next crop. In Bangladesh, most of the agricultural implements are being used by the service providers. The land size is small and fragmented, cropping systems are diversified. Thus the owner/operators will get benefit if they are able to change the crop establishment options (zero/strip/bed planting). Different types of small holder CA machinery and resource conservation technologies have been developed and utilized in Bangladesh and other parts of the world (Johansen *et al.*, 2012). The International Maize and Wheat Improvement Centre (CIMMYT) introduced Chinese seeder in 1995 in Bangladesh. This seeder accomplished three operations i.e. tilling, seeding and leveling in a single pass operation. In Bangladesh, 70% of wheat growers grow wheat after harvesting monsoon rice. In conventional agriculture, land preparation takes about two weeks. With this seeder, timely sowing of wheat was possible (Miah Monayem *et al.*, 2010). If sowing of wheat after rice harvest was delayed, the yield of wheat was reduced by 1 to 1.5 per cent per day of late sowing (Hobbs and Mehta, 2003). At present, more than 1000 units of Chinese seeders are being used in Bangladesh (Johansen *et al.*, 2012). Roy *et al.*, (2004) studied Chinese seeder for sowing wheat immediately after harvesting the monsoon rice without prior tilling soil. It reduced the turnaround time between two crops and ensures timely sowing of seeds, which is very essential for wheat. Haque *et al.*, (2004) studied the performance of two wheel tractor (Dongfeng type) operated zero till seed and fertilizer drill attachment for cultivating wheat and maize. The effective field capacity of the machine was found to be 0.18 ha hr^{-1} for simultaneous seeding and fertilizer application. Planting cost of wheat and maize were 83 and 89% less than that of conventional method. Matin (2008) tested the power tiller operated inclined plate planter (IPP) for maize establishment in three districts of Bangladesh. The average field capacity was 0.19 ha hr^{-1} saving 32.8% total cost and 79.2% labor costs over conventional practice. Wohab (2010) developed power tiller operated combined tillage bed former and seeder to make bed, seed sowing, covering and soil compaction in single pass operation. The seeder can be calibrated for smaller seed rate (3 kg ha^{-1} for sesame to 120 kg ha^{-1} for wheat). Field capacity of 60, 70 and 120 cm bed formers were 0.11, 0.15 and 0.20 ha hr^{-1} respectively.

Most of the CA implements in Bangladesh performed single operation (like zero, strip tillage, bed planting or conventional tillage). Recently, versatile multi-crop planters (VMP) were developed with a provision to multiple crop establishment options including zero tillage, strip tillage, single pass shallow tillage on the flat together with bed planting (both new and permanent beds), and even conventional tillage, seeding and fertilizer application options (Haque *et al.*, 2011 and Haque *et al.*, 2016). It was the follow-up of past machinery of Bangladesh and beyond, those were used mostly for rice based cropping systems. In the first prototype, while incorporating different types of tillage mode in a single machine, some mechanical faults were detected during field testing of the machine. An extra gear box was needed to attach the machine with power tiller. It increased the total length of the machine and the turning radius. The machine was imbalanced due to being overweight. Operator faced difficulties to operate the machine due to excess weight. Tyne holder was fixed, so interchangeability of tillage tyne for different tillage practices (zero, strip and bed) was absent. The planter needed a thorough investigation to observe the performance for various crop establishments under different tillage options. Thus, the research program was undertaken to improve the planter for use in farmers' fields.

Materials and methods

The modification and field testing works were done in the research workshop and research farm, Farm Machinery and Postharvest Technology Division, Bangladesh Rice Research Institute, Gazipur and Alam engineering workshop, Dhaka during 2010.

Problems identification in the first version of planter The first version of planter was aimed at single pass shallow tillage (SPST) with a press wheel added for covering seeds in strip and zero tillage. Press wheels (Photo 1) caused excessive seed breakage in case of dry field condition or pushed seed deeper in case of wet soil condition. Extra gear box was needed to attach the machine with PT (Photo 2). It increased the length and weight of the machine consequently its turning radius. There was maneuverability problem due to imbalanced weight. Round rotary shaft was attached for SPST and conventional tillage. Tyne holder was fixed so interchangeability of tillage tyne for different tillage practices was difficult (Photo 3). Extra tyne holder was needed to adjust the row spacing based on agronomic requirement of the crop (Photo 4). Seed box was fitted with fluted type seed meters having 4, 8 and 16 flutes for continuous seeding (Photo 5).

Photo 1 Press wheels

Photo 2 Extra gear box

Photo 3 Round rotary shaft with fixed tyne holder

Photo 4 Square shaft for strip tillage and bed forming

Photo 5 Flute type seed meter

Description of planter The planter has the provision to use adjustable row spacing of crops for zero tillage (ZT), strip tillage (ST), single pass shallow tillage (SPST) and bed planting (BP) to apply seed and fertilizer in a single pass operation and even to use for conventional tillage. Rice, lentil, chickpea, wheat, blackgram, mungbean, maize and even small seed like jute, mustard can be seeded successfully by this seeder. Two types of seed metering facility, vertical seed metering device for hill dropping and flute type seed metering device for continuous seed placement were incorporated in the machine. Both Dongfeng and Sifeng models of 2WT have a suitable hitching point to attach the planter.

Toolbar frame Toolbar frame was constructed with locally available mild steel materials. Seed and fertilizer boxes are mounted on the toolbar frame.

Rotary shaft Round rotary shaft was covered by mild steel sheet with a clearance of 10 mm from the tip of the tyne. Eight brackets can be accommodated in the square shaft and maximum four tynes can be bolted in each bracket. Therefore, maximum 32 tynes can be attached to the rotary shaft. Adjustable tyne holder was used to change the tillage spacing for different crops.

Attachment of rotary blades The number of blades attached to the rotor shaft varied from eight to 32. The number of blades was decided considering the optimum width of seedbed needed for seeding and fertilizing.

Power transmission system The power transmission system was located on the left side of the planter. The rotary shaft was operated through a chain and gear mechanism. The power for the fertilizer meters came from the 2WT differential shaft, through a chain driven by a 19-teeth sprocket and was relayed to the seed meter shaft through a chain and sprocket. Seed and fertilizer meters can be disengaged from the power source by shifting a lever.

Seed and fertilizer box Seed and fertilizer box was made from the same MS sheet and has the same external dimensions as the seed box. Seed box was attached to a shaft of 1,120 mm long with 17 mm diameter and fertilizer box was attached to another shaft of 1,220 mm length with 16 mm diameter.

Seed and fertilizer delivery tube Seed and fertilizer delivery tubes were made of 27 mm diameter clear polypropylene pipe joined behind the furrow opener.

Furrow opener Furrow openers were made from 2 mm steel sheet with a round leading edge to help stubble clearance. The furrow opener had 63.5 mm width. Welded to the base of the furrow opener was a solid 5 mm wide knife point sharpened on its leading edge. Each of the furrow openers was attached on the toolbar by two U-clamps, bolts and plate.

Press roller A pressing roller 670 mm long and 127 mm diameter, made of 2 mm iron sheet, was attached behind the furrow openers by a pair of arms 560 mm long. The arms were made from iron with L= 460 mm and W= 40 mm with 9 mm thickness flat bars.

Bed shaping Bed shaping capability was added by bolting to each side of the pressing roller with two truncated cones (outer side 320 mm and inner side 140 mm diameter with 180 mm length) made from 2.0 mm iron sheet and set with a flat bar frame.

Depth control lever Depth control lever with 10 holes was attached at the rear of the planter to adjust the seeding depth and provide maximum clearance for transportation of the planter. The roller arms have 10 holes at the end attached to the main body of the planter and that can be selected to set seeding depth by shifting the roller upward and downward.

Specification of the planter Table 1 presents the specification of the planter.

Table 1 Specification of planter

Item	Specification
Length, mm	990
Width, mm	1220
Height, mm	840
Weight, kg	152
Rotor speed, rpm	
Speed	
High, rpm	250
Low, rpm	150
No. of strips	4
No. of tynes	32

Speed ratio Speed ratio of planter was calculated based on the following formula

$$\text{Speed ratio} = \frac{D_1}{D_2} = \frac{N_1}{N_2} \quad (1)$$

Where,

D_1 = diameter of the drive shaft, mm
N_1 = number of teeth of the drive shaft
D_2 = diameter of the driven shaft, mm
N_2 = number of teeth of the driven shaft

Tyne arrangement Figures 1-4 present the tyne arrangement of planter in BP, ST, SPST and ZT mode.

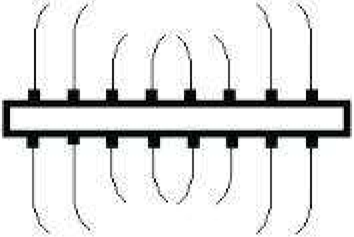


Fig. 1 Tyne arrangement of planter in BP mode

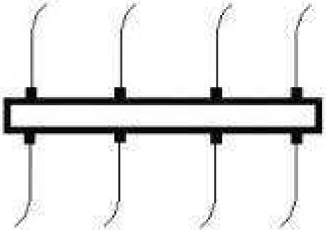


Fig. 2 Tyne arrangement of planter in ST mode

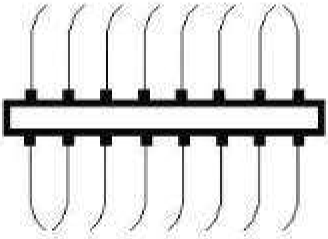


Fig. 3 Tyne arrangement of planter in SPST mode

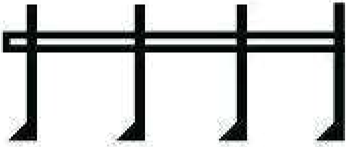


Fig. 4 Tyne arrangement of planter in ZT mode

Calibration of seeder Before seeding, flute type seed meters were calibrated for each treatment to get the recommended and uniform seed rate. In each trial, sample was collected from the seed dispensing tube in polythene bag from 10 revolution of drive wheel. Sample seeds were spread on a sheet to count the damaged seeds and taken weight. Uniform seed rate in each flute type seed meter was maintained by adjusting gap of seed meter. Seed adjusting level was placed in such a position so that the recommended rate is maintained. The seed rate of different types of seed for seeder machine was calculated using the following formula.

$$\text{Seed rate, kg ha}^{-1} = \frac{\text{Seeds obtained by 10 revolution of drive wheel, g}}{\text{Width of seeder, m} \times \text{Circumference of drive wheel, m}} \qquad (2)$$

Seedling emergence Seedling emergence was determined by daily counting the number of newly emerged seedlings in 1m length of row with three replications.

Results and discussion

The press wheels were replaced by a roller to cover and press the seed (Photo 6). The gear attachment system was modified by removing the extra gear box (Photo 7). Now, planter can be attached directly to the power tiller. The round rotary shaft was replaced by the square shaft with attachable brackets to clamp onto the shaft by two bolts to attach tynes(Photos 8 and 9). This permits rapid adjustment between tillage modes and row spacing. This was designed to minimize the time in changing shafts as well as reducing cost. Seed and fertilizer delivery was separated on the back of the furrow opener (Photo 10) to minimize seed and fertilizer contact after placement. Traditional hexagonal bolts were replaced with allen sockets for easy and quick adjustment of tillage tynes and other parts (Photo 11). Wheels of 2WT were replaced with try cycle wheels to make shorter width of bed and furrow (Photo 12).

Photo 6 Press roller

Photo 7 VMP attached without extra gear box

Photo 8 Square shaft

Photo 9 Tyne holder with bracket

Photo 10 Seed and fertilizer delivery line

Photo 11 Allen sockets

Photo 12 Try cycle wheel

Power transmission system

Figures 5 and 6 show the power transmission system of planter and Chinese seeder. Power comes from 2WT to VMP. Speed ratio of planter was compared with Chinese seeder and Table 2 presents the results. The planter had both high and low position to adjust the speed, whereas Chinese seeder is operated in single speed only. The Chinese seeder has higher speed ratio than VMP. The width of planter tillage was almost half of the Chinese seeder.

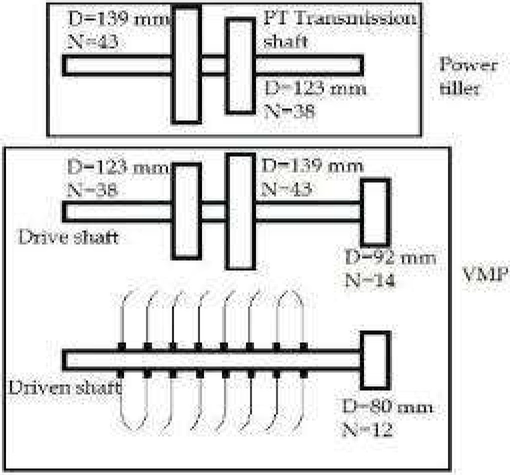


Fig. 5 Schematic diagram of the power transmission system of planter

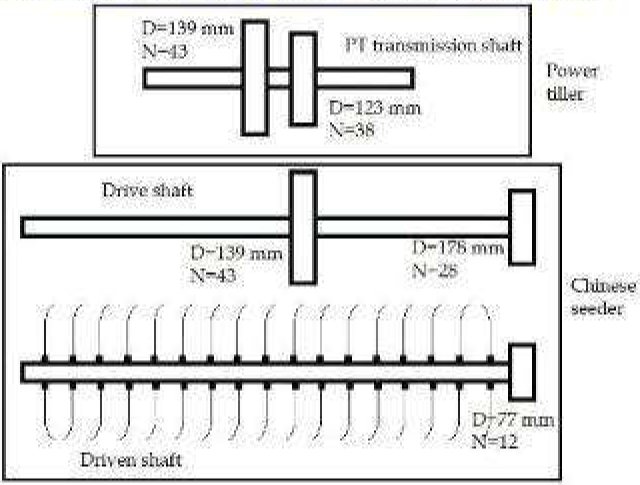


Fig. 6 Schematic diagram of the power transmission system of Chinese seeder

Table 2 Comparison of speed ratio in planter and Chinese seeder

Machine	Speed ratio		No. of tynes	Width, cm
	High	Low		
VMP	1.31	1.16	36	60-70
Chinese seeder	2.05		48	120

Seed box

The seed box has a volume of 12 litre. For chickpea, wheat, mungbean, blackgram, lentil and rice of 20, 14, 18, 18, 20 and 12 kg seed respectively can be filled up in the seed box for safe dispensing of seed (Table 3). Based on the seed rate of various crops, a 80% full seed box of chickpea, wheat, mungbean, blackgram, lentil and rice seed can cover 0.50, 0.16, 0.61, 0.61, 0.67 and 0.40 ha of land, respectively.

Table 3 Area coverage per full seed box of the planter with different seed sizes and seed rates

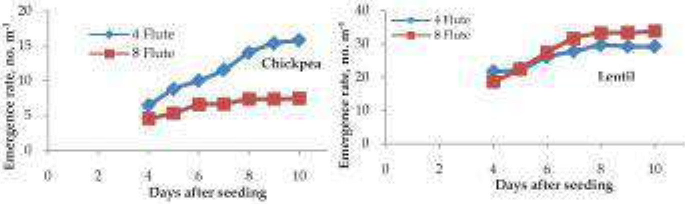
Species	Seed rate (kg/ha)	Capacity of seed box* (kg)	Area coverage per one fill of seed box (ha)
Chickpea	40	20	0.50
Wheat	120	19	0.16
Mungbean	30	18	0.61
Blackgram	30	18	0.61
Lentil	30	20	0.67
Rice	30	12	0.40

* Eighty percent of the seed box was filled with seeds to avoid spillage due to vibration

Seed meter test

Flute type seed meter

Flute type seed meter for four and eight flute was tested for chickpea, lentil, mungbean, rice and wheat sown in bed by planter (Fig. 7). The graph showed that four flute seed meter performed better in chickpea (Fig. 7a) as the seed size was bigger. Four flute and eight flute seed meters performed the same for lentil, mungbean, rice and wheat seeding.



(a) (b)

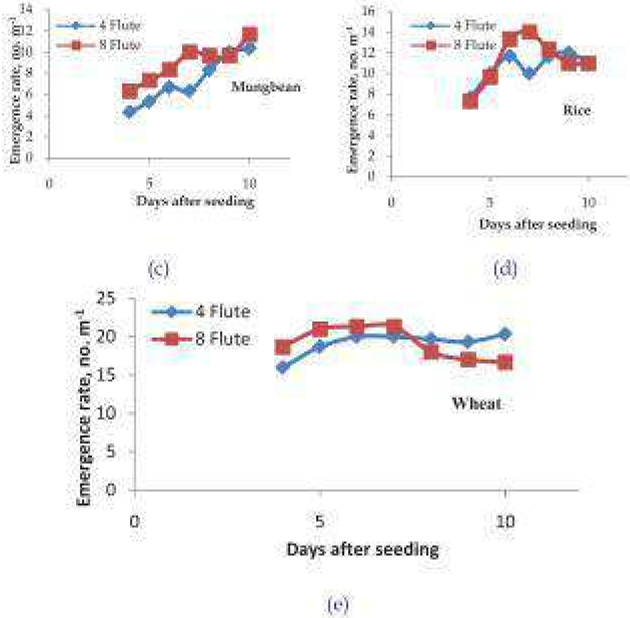


Fig. 7 Flute type seed meter test for seeding different crops

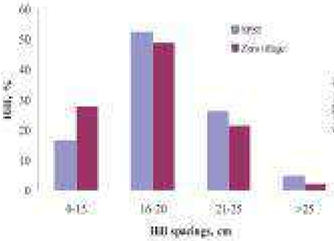
Vertical type seed meter

Hill spacing

Vertical seed metering device was tested to dispense rice seed in spaced hills (Fig. 8). Tillage treatments were taken as SPST and ZT. About 49-52 and 21-26% seeds were dispensed within 16-20 and 21-25 cm hill spacing, which satisfy the agronomic requirement of rice planting.

Seedling density per hill

Three seedlings per hill were emerged in 49-55% of hills (Fig. 9). Two to four seedlings per hill were emerged in 18-21% of hills. Single seedling was emerged in 2-16% of hills. The results indicated that vertical seed meter is suitable to dispense rice seed in hill configuration.



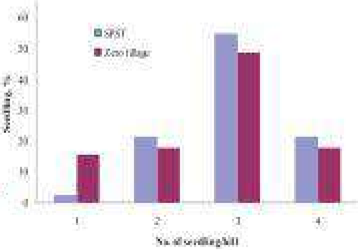


Fig. 8 Distribution of hill spacing of rice seed

Fig. 9 Percent rice seedling emergence per hill

Discussion

Planter can be attached directly to the power tiller without using extra gear. It reduced the length of machine and consequently decreased the turning radius. The square shaft with attachable brackets to clamp onto the shaft by two bolts to attach tynes permits rapid adjustment between tillage modes and row spacing. This was designed to minimize the time in changing shafts consequently reducing cost. Seed and fertilizer delivery was separated on the back of the furrow opener to minimize seed and fertilizer contact after placement. Close contact of seed and fertilizer creates toxicity, especially with soluble fertilizers (especially N, P or K fertilizers) on sandy or silty soils (Kabir *et al.*, 2010), but this depends on the rate of application, plant species and the soil moisture levels at sowing. Allen sockets helped for easy and quick adjustment of tillage tynes and other parts. In potato seeding, shorter width of bed and furrow can be made by adding try cycle wheels.

Speed ratio of Chinese seeder was higher than that of planter. Because of its higher speed ratio, Chinese seeder causes tremendous soil disturbance on the top soil in single pass operation. Hence, it cannot be treated as minimum tillage planter rather reduced tillage planter. Similar finding was observed by Johansen *et al.*, (2012). Four fluted seed meter performed better in chickpea as the seed size was bigger. Lentil, mungbean, rice and wheat seeding were suitable in eight flute seed meter due to smaller size of seed. Seed box with full capacity increased the weight of the machine and in addition seed can spill over the box due to vibration. Lid can help to avoid spill over grain. About 49-52% seeds were dispensed within 16-20, cm which satisfied the agronomic requirement of rice seeding. The results indicated that vertical seed meter was suitable to dispense seed in required space.

Conclusion

The VMP had limitations of press wheels, fixed tyne holder, extra gear box and close contact of seed and fertilizer delivery tubes. The problems were eliminated by removing press wheels, extra gear box and round rotary shaft. In addition, tri-cycle wheel was added for shorter bed width, vertical seed metering device for more precise seed placement, minimized seed and fertilizer contact through separating seed and fertilizer delivery systems, replacing hexagonal bolts with allen socket for easy and quick adjustment of tillage tynes and other parts and adding square shaft in place of round rotary shaft with flexible attachment of tyne for varying row spacing and tillage mode.

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CHAPTER II

MACHINE PERFORMANCE
Direct seeded rice in minimum tillage

Abstract

Proper placement of seed and fertilizer at desired depth is the prerequisite of planting machinery to create favorable environment of seedling establishment. This experiment was conducted in the farmer's field, high barind tract, Rajshahi to evaluate the performance of modified planter machine through establishing direct seeded rice during Aman and Aus season (2010) with four tillage treatments such as: (i) conventional tillage (CT) (ii) strip tillage (ST), (iii) bed formation (BP) and (iv) zero tillage (ZT). In later three treatments, seeding and fertilizer application was done simultaneously in a single pass operation by planter. Flute type seed metering device was tested to study the seed dispensing rate, placement of seed and fertilizers. Minimum tillage saved fuel consumption by almost 25-46%, and could represent a 27-48% cost saving in land preparation compared to CT. In addition to fuel savings, substantial time savings and additional benefits can be resulted. Seedling emergence was not affected by tillage options, which dictated that seeds were placed at proper depth. Seed meter worked well to dispense rice seed by maintaining actual seed rate. Seeds were not broken due to use of flute type seed metering device. Yield was not statistically significant under minimum tillage and CT. BP showed the lowest benefit-cost ratio due to higher input cost as well as gross margin was lower compared to other tillage treatment. Strip tillage performed better than the other two minimum tillage methods compared to conventional method. Planter reduced seeding time, saved fuel and labor costs compared to conventional method and helped timely sowing. Minimum tillage may be adapted to establish dry seeded rice in High Barind Tract.

Keywords: Fuel consumption, labor, seedling emergence, weeding, yield, cost

Introduction

Dry direct seeding has been the principal method of rice establishment since the 1950s in the developing countries (Pandey and Velasco, 2005). After harvesting Aman rice, lands dries at a faster rate leaving very short turnaround time for land preparation of the next Rabi crop. Reduced tillage practices can be useful after Aman rice harvest in areas of high water scarcity (Rashid and Islam, 2007). Rice seed can be broadcast after plowing, following only 150 mm of cumulative rainfall (Saleh and Bhuiyan, 1995). Earlier planted direct seeded rice (DSR) matures 1-2 weeks before transplanted rice, thus reducing the risk of terminal drought and allowing earlier planting of a following non-rice crop (Saleh *et. al.*, 2000). Kukal and Aggarwal (2002) mentioned that both direct seeding (viz. wet, dry or water seeding) and transplanting had similar yield. DSR offers several potential benefits as it uses less water with high efficiency, incurs low labor expenses and is conducive to mechanisation (Bhuiyan *et al.*, 1995). Despite these benefits, there are several constraints in DSR such as weed pressure, poor crop establishment, lodging and lower grain yield. Among them, poor seedling stand has been considered as the most important one due to bird damage, uneven sowing depth, seed soil contact, seed dryness and buoyance of seed. Farmers use a high seed rate because of poor plant stand and severe weed infestation in broadcast DSR fields (Pathinayake *et al.*, 1990). Timely line sowing i.e., sowing a week before the onset of monsoon rain may improve germination and plant stand of Aman rice (Kathiresan *et al.*, 1997). At present, 23% of rice is direct-seeded globally (Rao *et al.*, 2007).

Conventional tillage and hand broadcasting of seed is a laborious and time-consuming operation. Machine sowing permits crops to take advantage of residual moisture in crop fields. Rickman *et al.*, (1999) reported that crop lodging is a significant problem in dry seeded rice in Cambodia, particularly with traditional varieties with full conventional tillage systems but machine drilling of seeds could reduce lodging to less than 10%. Chinese engineers have developed a two-wheel tractor operated seeder that provides tillage, seeding and leveling in one operation (Hobbs *et al.*, 1997). The main components were shallow rotovator, six-row seeding system and soil compaction roller. Bell *et al.*, (1999) evaluated several commercial seeder systems for reduced and zero-tillage seeding of rice, including the Chinese seeder, and reported that rice seed flow was a problem for the tractor-mounted seeders. Many machines have been developed in rice-growing countries and international institutes suitable for DSR. For the small farm holders, the Versatile multi-crop planter (VMP) was developed to overcome some of the DSR constraints (Islam *et al.*, 2010 and Haque *et al.*, 2011). Residue management was difficult for the tyne based no tillage systems, as none of the seeders had trash cutters. Many of the seeders required a well-leveled and relatively clean surface to work properly. Crop establishment under minimum tillage practices are gaining attention throughout the world as it saves time in field preparation and reduces inputs. Therefore, the present study was undertaken to evaluate the performance of seed metering device and to evaluate the agronomic performance of direct seeded rice under line sowing by strip tillage, zero tillage, single pass shallow tillage and bed planting and fertilizer application in single pass operation using the planter.

Material and methods

This experiment was conducted in the farmer's field, Godagari, Rajshahi representing silty clay soil in High Barind Tract during Aus season (2010) and Aman season (2010). The treatments were (i) conventional tillage (CT), (ii) strip tillage (ST), (iii) bed planting (BP), (iv) zero tillage (ZT) and arranged in a randomized complete block (RCB) design with three replications. Table 1 presents the experimental characteristics. Before seeding, flute type seed meters were calibrated for each treatment to get the recommended and uniform seed rate. Seeds were poured into the hopper. In each trial, sample was collected from the seed dispensing tube in polythene bag from 10 revolution of drive wheel. Sample seeds were spread on a sheet to count the damaged seeds and taken weight. Uniform seed rate in each flute type seed meter was maintained by adjusting gap of seed meter. Seed adjusting level was placed in such a position to get recommended rate.

Table 1 Experimental characteristics to establish direct seeded rice

Season	Variety	Date of seeding	Date of harvesting
Aus	BRRI dhan42	24 April 2010	7 Aug 2010
Aman	BR11	17 June 2010	12 November 2010

Fuel consumption was measured by filling the fuel tank twice, before and after each operation. Refilled volume was the actual fuel consumption. In CT treatment, land was prepared with two passes tillage by 2WT followed by leveling. Seeds and fertilizer were hand broadcast in CT. In ST, BP and ZT method, land preparation, seeding and basal fertilizer application were done simultaneously in single pass operation by the planter. In BP, the width of bed and furrow were 38 cm (top) and 20 cm, respectively. Row to row spacing in CT, ST, BP and There 25, 20, 25 and 20 cm, respectively. The amount of human labor involved in each operation was investigated through field measurements. In Aus season, rice was grown after harvesting potato. Farmers usually use excess fertilizers in potato cultivation. Farmers did not apply basal or top dressed fertilizer after potato cultivation to grow Aus rice. In Aaman season, fertilizers were applied at 175, 80, 110, 100 and 10 kg ha^{-1} as urea, triple super phosphate (TSP), muriate of potash (MP), gypsum and zinc sulphate, respectively. In Aus season, land was irrigated at night and excess water was drained out in the morning due to high ambient temperature. Some crops were damaged due to high water temperature in Aus season. Subsequent irrigations were applied as and when required uniformly in all plots. In both the seasons, irrigation water was applied five times in all the plots. In Aman season, non-selective herbicide glyphosate was applied @ 7.5 l ha^{-1} one day before seeding in all the plots. In Aus season, pre-planting herbicide was not used and the weed infestation was severe in all plots. Hand weeding was done on 26 days after seeding (DAS) to keep the field weed free. During Aman season, weed infestation was less due to application of pre-planting herbicide. In addition, hand weeding was done twice at 35 and 60 DAS. Insecticide was not applied during Aus season. During Aman season, stem borer was controlled by a single application of diazinon 10G at vegetative stage. Number of tillers in the selected area was counted at each growth stage. Tiller mortality was calculated based on successive tiller count data as:

$$\text{Tiller mortality, \%} = \frac{(\text{Maximum number of tillers m}^{-2} - \text{No. of panicles m}^{-2})}{\text{Maximum number of tillers m}^{-2}} \times 100 \qquad (1)$$

Crop condition at maturity and panicle initiation stage in different tillage practices during Aus and Aman seasons are shown in photo 1 and 2. Grain yield was recorded from pre-selected 10 m^2 area and was adjusted to 14% moisture content. A simple economic analysis was done based on total production. Production cost included rental charge of the land and input cost. Price of the produce was collected from the local markets to compute total production cost, gross return, gross margin and benefit-cost ratio. Statistical analysis as a one way analysis of variance was done according to Gomez and Gomez (1984). Data were analysed by using statistical software Mstat-C. Means were compared with least significant difference (LSD) test.

Conventional tillage

Zero tillage

Strip tillage

Bed planting

Photo 1 Crop condition at maturity stage in Aus season

Conventional tillage

Zero tillage

Strip tillage

Bed planting

Photo 2 Crop condition at flowering stage in Aman season

Results

Fuel consumption

Fuel consumption varied significantly among the tillage options (Table 2). Fuel consumption was found to be the highest in CT due to two passes of tillage operation and the lowest was by ST, followed by ZT and BP. Strip tillage saved (25-46%) fuel in seeding operation compared with CT.

Labor requirement in land preparation and seeding

Tillage treatments showed significant differences in labor requirement for land preparation and seeding (Table 2). In both the seasons, CT showed the highest labor requirement in land preparation. Labor requirement in land preparation was at par between BP and ZT in Aus season, whereas in Aman season, it was similar in ST and ZT. Labor requirements for seed sowing by planter was decreased by 37-55% compared to hand broadcasting.

Land preparation and seeding cost

Tillage treatment showed significant effect on land preparation and seeding cost (Table 2). For both the seasons, land preparation cost was the highest in case of CT and the lowest in ST. ST incurred the lowest cost due to its single pass operation; seeding, fertilizing, and leveling simultaneously that decreased upto 27-48% cost compared to CT.

Weeding cost

Table 3 shows the weeding cost under different tillage options in Aus and Aman seasons. In Aus season, tillage options showed significant effect on weeding cost. Weeding cost was the highest in ST followed by CT, ZT and BP, respectively. In Aman season, tillage treatment showed insignificant effect on weeding cost.

Seedling emergence

Figures 1a and 1b show the emergence of seedling from direct seeded rice under different tillage options at 12-18 days after seeding (DAS). Similar seed rate was used in both the seasons. Seedlings started to emerge on 12 and 13 DAS in all tillage treatment during Aus and Aman season, respectively. Tillage treatments had no significant effect on seedling emergence at different DAS.

Table 2 Tillage effect on fuel consumption, labor requirement and cost in land preparation

Parameter	Treatment	Aus	Aman	Mean	% decrease relative to CT
Fuel consumption ($l\ ha^{-1}$)	CT	21	36	29	-
	ST	10	21	16	46
	BP	15	28	22	25
	ZT	12	24	18	37
	CV, %	11	14		
	$LSD_{0.05}$	3.2	7.6		
Labor requirement in land preparation and seeding (man-hr ha^{-1})	CT	25	48	37	-
	ST	15	18	17	55
	BP	20	26	23	37
	ZT	20	18	19	48
	CV, %	8.2	11.9		
	$LSD_{0.05}$	3.3	6.5		
Land preparation and seeding cost (Tk hr^{-1})	CT	1,629	2,975	2,302	-
	ST	921	1,468	1,195	48
	BP	1,303	2,050	1,677	27
	ZT	1,149	1,624	1,387	40
	CV, %	8.5	9.9		
	$LSD_{0.05}$	212.	401		

N.B. Values are the means of three replicates

Table 3 Weeding cost (Tk hr^{-1}) under different tillage options

Treatment	Aus	Aman	Mean	Percent change relative to CT
CT	6,889	1,329	4,109	
ST	8,556	1,340	4,948	-20
BP	6,167	1,306	3,737	9
ZT	6,722	1,315	4,019	2
CV (%)	1.34	19.8		
$LSD_{0.05}$	192	NS		

N.B. Values are the means of three replicates

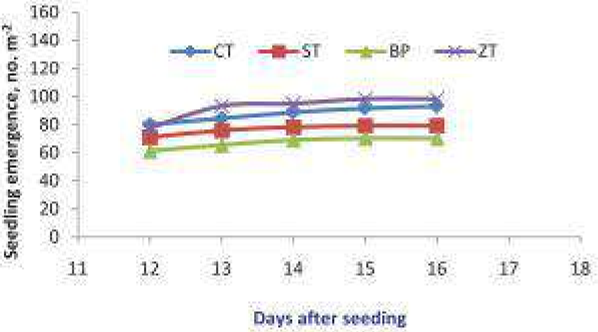

Fig. 1a Effect of tillage on seedling emergence of Aus rice

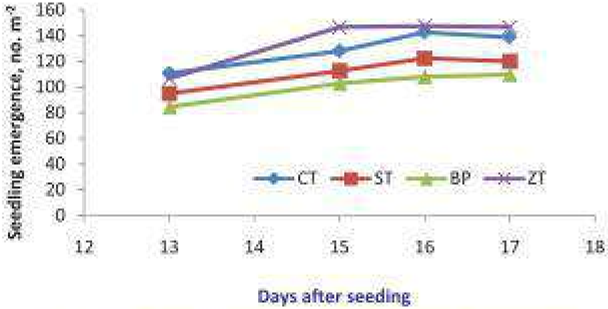

Fig. 1b Effect of tillage on seedling emergence of Aman rice

Tillering pattern

Figures 2a and 2b show the effect of tillage on tillering pattern of direct seeded rice. Tillage treatment significantly influenced the plant population throughout the crop cycle in both the seasons except at the maturity stage in Aus season. In both the seasons, CT produced 10-40% more tillers than the other treatments. At maturity stage, tillage options showed significant effect on tiller production in Aus season. However, tillage options did not show significant effect on tiller production in Aman season (Table 4).

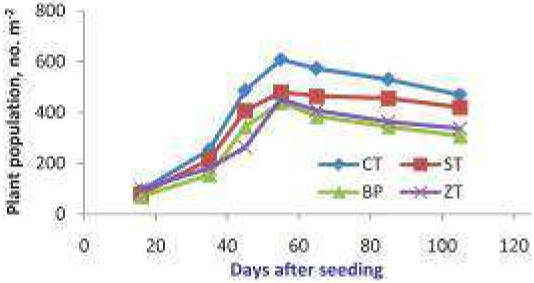

Fig. 2a Effect of tillage on tiller production of Aus rice

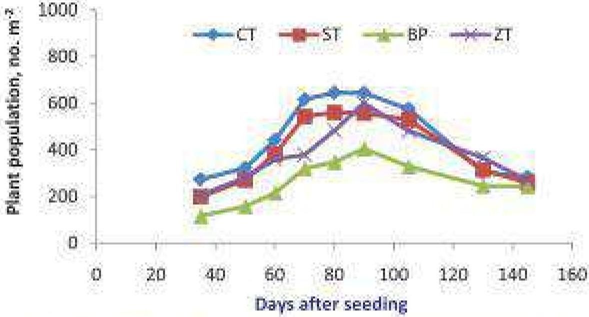

Fig. 2b Effect of tillage on tiller production of Aman rice

Panicle density

Table 4 shows the panicle density as influenced by tillage method in Aus and Aman seasons. Tillage treatments showed insignificant effect on panicle density and CT produced maximum number of panicles in both the seasons. In Aus season, although tillage treatment showed significant effect on plant population at maturity stage, panicle intensity was not affected due to variation in the number of non-bearing tillers. The lowest number of panicles was observed in BP (292 m^{-2}) and ST (219 m^{-2}) in Aus and Aman season, respectively.

Table 4 Yield contributing character of direct seeded rice

Treatment	Number of tiller (m^{-2})		Number of panicle (m^{-2})	
	Aus	Aman	Aus	Aman
CT	469	283	345	260
ST	420	258	334	219
BP	308	243	292	221
ZT	338	268	315	238
CV (%)	12.7	17.2	13.8	20.5
$LSD_{0.05}$	97	NS	NS	NS

N.B. Values are the means of three replicates

Grain yield

Table 5 shows the grain and straw yield of direct seeded rice in Aus and Aman season. During both the seasons, rice and straw yield were similar across all treatments. In Aus season, the highest grain yield was in CT followed by ST, ZT and BP. In Aman season, the highest grain yield was obtained in ST, ZT, CT and BP. Minimum tillage had no effect on rice yields in either season.

Table 5 Grain and straw yield

Treatment	Grain yield (t ha^{-1})		Straw yield (t ha^{-1})	
	Aus	Aman	Aus	Aman
CT	3.12	3.35	3.37	3.62
ST	3.03	3.65	3.03	3.77
BP	2.46	2.86	2.79	2.83
ZT	2.67	3.46	2.59	3.61
CV(%)	17.4	9.3	33.8	13.2
$LSD_{0.05}$	NS	NS	NS	NS

N.B. Values are the means of three replicates

Economic analysis

Table 6 includes all inputs (fuel, labor, machine rental charge and other expenses) from land preparation to harvesting operation including transportation. Same amount of seed (30 kg ha^{-1}), and irrigation water was applied in all the plots. Tillage treatment showed significant effect on input cost but no significant effect on gross return, gross margin and benefit cost ratio (BCR) in both the seasons. In Aus season, gross margin was the highest in CT and the lowest in BP. Minimum tillage indicated the low gross margin compared to CT. Grain yield was higher in CT in Aus season whereas higher in ST in Aman season, which led to increase gross return. In Aman season, gross margin was the highest in ST and the lowest in BP. BCR was the highest in CT and ST in Aus and Aman season, respectively. BCR was the lowest in BP in both the seasons.

Table 6 Economic productivity of direct seeded rice as affected by tillage options

Tillage option	Aus				Aman			
	Input cost (Tk ha^{-1})	Gross return (Tk ha^{-1})	Gross margin (Tk ha^{-1})	BCR	Input cost (Tk ha^{-1})	Gross return (Tk ha^{-1})	Gross margin (Tk ha^{-1})	BCR
CT	37,980	56,973	18,994	1.50	51,940	61,059	9,119	1.18
ST	38,680	54,568	15,884	1.41	49,560	66,075	16,512	1.33
BP	36,900	45,324	8,420	1.23	49,720	51,369	1,644	1.03
ZT	37,310	47,785	10,477	1.28	49,460	62,665	13,202	1.27

N.B. Values are the means of three replicates

Discussion

Fuel consumption was influenced by a number of factors including equipment type, operation speed, tillage depth, soil type, crop residue levels, soil moisture content, field shape and the number of tillage operations. Fuel consumption was higher in Aman than Aus season, because Aus rice was sown after harvesting potato and the soil was loosened; whereas in Aman season the soil surface was harder. The lowest fuel consumption in case of ST, compared to ZT may be due to negative draft and comparatively higher field capacity. Strip tillage saved 25-46% fuel compared to CT. Similar result was obtained by Hossain *et al.*, (2005). Fuel consumption was the highest in BP among the minimum tillage practices due to use of 24 tynes to till and throw the soil inward for bed formation indicating that more energy was needed to accomplish the task of bed shaping. The highest cost in CT was due to more tillage and hand broadcast seed and fertilizers, which increased the fuel and labor requirement. ST was the highest cost saving tillage technology for DSR establishment. Weed infestation is a common problem in direct seeding of rice ,which results in lower grain yield (Singh *et al.*, 2011). Weeding cost was lower in Aman season than Aus season due to application of herbicide before seeding. There are many pre and post emergence herbicides available in the market (Komatsubara *et al.*, 2009; Zahan *et al.*, 2014). Proper selection and application of herbicide at right time and right dose effectively control weed. Irrespective of the tillage treatment, tillering pattern followed increasing trend upto 55 and 95 DAS in Aus and Aman seasons, respectively and then it decreased gradually due to tiller mortality and leaf senescence. The yield attributes of rice crop showed that panicle intensity was higher in CT than the other treatment but the compensating behavior of various yield components such as 1000-grain weight, grain weight per panicle, or number of spikelets per panicle etc resulted in similar grain yields for different tillage options in both the seasons.

The number of passes and operation charges in terms of fuel consumption and task time were different in tillage options. In Aus season, ST showed the highest input costs, which was due to more weed infestation although it saved fuel, time and labor consumption in seeding operation. Grain yield was higher in CT and ST in Aus and Aman season, respectively which led to increase gross return. The insignificant difference in gross margins among the treatments could not be explained on the difference in their yields only as the net returns are affected by variable cost also. Minimum tillage indicated the low gross margin compared to CT. The gross margin for CT was the highest due to the highest gross return compared with other tillage systems. In Aus season, BCR was higher in all the tillage treatment as fertilizer was not applied in the field. Malhi *et al.*, (1988) and Hoffman *et al.*, (1999) reported that net economic returns were lower and little or no yield advantage for reduced tillage. This study also reflected the same trend. Profitability of establishing direct seeded rice in ST was higher than that of planting seeds in CT. Direct seeded rice established in BP was less profitable in high barind tract.

Limitation

- Machine vibration creates uneven seed dispensing
- Seedloss occurred during headland turning
- Seed was not covered properly due to undulated land

Conclusion

Seeds were not broken due to use of flute type seed metering device. Planter reduced seeding time, saved fuel and labor costs compared to conventional method. Yields were not significantly different under minimum tillage and CT. BP showed the lowest benefit-cost ratio compared to other tillage treatments. Strip tillage performed better than the other two minimum tillage methods compared to conventional method. Minimum tillage ensured the timeliness of operation in seeding operation. ST may be adapted to establish dry seeded rice in high barind tract.

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Planter for cereals and pulses

Abstract

Minimum tillage planting machinery is needed for successful adoption of conservation tillage. Five tillage methods namely conventional tillage (CT), single pass shallow tillage (SPST),zero tillage (ZT),bed planting (BP) and strip tillage (ST) were compared to study the performance and economics of planting machine in establishing pulse and wheat in High Barind Tract, Godagari, Rajshahi. Vertical seed metering device was used to assess the seed dispensing rate. The fuel consumption for tillage operation in minimum tillage especially SPST, ZT, BP and ST accounted for less than 15-48% compared to CT. Labor requirement in land preparation was significantly reduced in pulse and wheat cultivation under minimum tillage. The highest labor and fuel input resulted from CT when compared with minimum tillage systems because of the high number of field operation in land preparation. Depending on the tillage intensity, minimum tillage saved 26-46% land preparation and seeding cost. Seedling emergence rate was found satisfactory in all minimum tillage options. Furrow openers gave better crop emergence and establishment, which was due to improved depth control and seed to soil contact. The tillage practices revealed that pulses and wheat grown under minimum tillage options could not provide yield advantage over conventional tillage. Minimum tillage resulted in the least cost because of less fuel, time and labor consumption. The gross margin was the highest in minimum tillage due to the highest gross income compared with other tillage systems. The highest benefit cost ratio was observed in minimum tillage operation compared to CT. Uniform seed placement and proper depth can be ensured in machine sowing, which facilitates seedling emergence. The planter shows potential for mechanized establishment of a range of crops under minimum tillage and also to increase profitability of pulses and cereal crops.

Keywords: Strip tillage, zero tillage, bed planting, fuel, labor, seedling emergence, yield

Introduction

Winter pulses (chickpea and lentil) and wheat are grown after harvesting Aman rice by using residual moisture. Summer pulses (mungbean and blackgram) are cultivated after harvesting of Aman, wheat, mustard and lentil. Successful stand establishment is achieved by providing the seed with an environment, which encourages early germination and emergence. Gan *et al*., (1992) reported that plants that emerge early contribute more to crop yield than those that emerge later. Thus, desirable crop yields are achieved by providing seeds with an environment that encourages early germination and emergence. Seed quality, soil conditions, seeder design, and the skill of the operator play a vital role in determining the final plant stand (Karayel and Özmerzi, 2001). Chaudhuri (2001) reported that the soil resistance was a critical factor affecting uniformity of sowing depth of the furrow openers.

Several authors have emphasized the importance of analyzing the stand establishment process and have shown that the main factors affecting germination, seedling emergence and plant establishment are associated with the mechanical characteristics of the seedbed. The mechanical characteristics of seedbeds are influenced by tillage practices. Tillage influences bulk density, penetration resistance, aggregate mean weight diameter and surface roughness (Carman, 1997) and was practiced to induce a congenial environment for crop establishment. Traditionally, seeds and fertilizer are broadcast after 1-2 passes of tillage by power tiller. Additional tillage is provided after seeding followed by leveling. Hand broadcasting lacks uniform placement of seed at a proper depth. Conventional tillage and hand broadcasting of seed is a laborious, input intensive and time-consuming operation. Researchers developed different types of planter that provides tillage, seeding, fertilizer application, soil coverage and leveling in single pass operation. The versatile multi-crop planter (VMP) was developed to overcome some of the constraints of direct seeding. The VMP has facilities to sow seed and place basal fertilizer simultaneously in a single pass operation under different tillage systems. Minimum tillage technologies are now gaining popularity throughout the world to save time in field preparation and reduce inputs. The labor input, energy input, capacity and costs are different for each of these systems. Therefore, the present study was undertaken to evaluate the field performance of planter to establish pulse and wheat under different tillage options.

Materials and methods

The experiment was conducted in the farmers' fields at Godagari upazila under Rajshahi district of Bangladesh during cool winter *Rabi* season of 2010 and hot and dry kharif-1 season in 2011. Lentil (*Lens culinaris* Medik.), chickpea (*Cicer arietinum* L.), mungbean (*Vigna radiata* (L.)R. Wilczek), blackgram (*Vigna mungo* (L.) Hepper), and wheat were established with these tillage options using VMP at five locations in Bangladesh (Table 1). The treatments were arranged in conventional tillage (CT), single pass shallow tillage (SPST), zero tillage (ZT), bed planting (BP) and strip tillage (ST). The randomized complete block design was followed with three replications. In CT, land was prepared with two passes tillage by 2WT followed by leveling. Seeds and fertilizer were hand broadcast in CT. In SPST, ZT, BP and ST method, land preparation, seeding and basal fertilizer application were done simultaneously in single pass operation by the planter (Photo 1 to 6). Before seeding, seeder should be calibrated for each treatment to get the recommended and uniform seed rate. In each trial, sample was collected from the seed dispensing tube in polythene bag from 10 revolutions of drive wheel. Sample seeds were spread on a sheet to count the damaged seeds and weight was taken. Uniform seed rate in each flute type seed meter was maintained by adjusting gap of seed meter.

Table 1 Experimental characteristic to establish pulse and wheat

Crop	Variety	Seeding date	Harvesting date
Winter pulse			
Chickpea	BINA chola4	4 Dec 2010	2 Apr 2011
Lentil	BARI masur4	15 Nov 2010	10 Mar 2011
Summer pulse			
Mungbean	BARI mung6	25 Feb 2011	10 May 2011
Blackgram	BARI mash3	28 Feb 2011	17 May 2011
Cereal			
Wheat	Satabdi	20 Nov 2010	24 Mar 2011

Photo 1 Strip tillage planting of blackgram

Photo 2 Bed planting of wheat

Photo 3 Chickpea seeding in strip tillage (seeds and fertilizer)

Photo 4 Chickpea seeding in zero tillage (seeds and fertilizer)


Photo 5 Lentil seeding in strip tillage (seeds and fertilizer) **Photo 6 Lentil seeding in zero tillage (seeds and fertilizer)**

Fuel consumption was measured by filling the fuel tank twice, before and after each operation. Re-filled volume was the actual fuel consumption. Data on labor requirement, operational time, time losses due to turning, clogging and operators personal necessity were recorded during the field operation. Field capacity was determined following Hunt (1995) as:

$$C_{th} = \frac{SW}{10} \quad (1)$$

$$C_{eff} = \frac{A}{T} \quad (2)$$

$$e = \frac{C_{eff}}{C_{th}} X100 \quad (3)$$

Where,

C_{th} = theoretical field capacity, ha hr^{-1}
C_{eff} = effective field capacity, ha hr^{-1}
e = field efficiency
S = speed of travel, km hr^{-1}
W = rated width of tillage, m
A = total area planted, ha
T = total time for planting operation, hr

Table 2 presents the fertilizer application rates of different crops. For pulses, the entire amount of urea, triple super phosphate, muriate of potash and gypsum was applied into the soil at final land preparation. For wheat, urea was top dressed in three equal installments. Seedling emergence was determined by daily counting the number of newly emerged seedlings in 1m length of row with three replications. Irrigation water was only applied four times in wheat cultivation. But pulses relied entirely on stored profile water.

Table 2 Fertilizer application rates in pulse and wheat production

Crop	Urea ($kg\ ha^{-1}$)	MP ($kg\ ha^{-1}$)	TSP ($kg\ ha^{-1}$)	Gypsum ($kg\ ha^{-1}$)
Wheat	217	100	100	110
Mungbean	35	50	90	55
Blackgram	35	50	90	55
Lentil	35	50	90	30
Chickpea	35	50	100	55

The cost of operating the planter was computed using the following equation involving the fixed and variable cost items.

$$AC = FC + VC \qquad (4)$$

Where,

AC = annual operating cost, $Tk\ yr^{-1}$
FC = annual fixed cost, %
VC= variable cost, $Tk\ yr^{-1}$

Fixed cost (FC) is independent of machine use. Fixed cost was calculated on the basis of capital consumption (CC) method. A capital recovery factor (CRF) was used to combine the total depreciation and interest changes into a series of equal annual payments at compound interest. The capital recovery factor can be interpreted as the amount of equal (or uniform) payments to be received for n years such that the total present value of all these equal payments is equivalent to a payment of one taka at present, if interest rate is i. This payment is used to estimate the capital consumption for farm machinery (Hunt, 1995).

$$CC = (P-S)CRF + S \times i \qquad (5)$$

$$CRF = \frac{i(i+1)^n}{(1+i)^n - 1} \qquad (6)$$

Where,

CC = Capital consumption
P = purchase price of the VMP, Tk
S = salvage value, Tk
CRF = Capital recovery factor
i = interest on investment, %
n = Life of machine, yr

Variable costs (VC) are associated with use of the machine and calculated on the basis of the following equation (Hunt, 1995).

$$VC_j = \frac{A_j}{C_j}\left[(R \& M) \times P + L + H\right] \qquad (7)$$

Where,

A = annual tillage area coverage in j tillage mode, ha
C = effective field capacity of the VMP in j tillage mode, ha hr^{-1}
R &M = repair and maintenance cost, %
L = labor cost, Tk hr^{-1}
H = power tiller hire price, Tk hr^{-1}

The break-even point (BEP) is that point at which neither profit is made nor loss incurred. The total costs of the farm enterprise would be the same as the gross income. It is important to continuously investigate the cost of operation of the farm machine. The farm's fixed costs have to be covered by the income: the higher the fixed costs, the longer it will take for the business to reach break-even and make a profit. Therefore, it is important to keep fixed costs down to a minimum. The following formula was used to estimate the BEP of the machine.

$$BEP_j = \frac{FC_j}{CR - VC_j} \qquad (8)$$

Where,

BEP = breakeven point, ha yr^{-1}
FC = fixed cost, Tk yr^{-1}
VC = variable cost, Tk ha^{-1}
CR =custom hire rate, Tk ha^{-1}

Grain yield was recorded from pre-selected 10 m^2 area and was adjusted to 14% moisture content. Border areas of all sides of the plot were excluded from samples to avoid edge effects. A simple economic analysis was done based on total production. Production cost included rental charge of the land and input cost. Price of the produce was collected from the local markets to compute total production cost, gross return, gross margin and benefit-cost ratio. Statistical analysis as a one way analysis of variance was done according to Gomez and Gomez (1984). Data were analysed by using statistical software Mstat-C. Means were compared with least significant difference (LSD) test.

Results

Field capacity

Table 3 presents the field capacity of 2WT and VMP to establish pulses and wheat. Tillage treatment showed significant effect on field capacity in land preparation. Field capacity of 2WT and planter under minimum tillage operations varied in different crop cultivation.

Table 3 Effect of tillage on field capacity (ha hr⁻¹) of 2WT and VMP

Treatment	Chickpea	Lentil	Mungbean	Blackgram	Wheat	Mean
CT	0.08	0.07	0.09	0.07	0.11	0.08
SPST	0.05	0.04	0.09	0.06	0.06	0.06
ZT	0.06	0.06	0.05	0.05	0.06	0.06
BP	0.05	0.05	0.05	0.04	0.05	0.05
ST	0.06	0.05	0.09	0.05	0.06	0.06
CV, %	5.79	12.06	4.06	8.94	6.43	
$LSD_{0.05}$	0.01	0.01	0.01	0.01	0.01	

N.B. Values are the means of three replicates

Fuel consumption

Table 4 presents fuel consumption under different tillage operations in chickpea, lentil, wheat, blackgram and mungbean. Tillage treatment showed significant effect in fuel consumption for land preparation. Fuel consumption varied in different tillage modes in pulse and wheat cultivation. Minimum tillage saved 21-34% diesel fuel compared to CT.

Table 4 Effect of tillage on fuel consumption ($l\ ha^{-1}$) in pulse and wheat cultivation

Treatment	Chickpea	Lentil	Mungbean	Blackgram	Wheat	Mean
CT	30	44	55	40	29	40
SPST	27	41	30	31	16	29
ZT	24	21	23	32	21	24
BP	28	43	31	37	29	34
ST	16	21	29	29	10	21
CV (%)	6.2	12.9	7.2	11.2	5.8	
$LSD_{0.05}$	2.89	8.23	11.44	7.15	2.28	

N.B. Values are the means of three replicates

Labor requirement in land preparation and seeding

Table 5 shows the labor requirement in land preparation for each tillage system in pulse and wheat cultivation. Tillage options showed significant effect on labor requirement in land preparation and seeding. Labor requirement in CT was almost two times higher than minimum tillage treatment. On average five crops, SPST, ZT, BP and ST saved 50-60% labor requirement in land preparation compared to CT in pulse and wheat cultivation, respectively.

Table 5 Labor requirement (man-hr ha^{-1}) in land preparation and seeding under different tillage systems

Treatment	Chickpea	Lentil	Mungbean	Blackgram	Wheat	Mean
CT	31	58	37	41	47	43
SPST	18	23	12	18	17	18
ZT	18	17	18	21	16	18
BP	18	21	19	27	22	21
ST	16	22	12	19	16	17
CV (%)	5.20	8.79	4.79	9.12	7.72	
$LSD_{0.05}$	2.01	4.63	1.74	4.30	3.44	

N.B. Values are the means of three replicates

Land preparation and seeding cost

Table 6 shows the sum of labor, fuel and seeding cost included in the land preparation cost in each tillage. Cost of land preparation and seeding was higher in CT and the lowest cost was obtained in ST. On average five crops, in comparison to CT, land preparation cost was reduced by 37, 41, 26 and 46% in SPST, ZT, BP and ST, respectively.

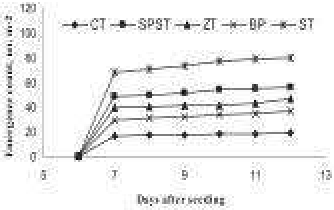
Table 6 Cost (Tk ha^{-1}) of land preparation and seeding under different tillage systems

Treatment	Chickpea	Lentil	Mungbean	Blackgram	Wheat	Mean
CT	3,426	5,426	4,570	5,002	3,993	4,483
SPST	2,708	3,637	2,286	3,460	2,091	2,836
ZT	2,554	2,295	2,486	3,653	2,253	2,648
BP	2,667	3,592	2,884	4,353	3,054	3,310
ST	2,034	2,715	2,233	3,303	1,723	2,402
CV (%)	3.1	6.1	7.5	9.0	4.7	
$LSD_{0.05}$	158	405	407	670	211	

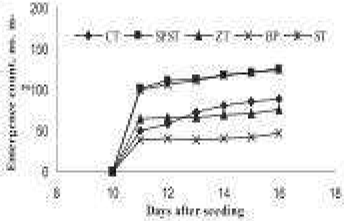
N.B. Values are the means of three replicates

Seedling emergence

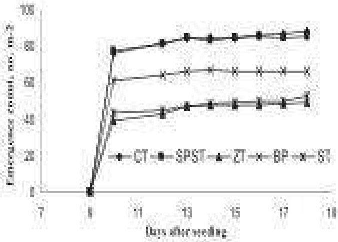
Figure 1 shows seedling emergence with respect to days to seeding of pulse and wheat. Emergence rate of chickpea was the highest in ST and the lowest in CT (Fig. 1a). Emergence rate of lentil was the highest in ST followed by SPST, CT, ZT and BP (Fig. 1b). Emergence rate of mungbean was favored more in CT than the methods of minimum tillage (Fig. 1c). Emergence rate of blackgram was the highest in ZT followed by SPST, ST, BP and CT (Fig. 1d). Emergence rate of wheat was the highest and statistically identical in CT, ZT and SPST whereas, the lowest in BP and ST (Fig. 1e).



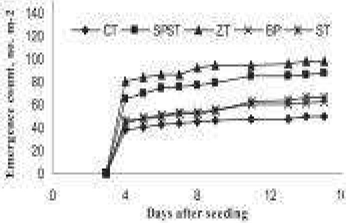
(a) Chickpea



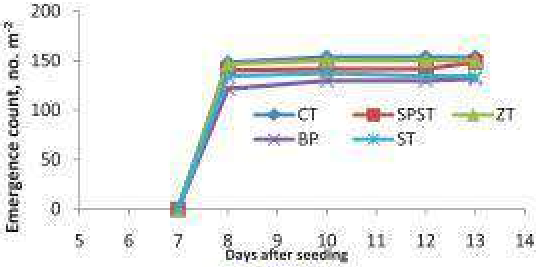
(b) Lentil



(c) Mungbean



(d) Blackgram



(e) Wheat

Fig. 1 Emergence count of pulses and wheat at different days after seeding

Grain yield

Table 7 shows the yield comparison of winter and summer pulse and wheat under different tillage options. Grain yield was quite similar to all tillage options in pulse and wheat production. Minimum tillage showed no yield advantage over conventional tillage in pulse and wheat cultivation.

Table 7 Grain yield (t ha-1) of pulses and wheat as affected by tillage options

Treatment	Chickpea	Lentil	Mungbean	Blackgram	Wheat
CT	1.13	0.59	0.77	0.60	3.73
SPST	1.13	0.56	0.76	0.61	4.00
ZT	1.05	0.52	0.71	0.60	3.24
BP	1.15	0.55	0.73	0.62	3.91
ST	1.11	0.58	0.74	0.61	3.75
CV (%)	3.3	9.3	1.8	4.4	3.2
$LSD_{0.05}$	NS	NS	0.03	NS	NS

N.B. Values are the means of three replicates

Economic analysis

Table 8 presents the total input costs (labor, land preparation and other expenses) from seedbed preparation to harvesting operations including transportation. Seed, fertilizer, chemical and labor input for cultivation practices during the growing period were same. In pulse and wheat cultivation, CT incurred the highest costs and the lowest cost in minimum tillage. Minimum tillage had the highest gross return and BCR.

Table 8 Economic productivity of pulses and wheat under different tillage

Crop	Tillage option	Total production cost (Tk ha-1)	Gross income (Tk ha-1)	Gross margin (Tk ha-1)	BCR
Chickpea	CT	32,550	52,808	20,259	1.62
	SPST	31,820	52,810	20,992	1.66
	ZT	31,660	49,069	17,408	1.55
	BP	31,780	53,931	22,155	1.70
	ST	31,120	52,203	21,083	1.68
Lentil	CT	34,670	43,124	8,453	1.25
	SPST	33,720	40,508	6,791	1.20
	ZT	32,330	37,962	5,634	1.17
	BP	33,770	40,118	6,347	1.19
	ST	31,870	42,137	10,264	1.32
Mungbean	CT	33,680	44,850	11,170	1.33
	SPST	31,350	44,140	12,790	1.41
	ZT	31,550	41,280	9,727	1.31
	BP	31,960	41,990	10,040	1.31
	ST	31,290	43,060	11,770	1.38
Blackgram	CT	28,420	35,455	7,034	1.25
	SPST	26,780	35,603	8,825	1.33
	ZT	27,090	35,455	8,367	1.31
	BP	27,810	36,345	8,534	1.31
	ST	27,130	35,900	8,767	1.32
Wheat	CT	41,340	51,040	9,697	1.24
	SPST	39,400	54,700	15,300	1.39
	ZT	39,570	44,380	4,816	1.12
	BP	40,380	53,670	13,290	1.33
	ST	39,020	51,600	12,580	1.32

N.B. Values are the means of three replicates; US$1=Tk 80.

Break-even analysis

Figure 2 shows the break-even point of planter in seeding operation. The break-even area under SPST, ST, ZT and BP was 8, 8, 11 and 7 ha, respectively. It means that the seeder machine should be operated on at least 7 ha per year to produce break-even outcome with neither loss nor profit.

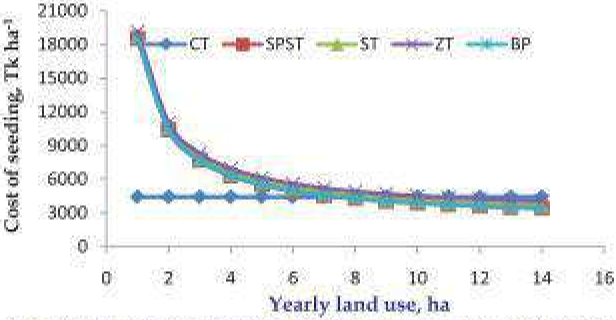


Fig. 2 Break-even analysis of planter for pulse and wheat cultivation

Discussion

Field capacity of 2WT in CT was the highest due to riding type facility with high running speed and the lowest was of VMP in ST, BP and ZT due to walking type with moderate running speed. CT required two passes operations to complete land preparation whereas, minimum tillage by planter required single pass operation to complete tilling, seeding, fertilizer application and leveling. Among the minimum tillages, field capacity of SPST and ST was the highest compared to ZT and BP. It was due to negative draft and more energy was needed to till and throw the soil inward to make bed in BP. Winter pulses and wheat consumed the lowest fuel under CT systems possibly due to optimum moisture content in the soil. In case of lentil, fuel consumption in all tillage modes was higher than chickpea and wheat because the soil was dry compared to chickpea and wheat field. Summer pulses consumed the highest fuel in all tillage operation due to dry soil. BP required almost similar fuel to CT due to more tynes fitted to make the bed. The fuel savings in SPST, ZT, BP and ST accounted for 28, 40, 15 and 48% compared to CT. This result was consistent to the findings of Hernánz *et al.* (1995) and Sijtsma *et al.* (1998). They reported that a decrease in tillage intensity resulted in significant fuel savings. Variable seed placement occurred due to jerking of the planter during operation. Emergence rate of chickpea was the highest in ST and the lowest in CT. Proper seed depth and high moisture content of soil might be the reasons for reduced number of seedling emergence. Moisture gradient was observed in CT and SPST plot compared to other plot due to low elevation and rainfall did not occur during chickpea cultivation. Soil moisture was depleted rapidly due to high temperature and it restricted the emergence of chickpea seeds. Emergence rate of lentil was the lowest in ZT and BP possibly due to cooler and wetter soils (Gupta *et. al.*, 1983 and Kasper *et al.*, 1990). Emergence rate of mungbean was favored more by CT than by minimum tillage. Poor emergence in minimum tillage may be attributed to lower seed bed temperature (Gupta *et. al.*, 1988 and Hayhoe *et. al.*, 1993). Emergence rate of blackgram was the highest in ZT may be due to typical trap and retain more moisture than CT system (Roygard *et al.*, 2002). Delayed emergence due to increased seeding depth has been observed in wheat (Mahdi *et al.*, 1998). In some cases seedling emergences were low and patchy in CT. Uneven seed distribution and seed depth variation may be attributed to reduced seedling emergence in CT (Tessier *et al.*,1991 and Eshraghi *et al.*, 2007). Shallow planting may have led to moisture stress that resulted in seedling mortality and decreased vigor. Emergence rate was the highest in ST. It might be due to tilling only in the row encourages more favorable soil temperature, moisture and aeration (Pierce *et al.*, 1992). Placement of seeds in shallow depth may result easy access to bird damage. Furrow openers of planter gave better crop emergence and establishment, which was due to improve depth control and seed to soil contact (Asoodar and Barzegar, 2006). No linear relationship was found to exist between crop yield and tillage intensity. The soils of Rajshahi regions are deficient in nitrogen fixing bacteria (*Rhizobium* spp.), which caused poor yield of lentil (Khanam *et al.*, 1999). Grain yield of mungbean under ZT was low might be due to greater soil strength of surface soil that caused unfavorable soil conditions (Azooz *et al.*, 1995). In wheat cultivation, the superior yield was obtained in SPST followed by BP, ST and CT. The lowest yield was obtained in ZT. These results are in contrast to those who found increased yields for minimum tillage as compared to the conventional tillage systems. Hossain *et al.*, (2005) found that wheat yield in raised-bed planting was significantly greater. The tillage practices revealed that pulses and wheat grown under minimum tillage options could not provide yield advantage over conventional tillage. Although, seedling emergence was differed in tillage options, but yield difference was not significant. Hajabbasi and Hemmat (2000) observed that moldboard plowing increased 3-29% yield in comparison with reduced tillage systems in central Iran on a clay-loam soil. In minimum tillage, the lower soil temperature and inadequate plant populations may reduce the grain yield (Mallarina *et al.*, 1999). These types of adverse effects are more common in sandy clay loam to sandy loam soils (Carter *et al.*, 1988). However, Karunatilake *et al.*, (2000) reported a similar or even higher yield under ZT than with CT. Therefore, consistent benefit of increased grain yield from minimum tillage was not observed in pulse and wheat production in high barind tract. Input cost varied among five tillage systems. CT resulted in the highest costs due to more fuel and labor requirement in land preparation. Minimum tillage resulted in the least cost, because it has less number of field operations for land preparation and resulted with savings, of fuel, time and labor use. This can be explained by the fact that more fuel per unit area is necessary in CT that charges high rates for tillage operations. Minimum tillage gave the highest gross margin compared to CT due to the highest gross income. Moreover, costs particularly in land preparation were the lowest in minimum tillage compared to CT. The highest BCR was observed in minimum tillage operation compared to CT. Some researchers (e.g. Abu-Hamdeh, 2003; Zentner *et al.*, 1996) reported that net economic return was higher in minimum tillage than in conventional tillage as in the case of SPST and ST in this study. Some researchers (e.g., Malhi *et al.*, 1988; Hoffman *et al.*, 1999) also reported that net economic returns were lower for reduced tillage systems as in case of ZT and BP in this study.

Conclusion

The minimum tillage for seeding pulse and wheat substantially reduced fuel consumption. Crops grown under various minimum tillage options did not reduce yield compared to the conventional tillage. Minimum tillage by VMP reduced turn-around time and timely planting in addition to the reduction of fuel and labor costs. VMP appeared as reliable mechanized planter with capability for seed and fertilizer application by SPST, ST, ZT, and BP. A preliminary estimate indicated that the entrepreneur of planter can get their return on investment with annual cultivation of 7-11 ha through providing rental service.

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Sprouted seeded rice in strip planting

Abstract

This experiment was conducted at farmers' field, Godagari, Rajshahi during Aus and Aman 2010 season to estimate the damage of radicle and plumule of sprouted seeds in mechanized sowing by versatile multi-crop planter (VMP). The seed treatments were: dry seed (T_1); soaking overnight (T_2); soaking overnight and 24 hours incubation (T_3); soaking overnight and 48 hours incubation (T_4); and soaking overnight and 72 hours incubation (T_5). The fluted type seed meter was used to dispense incubated seed in strip tillage condition in dry soil. Plumule and radicle were not broken and whole seed was also not damaged. Except in Aman season, radicle length of 72 hrs incubate seed was longer than others. In some cases, tip of radicle was broken but total radicle was not detached from the seed during dispensing seed through the fluted type seed meter. Seedling emergence was not significantly affected by incubation, although, same seed rate was used in both the seasons. Population at maximum tillering stage was almost same in two seasons in all treatments although seedling emergence was varied. Tiller mortality was higher in Aman season compared to Aus season. At maturity, total tiller and effective tiller was not significantly affected by incubation period. In Aus season, incubation period under investigation had shown a wide range of variability among them in respect to grain yield but in Aman season, no significant variation was observed on grain yield. Sprouted seed has no effect on the crop duration but takes longer time to sprout. Partly broken plumule in Aman season has no effect on grain yield. Sprouted seed has no yield advantage over non-sprouted seed indicating that flute type seed meter safely dispensed sprouted seed.

Keywords: Planter, radicle, plumule, seedling emergence, yield

Introduction

Wet and dry seeding methods are often referred to as direct seeding (Pandey and Velasco, 1999). Wet seeding refers to sowing of pre-germinated seeds in wet and puddle soils. Most of the developed countries establish rice by wet seeding because of high wages and scarcity of labor (Smith and Show, 1996). Farmers in developing countries have increasingly adopt wet seeding because of the migration of farm labor to non-farm jobs and the consequent labor shortage and high wage rates for manual transplanting (Ho, 1995 and Pandey, 1995). Seeds may be broadcast in rows on dry/moist/puddle soil, whereas only broadcasting is used for seeding on water (Balasubramanian and Hill, 2002). Satter and Khan (1994) reported that direct-wet-seeded rice was grown initially under saturated condition and they could withstand drought better. In Bangladesh, direct seeding using either broadcast or line sowing gave significantly higher grain yield than transplanting under proper management (Elahi *et al.*, 1997 and Hussain *et al.*, 2000). Khan *et al.* (2001) and

Balasubramanian *et al.*, (2003) reported that dry-seeded rice on flat land with reduced or zero tillage produced rice yields similar to higher than that of transplant rice on puddled soil. Santhi (1999) reported that crop established through broadcasting of sprouted seeds had seven days earlier flowering than a transplanted crop. The delay in flowering by around a week in transplanted rice might be due to pulling and transplanting shock of rice seedlings. Islam (2008) observed that radicle and plumule length was increased with the increase in incubation period and seed rate was reduced when sown by drum seeder with incubated seed. Islam (2008) also reported that significantly higher grain yield was obtained with 96 hours incubated seed. However, insignificant difference was observed among 24, 48 and 72 hours incubated seeds. Many machines have been developed in rice-growing countries and international institutes suitable for direct seeded rice (DSR). For the small farm holders, the versatile multi-crop planter (VMP) was developed to overcome some of the DSR constraints. To obtain the direct-seeded rice establishment benefits, the planter was evaluated to assess the performance of sprouted rice seed sowing. Therefore, the present study was undertaken to estimate the damage of radicle and plumule of sprouted seeds during mechanized sowing and to determine the optimum seed incubation period for seeding by planter.

Materials and methods

This experiment was conducted at farmers' field, Godagari, Rajshahi during Aus 2010 and Aman 2010. The seed treatments were: dry seed (T_1); soaking overnight (T_2); soaking overnight and 24 hours incubation (T_3); soaking overnight and 48 hours incubation (T_4); and soaking overnight and 72 hours incubation (T_5). The treatment combinations were arranged in a randomized complete block (RCB) design with three replications. Seeds were cleaned by immersing them in clean water and removing the floated seeds. Seeds were soaked in tap water. Equal dry weights of uniform seeds were put into fresh water, soaked overnight and removed from water in the morning. The soaked rice seeds were kept in gunny bags at an ambient temperature for incubation. During Aus season, seeds of BRRI dhan42 were soaked with fresh water in the evening on 25, 26, 27 and 28th April 2010 and removed from water in the next morning. Presoaked seeds were kept in a gunny bag for incubation upto 26, 27, 28 and 29th April 2010. During Aman season, seeds of BR11 were soaked with fresh water in the evening on 14, 15, 16 and 17th June 2010 and removed from water in the next morning. Presoaked seeds were kept in a gunny bag for incubation upto 15, 16, 17 and 18th June 2010. Before sowing, seeds were removed from the gunny bag and air dried in the shade for two hours. The length of plumule and radicle was measured from 15 randomly selected rice seeds in all treatment samples. Slide caliper was used to measure the length of plumule and radicle from their junction with the seed. Dry weight of all rice seeds having germination over 95% were taken and put into fresh water for soaking. Final weight of the incubated seeds were taken after completion of incubation. Seeds were sown in dry land in strip tilled condition by VMP as it was appeared as a fuel saving tillage technology in crop production (Islam *et al.*, 2010). In Aus season, rice variety BRRI dhan42 was sown on 29th April 2010 and in Aman rice variety BR11 was sown on 18th June 2010. Pressing roller attached with VMP was used to cover the seed (Photo 1). Before seeding, flute type seed meters were calibrated for each treatment to get the recommended and uniform seed rate. Seeds were poured into the hopper. In each trial, sample was collected from the seed dispensing tube in polythene bag from 10 revolution of drive wheel.

Photo 1 Planter in operation for seeding sprouted seed

In Aus season, rice was grown after harvesting potato. Farmers usually use excess fertilizers in potato cultivation. Farmers did not apply basal or top dressed fertilizer after potato cultivation to grow Aus rice. In Aman season, fertilizers were applied at 175, 80, 110, 100 and 10 kg ha^{-1} as urea, triple super phosphate (TSP), muriate of potash (MP), gypsum and zinc sulphate, respectively. Irrigation water was applied to the plots just after sowing of sprouted seeds. In Aus season, land was irrigated at night and excess water was drained out in the morning due to high ambient temperature. Some crops were damaged due to high water temperature in Aus season. Subsequent irrigations were applied as when required uniformly in all the plots. In both seasons, irrigation water was applied five times in all the plots. In Aman season, non-selective herbicide roundup (glyphosate) was applied @ 7.5 l ha^{-1} one day before seeding in all the plots. In Aus season, pre-planting herbicide was not used and the weed infestation was severe in all the plots. Hand weeding was done on 26 days after seeding (DAS) to keep the field weed free. In Aman season, weed infestation was less due to application of pre-planting herbicide. In addition, hand weeding was done twice at 35 and 60 DAS. Insecticide was not applied in Aus season. In Aman season, however, insects were controlled by a single application of Basudin 10G at vegetative stage.

Number of tillers in the selected area was counted at each growth stage. Tiller mortality was calculated based on successive tiller count data. Grain yield was recorded from pre-selected 10 m^2 area and was adjusted to 14% moisture content. Panicle number in each unit area was counted to determine the panicle number per m^2. Border areas of all sides of the plot were excluded from samples to avoid edge effects. A simple economic analysis was done based on total production. Production cost included rental charge of the land and input cost. Price of the produce was collected from the local markets to compute total production cost, gross return, gross margin and benefit-cost ratio. Statistical analysis as a one way analysis of variance was done according to Gomez and Gomez (1984). Data were analysed by using statistical software Mstat-C. Means were compared with least significant difference (LSD) test.

Results

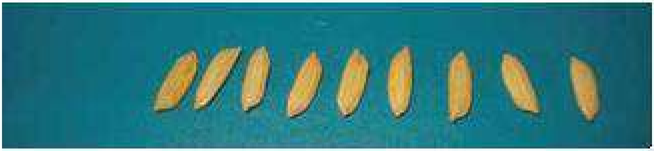
Effect of incubation period on plumule and radicle elongation

Radicle length was increased with days of incubation in both the seasons (Table 1, Photo 2 and 3). Radicle length was longer in BR11 than in BRRI dhan42.

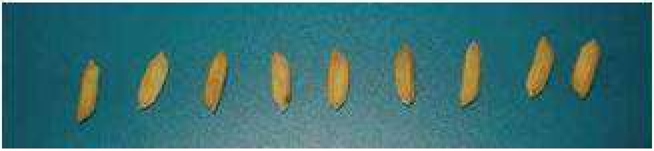
Table 1 Effect of incubation period of seeds on radicle and plumule growth and weight increased after incubation period

Soaking and incubation period	Plumule (mm)		Radicle (mm)		Weight increased (%)	
	Aus (BRRI dhan42)	Aman (BR11)	Aus (BRRI dhan42)	Aman (BR11)	Aus (BRRI dhan42)	Aman (BR11)
Dry seed (T_1)	-	-	-	-	-	-
Soaking overnight (T_2)	-	-	-	-	19.0	4.2
Soaking overnight and 24 hours incubation (T_3)	1.5	1.5	3.0	2.1	38.0	5.8
Soaking overnight and 48 hours incubation (T_4)	2.5	2.5	8.7	7.1	50.0	5.8
Soaking overnight and 72 hours incubation (T_5)	3.0	3.0	11.1	21.2	40.0	8.3

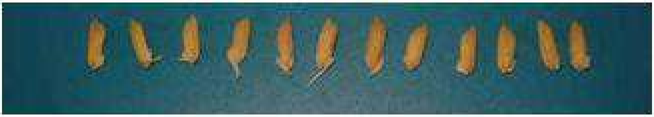
N.B. Values are the means of three replicates



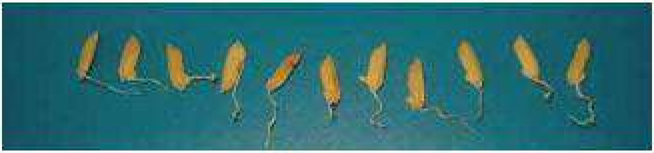
(a) Dry seed (T_1)



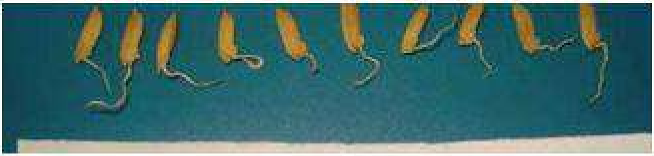
(b) 24 hrs soaked seed (T_2)



(c) 24 hrs soaked and 24 hrs incubated seed (T_3)

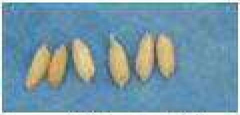


(d) 24 hrs soaked and 42 hrs incubated seed (T_4)

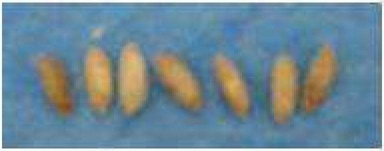


(e) 24 hrs soaked and 72 hrs incubated seed (T_5)

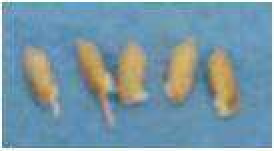
Photo 2 Radicle and plumule of incubated seed in Aus season (BRRI dhan42)



(a) Dry seed (T_1)



(b) 24 hrs soaked seed (T_2)



(c) 24 hrs soaked and 24 hrs incubated seed (T_3)

(d) 24 hrs soaked and 42 hrs incubated seed (T_4)

(e) 24 hrs soaked and 72 hrs incubated seed (T_5)

Photo 3 Radicle and plumule of incubated seed in Aman season (BR11)

Effect of incubation period on seed damage

Breakage was not observed in plumule, radicle and whole seed due to rotation of seed metering device. Except in the Aman season, in case of 72 hrs of incubation, very few radicles were broken from the tip due to rotation of seed metering device. Moreover, the whole radicle was not detached from the seed contact.

Effect of incubation period on seedling emergence

Figure 1 presents seedling emergence at different DAS. Seedling emergence started from 7 DAS. In Aus season, seedling emergence was significantly affected by seed incubation.

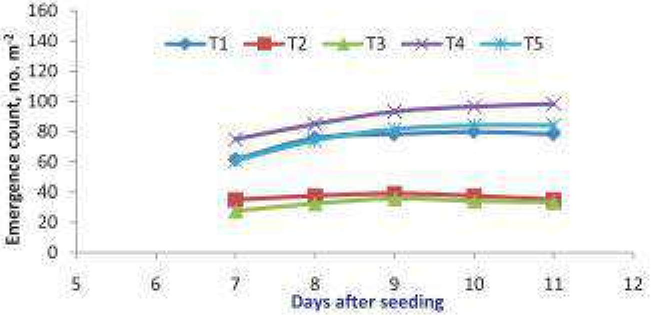


Fig. 1a Effect of incubation period on seedling emergence in Aus season

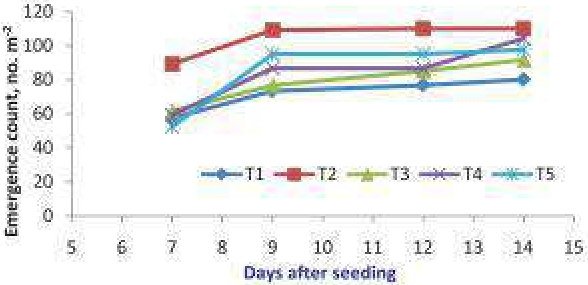


Fig. 1b Effect of incubation period on seedling emergence in Aman season

Effect of incubation period on agronomic performance of rice

Tillering dynamics and plant height

In Aus season, tillering pattern followed increasing trend up to 50 DAS and then decreased gradually due to tiller mortality (Fig. 2a). Maximum tiller (487 m^{-2}) was produced at 50 DAS in dry seed. At maturity, incubation period had no effect on tiller production. In Aman season, tillering pattern followed the increasing trend upto 75 DAS. Tiller production was not significantly affected by incubation period throughout the production cycle. Maximum tiller (597 m^{-2}) was observed in 24 hrs incubated seed. Tiller production decreased gradually after 75 DAS due to tiller mortality (Fig. 2b). At maturity, incubation period did not have significant effect on tiller production. Figure 3 shows plant height as affected by seed incubation. Plant height was not significantly affected by seed incubation in both the seasons.

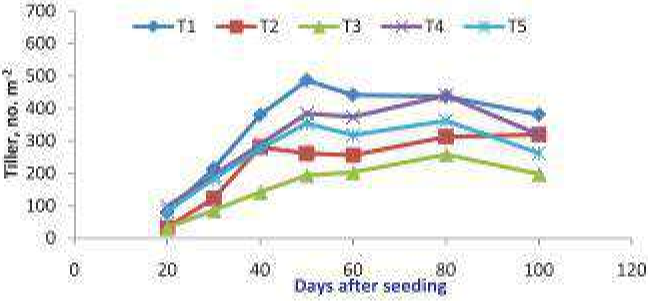


Fig. 2a Effect of incubation period on tiller production of Aus rice

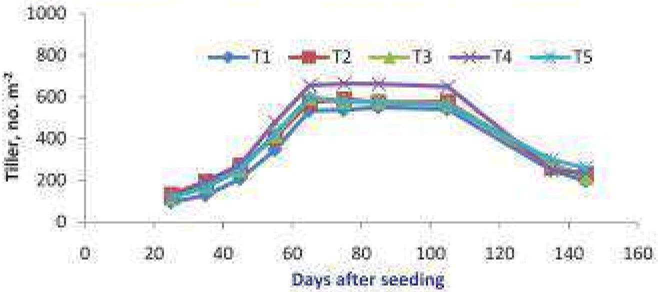


Fig. 2b Effect of incubation period on tiller production of Aman rice

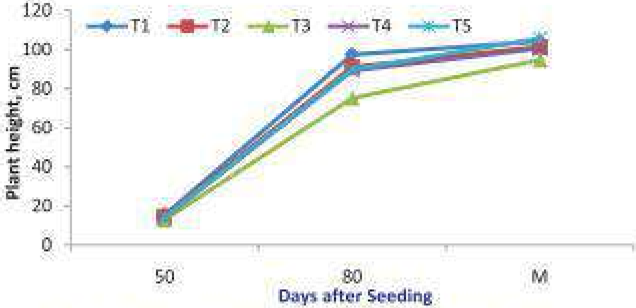


Fig. 3a Effect of incubation period on plant height of Aus rice

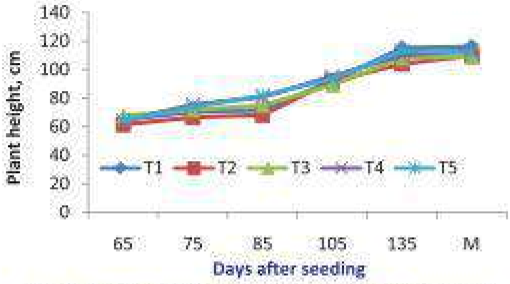


Fig. 3b Effect of tillage on plant height of Aman rice

Tiller and panicle production

Table 2 shows tiller and panicle production at the maturity stage. Incubation of seed did not significantly affect tiller production and panicle intensity at maturity stage. The highest tiller was produced in dry seed followed by 24 and 48 hrs incubation of seed in Aus season. In Aman season, the highest tiller number was produced in dry seed followed by 24 and 48 hrs incubated seed. There was no statistical difference on panicle intensity among the treatments in both the seasons. In Aus season, the highest number of panicle was observed in dry seed (381 m^{-2}) followed by 48 hrs (319 m^{-2}) incubation of seed. The lowest panicle number was obtained in 24 hrs incubation of seed. In Aman season, the highest number of panicle was observed in 72 hrs (256 m^{-2}) incubation seed followed by 48 hrs (232 m^{-2}). Panicle intensity was the lowest (193 m^{-2}) in dry seed.

Table 2 Tiller and panicle production in Aus and Aman rice as affected by different soaking and incubation period

Treatment	Tiller (no. m^{-2})		Panicle (no. m^{-2})	
	Aus	Aman	Aus	Aman
Dry seed (T_1)	298	198	250	193
Soaking overnight (T_2)	256	230	223	213
Soaking overnight and 24 hours incubation (T_3)	227	217	207	206
Soaking overnight and 48 hours incubation (T_4)	288	234	273	232
Soaking overnight and 72 hours incubation (T_5)	248	259	211	256
CV(%)	11.3	19.6	11.7	21.4
$LSD_{0.05}$	NS	NS	NS	NS

N.B. Values are the means of three replicates

Grain yield

Table 3 shows grain yield of Aus and Aman rice. Irrespective of seed incubation period, crops were matured in 100 days in Aus season. Grain yield was significantly affected by incubation period. The highest grain yield was obtained in 72 hrs incubation seed. There was no statistical difference on yield between dry seed and 72 hrs incubation seed. It was also noticed here that there was no statistical difference among 24 hrs soaked seed, and 24 and 48 hrs incubated seed. In Aman season, irrespective of incubation period, crops were matured in 145 days.

Table 3 Grain yield of Aus and Aman rice

Treatment	Aus (t ha^{-1})	Aman (t ha^{-1})
Dry seed (T_1)	3.52	4.24
Soaking overnight (T_2)	2.48	3.25
Soaking overnight and 24 hours incubation (T_3)	2.25	3.31
Soaking overnight and 48 hours incubation (T_4)	2.9	3.94
Soaking overnight and 72 hours incubation (T_5)	3.80	3.57
CV(%)	10	12.4
$LSD_{0.05}$	*	NS

N.B. Values are the means of three replicates

Economic analysis

Table 4 shows the economic productivity of sprouted seed from land preparation to harvest operations including transportation. Seed, fertilizer and irrigation was applied equally in all the plots. Variable costs were similar in all the treatment plots due to equal inputs. In Aus season, gross margin was the highest in 72 hrs incubation of seed and lowest in 24 hrs soaked seeds. The gross margin for 72 hrs incubation and dry seed was the highest due to the highest grain yield compared with other treatment. BCR was the highest in 72 hrs seed incubation and the lowest in 24 hrs incubation. In Aman season, gross margin was the highest in dry seed and the lowest in 24hrs soaked seeds. The gross margin for dry seed and 48 hrs incubation was the highest due to the highest grain yield compared with the other treatment. BCR was the highest in dry seed and the lowest in 24 hrs incubation.

Table 4 Economic productivity of rice as affected by seed incubation period

Treatment	Aus			Aman			BCR	
	Variable cost (Tk ha^{-1})	Gross return (Tk ha^{-1})	Gross margin (Tk ha^{-1})	Variable cost (Tk ha^{-1})	Gross return (Tk ha^{-1})	Gross margin (Tk ha^{-1})	Aus	Aman
T_1	41,162	64,319	23,157	45,330	76,839	31,509	1.56	1.70
T_2	40,937	44,304	3,367	45,099	58,898	13,799	1.08	1.31
T_3	40,919	42,745	1,826	44,993	59,985	14,992	1.04	1.33
T_4	41,006	52,790	11,783	45,141	71,402	26,262	1.29	1.58
T_5	41,055	68,845	27,791	44,573	64,697	20,124	1.68	1.45

N.B. Values are the means of three replicates

Discussion

During Aus and Aman seasons, plumule length of incubated seed did not increase as radicle with the incubation period. Similar results were obtained by Islam (2008). During Aus season, some seeds might be placed deeper and buried under soil causing poor seedlings emergence. Similar results were reported by Yoshida (1981) and Islam (2007). The highest emergence was found with 48 hrs of incubation (98 no. m^{-2}) at 11 DAS. In Aman season, the effect of seed incubation on seedling emergence was insignificant although few radicles were broken from the tip due to rotation of seed meter. Partly broken radicle did not restrict the seedling emergence. Seedling emergence indicated that flute type seed meter satisfactorily dispensed incubated seed without damaging plumule, radicle and whole seed. Tiller mortality was higher in Aman season than Aus season. It might be due to varietal difference and sometimes mortality depends on water management. Partly broken radicle in Aman season has no effect on grain yield. Grain yield was not significant among the incubated seed. Islam (2007) also observed that seed incubation had no significant effect on grain yield.

T_5 T_4

T_3 T_2

T_1

Photo 4 Crop condition at maturity stage in *Aus* season

T_5

T_4

T_3

T_2

T_1

Photo 5 Crop condition at panicle initiation stage in Aman season

Conclusion

Incubated seed required more days to sprout but matured the rice crops in the same duration. Sprouted rice seed did not reduce the field duration and could not provide yield advantage over non-sprouted seed. It can be concluded that sprouted rice seeds can be dispensed safely through the seed meters of VMP.

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CHAPTER III

UNPUDDLED RICE TRANSPLANTING

Rice cultivation in minimum tillage

Abstract

Alternate to puddling, unpuddled rice transplanting is a new concept in rice based cropping system. Tillage options in puddled condition (i) conventional tillage (CT) and (ii) single pass wet tillage (SPWT) and in unpuddled condition (iii) strip tillage (ST) and (iv) bed planting (BP) were evaluated to establish rice in the High Barind Tract, Godagari, Rajshahi during Aus (2010) and Boro (2011) seasons with a view to explore the profitability of growing rice in unpuddled condition. Minimum tillage (SPWT, ST and BP) saved about 30-54% fuel consumption among the tillage treatments in land preparation compared to CT. Minimum tillage saved (40-49%) labor compared to CT in land preparation. CT provided higher cost compared to other tillage treatment due to more fuel and labor used in land preparation. Labor did not face difficulties to transplant seedling in unpuddled field. Weeding time was higher in unpuddled than puddled transplanting. Tillage options showed significant effect on grain yield in unpuddled transplanting of Aus rice whereas, insignificant effect on grain yield in Boro rice. The present findings showed that grain yield in minimum tillage puddled and unpuddled transplanting of rice was similar to CT indicating that tillage intensity can be reduced to establish transplanted rice without sacrificing grain yield. In both the seasons, CT showed the highest input costs due to more number of tillage passes and fuel requirement in land preparation. The BCR showed the highest in SPWT. Transplanting rice in minimum tillage puddled SPWT and unpuddled ST and BP indicated more profitable than transplanting rice in conventional puddling.

Keywords: Strip tillage, bed planting, fuel consumption, yield, cost

Introduction

Transplanting rice in puddled soil is a common practice of crop production in lowland rice in the tropics and subtropics of Asia (Cassman and Pingali, 1995). Farmers typically prepare land by two passes of dry tillage followed by exposure to sun for a few days and then they deal with inundation of the field, plowing and harrowing with standing water. This tillage practice is laborious, time consuming and capital intensive process. Plowing of puddled soil after rice results in the formation of large clods, having high breaking strength (Sharma and Bhagat, 1993) and very large amounts of energy and time are consumed in producing fine seed beds. Puddling destroys soil aggregates, breaks capillary pores, and disperses the soils leading to increased bulk density of surface layers (Gupta *et al.*, 2003). It helps to control weeds and facilitate easy transplanting. Puddling to a greater extent creates soil physical condition detrimental to the following crop in rice based cropping system (Hobbs and Morris, 1996). Puddling makes land preparation difficult for the following wheat or other winter crops, resulting in cloddy soil structure, loss of soil moisture, delayed planting and inadequate seed-soil contact (Sharma *et al.*, 1995). Excessive wetness in puddled rice soil can delay the planting of the following wheat and result in yield reductions of 35-40 kg ha^{-1} per day by a delay in planting after November 20 (Randhawa *et al.*, 1981 and Hobbs, 1987). Puddling should preferably be avoided as it is an unfavorable practice for the succeeding upland crops. Minimum tillage was shown to have an advantage over puddling in a clay loam soil for maintaining physical condition and saving field preparation time (Brown and Quantrill, 1973). Sharma *et al.* (1988) revealed that rice grown after minimum tillage produced yields similar to that under conventional puddling with minimised expenses on field preparation. Haque (2009) evaluated the unpuddled transplanting of rice on bed, strip and single pass shallow tillage practices and found similar yield compared to conventional puddling with additional benefits in fuel and water savings. Kukal *et al.*, (2005) summarized the results on the performance of rice and wheat on raised beds from 18 sites in India and Pakistan. Across all sites, yield of unpuddled transplanted rice on bed was generally lower than puddle transplanted rice by 20-25%, while direct seeded rice on bed yield was generally lower by 30–40%. Islam *et al.*, (2012) stated that in Aman season, bed planting and strip tillage under unpuddled condition saved fuel and water usage by 31-76 % and 25-26 % compared to conventional tillage, respectively. The authors also observed that unpuddled transplanting could not provide yield advantage over puddled transplanting. Considerable research work has been done on puddle transplanting but almost limited data are available on unpuddled rice transplanting in Aus and Boro season. Therefore, a rice transplanting experiment needs to be conducted to explore the possibility of avoiding field puddling through unpuddled rice transplanting under minimum tillage options.

Materials and methods

The experiment was conducted in the farmer's field, Godagari, Rajshahi during Aus (May-August) 2010 and Boro (December-May) 2011 season. In the High Barind Tract (HBT) Grey terrace soils are predominant (Brammer, 1996). These soils are mostly of silty clay surface horizons. Agro-climatic (rainfall and thermal condition) data were collected from the nearest weather station (Fig. 1). The treatments were in puddled condition (i) conventional puddling (CT); (ii) single pass wet tillage (SPWT); and in unpuddled condition (iii) strip tillage (ST) and; (iv) bed planting (BP). The treatments were arranged in a randomized complete block (RCB) design with three replications. In land preparation, CT consisted of two passes primary tillage by 2WT and exposed to sun for two days followed by inundating whole plot and puddling by 2WT with 2 passes to complete land preparation. In SPWT, one pass tillage by 2WT after inundating the field. ST and BP were done by VMP in single pass operation before inundating the field. Table 1 presents the experimental characteristic. Land was inundated one day before transplanting operation for making the land soft to transplant seedling in ST and BP (Photo 1). In BP, the width of bed and furrow were 35 cm and 20 cm, respectively. The seedling spacing for CT, BP and SPWT was 25 x 15 cm and 20 x 15 cm for ST.

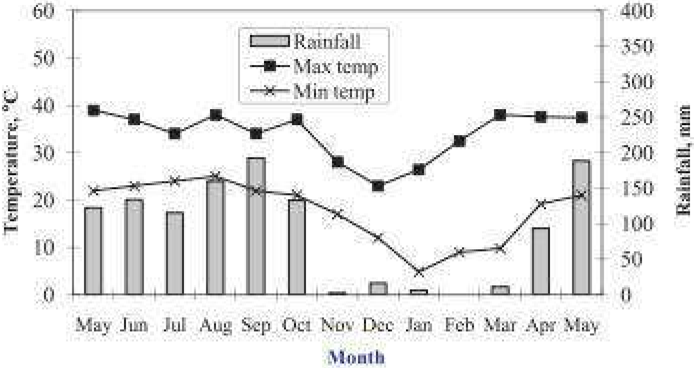

Fig. 1 Monthly temperature and rainfall distribution pattern in Godagari, Rajshahi during 2010-11

Bed

Strip tillage

Photo 1 Transplanting rice in unpuddled bed and strip tillage plot

Fuel consumption was measured by filling the fuel tank twice, before and after each operation. Table 2 presents the fertilizer application rate. The entire amount of triple super phosphate, muriate of potash, gypsum and zinc sulphate was broadcast and incorporated into the soil at final land preparation. Urea was top dressed in three equal installments. Crop condition at maturity stage in tillage practices (Photo 2). Grain yield was recorded from pre-selected 10 m^2 area and was adjusted to 14% moisture content. Panicle number in each unit area was counted to determine the panicle number per m^2. Border areas of all sides of the plot were excluded from samples to avoid edge effects. A simple economic analysis was done based on the total production. Production cost included rental charge of the land and input cost. Price of the produce was collected from the local markets to compute total production cost, gross return, gross margin and benefit-cost ratio. Statistical analysis as a one way analysis of variance was done according to Gomez and Gomez (1984). Data were analysed by using statistical software Mstat-C. Means were compared with least significant difference (LSD) test.

Table 1 Experimental characteristic to establish transplanted rice

Season	Variety	Date of seeding	Date of transplanting	Date of harvesting
Aus	Parija	11 May 2010	15 Jun 2010	28 Aug 2010
Boro	BRRI dhan28	5 Dec 2010	26 Jan 2011	07 May 2011

Table 2 Fertilizer application rate in rice production

Crop	Urea (kg ha^{-1})	MP (kg ha^{-1})	TSP (kg ha^{-1})	Zinc (kg ha^{-1})	Gypsum (kg ha^{-1})
Aus	175	67	133	-	56
Boro	217	100	178	7.5	83

Conventional tillage

Single pass wet tillage

Bed planting

Strip tillage

Photo 2 Rice crop condition at maturity

Results

Fuel consumption

Tillage treatment showed significant effect in fuel consumption in land preparation. SPWT and ST saved the highest (51-54%) fuel whereas 30% in BP in land preparation compared to CT (Table 3).

Table 3 Tillage effect on fuel consumption

Treatment	Fuel consumption (l ha^{-1})		
	Aus	Boro	Mean
CT	33	41	37
SPWT	14	21	18
ST	18	15	17
BP	20	31	26
CV (%)	16.1	7.6	
$LSD_{0.05}$	6.9	4.1	

N.B. Values are the means of three replicates

Labor requirement in land preparation, transplanting and weeding

Tillage treatment showed significant effect in labor requirement for land preparation in Aus and Boro seasons (Table 4). CT showed the highest labor requirement and ST showed the lowest labor requirement in land preparation. Minimum tillage saved (40-49%) labor compared to CT in land preparation. Tillage treatment indicated no significant effect in labor requirement between transplanting seedling in puddled and unpuddled conditions in two seasons. Tillage treatment significantly affected the weed infestation in Boro season. Weeding time was the highest in ST followed by BP, SPWT and CT.

Table 4 Labor requirement (man-hr ha^{-1}) in land preparation, transplanting and weeding

Treatment	Land preparation			Transplanting			Weeding	
	Aus	Boro	Mean	Aus	Boro	Mean	Aus	Boro
Puddled								
CT	47	43	45	106	79	93	Pretilachlor	116
SPWT	23	30	27	111	75	93	applied,	125
Unpuddled							no weeds	
ST	24	22	23	109	93	101	grown	345
BP	30	23	27	110	92	101		262
CV (%)	6.2	4.6		11.2	16.7			9.3
$LSD_{0.05}$	3.8	7.7		NS	NS			39.3

N.B. Values are the means of three replicates

Cost of land preparation, transplanting and weeding

Table 5 shows the cost of land preparation, transplanting and weeding as affected by tillage options. Tillage treatment showed significant effect in cost of land preparation. Land preparation cost was the highest in CT followed by BP, ST and SPWT. The land preparation cost under minimum tillage decreased upto 34-49% compared to conventional puddling. Tillage treatment had no significant effect on transplanting cost in puddled and unpuddled condition. Tillage treatment significantly affected the weeding cost which was the highest in ST followed by BP, SPWT and CT, respectively. Weeding cost increased as tillage passes decreased.

Table 5 Cost (Tk ha^{-1}) of land preparation, transplanting and weeding

Treatment	Land preparation			Transplanting			Weeding	
	Aus	Boro	Mean	Aus	Boro	Mean	Aus	Boro
Puddled								
CT	4,858	4,494	4,676	2,640	1,977	2,309	Pretilachlor	2,894
SPWT	2,246	2,410	2,328	2,778	1,877	2,328	applied,	3,135
Unpuddled							no weeds	
ST	2,592	2,218	2,405	2,723	2,317	2,520	grown	8,616
BP	3,121	3,004	3,063	2,739	2,305	2,522		6,559
$LSD_{0.05}$	635.9	179.6		NS	NS			982.2
CV, %	9.93	2.97		11.15	16.72			9.27

N.B. Values are the means of three replicates

Grain yield

At maturity stage, plant population and number of effective tillers per square meter did not vary significantly among tillage treatments in both the seasons (Table 6). Tillage options showed significant effect on grain yield in unpuddled transplanting of Aus rice whereas, insignificant effect in Boro rice cultivation.

Economic analysis

Table 7 shows economic productivity of unpuddled transplanting of rice as affected by tillage options. In both the seasons, CT showed the highest input costs due to more number of tillage passes and fuel requirement in land preparation. BCR was the highest in SPWT followed by ST, CT and BP, respectively in the two seasons.

Table 6 Yield and yield attributes of unpuddled transplanted rice

Treatment	Tiller (no. m^{-2})		Effective tiller (no. m^{-2})		Grain yield (t ha^{-1})	
	Aus	Boro	Aus	Boro	Aus	Boro
Puddled						
CT	408	440	362	348	4.03	4.10
SPWT	477	541	443	455	4.46	3.97
Unpuddled						
ST	412	462	368	371	4.02	4.14
BP	394	482	359	391	3.34	4.36
CV (%)	12.8	17.5	13.8	21.0	9.1	5.7
$LSD_{0.05}$	NS	NS	NS	NS	0.72	NS

N.B. Values are the means of three replicates

Table 7 Economic productivity of unpuddled transplanted rice as affected by tillage options

Tillage option	Aus		Boro		BCR		
	Input cost (Tk. ha^{-1})	Gross return (Tk. ha^{-1})	Input cost (Tk. ha^{-1})	Gross return (Tk. ha^{-1})	Aus	Boro	Mean
CT	50,590	72,960	50,050	72,855	1.44	1.46	1.45
SPWT	49,020	80,770	48,520	70,643	1.65	1.46	1.56
ST	49,630	72,840	48,370	75,293	1.47	1.56	1.52
BP	49,630	61,400	48,630	78,034	1.24	1.61	1.43

N.B. Values are the means of three replicates

Discussion

Minimum tillage reduced fuel and labor in land preparation due to limited number of tillage operations. Labor did not encounter any difficulties to transplant seedlings in unpuddled field due to soil softness as water applied before transplanting and soil was silty clay. The soil type may interact with the length of wetting in order to facilitate unpuddled transplanting. Weeding was not needed in Aus season. This might be due to short duration variety and crop canopy suppressed the weeds. In Boro season, weed infestation is severe in unpuddled plot, which incurred the highest cost than puddled plot. This can be attributed to dry zone on the top of bed and in the strip tillage that aided weed emergence. Ladha *et al.*, (2009) stated that the shallow soil tillage may be sufficient for weed control. Applying non-selective herbicide (glyphosate) before land preparation might be helpful to control weed in unpuddled plot as in the case of wheat (Om *et al.*, 2006), direct seeded rice (Subramanian *et al.*, 2006) and transplanted rice (Natarajan and Kuppuswarmy, 1999). There are many pre and post emergence herbicides available in the market (Komatsubara *et al.* 2009; Zahan *et al.*, 2014). Proper selection and application of herbicide at right time and right dose effectively control weed. BP showed the lowest grain yield. It was due to the lowest number of plant population and effective tillers. This lower number of effective tillers was attributed to poor establishment of the crop. Grain yield was statistically similar among CT, SPWT, ST and BP in Boro season. Sharma *et al.* (2005) reported that similar yield was obtained in transplanted rice after one pass in wet soil and conventional puddling. All tillage treatments provided similar grain yield of rice as was reported with many studies on minimum tillage even though most of this research was on rainfed crops (Sharma *et al.*, 2011) rather than transplanted rice. The present findings showed that grain yield in minimum tillage puddled and unpuddled transplanting of rice was similar to CT indicating that tillage intensity can be reduced to establish transplanted rice without sacrificing yield. The present results contradict the suggestion by Baker and Saxton (2007). Input costs included fuel, labor, machine rental charge and other expenses from seedbed preparation to harvest operations including transportation. Same amount of seed, fertilizer, pesticides and irrigation water was applied in all the plots. The number of passes and operation of costs in terms of fuel and time consumption were different among tillage options. In both season, CT showed the highest input costs due to more number of tillage passes and fuel requirement in land preparation. In both seasons, minimum tillage decreased input cost. This was coincided with Raper *et al.*, (1994) who stated that minimum tillage decreased the input costs for labor, fuel, tractors, and other equipment. In Aus season, gross return was the highest in SPWT due to the highest grain yield. In Boro season, tillage options did not show significant effect on gross return due to similar grain yield. The benefit cost ratio was found higher in SPWT, because of the higher grain yield and lower input costs. BP showed the lowest BCR due to the fact that input cost was higher as well as gross margin was lower compared to other tillage treatment.

Limitation

- Difficult to find out the strip to transplant seedling manually due to poor visibility in muddy field
- Movement of farm machinery in moist fields creates ruts and compacts soil.
- As a new technology, farmers showed the reluctance to transplant seedling in unpuddled plot
- Weed infestation is severe in unpuddled than puddle plot

Conclusion

Minimum tillage unpuddled transplanting reduced fuel consumption, time and labor requirement in land preparation. Tillage intensity can be reduced to establish transplanted rice without sacrificing yield. Single pass wet tillage could be promoted in the traditional puddled rice cultivation areas in High Barind Tract. Transplanting rice in unpuddled strip and bed was also promising in Aus and Boro season.

Recommendation

- It is needed to find out the weed management practices in unpuddled transplanting
- Transplanting can be done using mechanical transplanter in unpuddled field
- It is needed to change the mindset of the farmers to transplant seedling in unpuddled field

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Resource saving in dry season rice cultivation

Abstract

The experiment was conducted to evaluate the unpuddled transplanting of rice in high barind tract in *Boro* season during 2010. Four tillage treatments such as CT (Conventional puddling/tillage), ST (Strip tillage), BP (Bed planting) and DPDT (Double pass dry tillage) were considered in this experiment. The soil of barind tract was silt clay loam. Lands were inundated before one day of transplanting and 52 days seedlings were transplanted in puddled condition for CT and unpuddled condition for ST, BP and DPDT. Minimum tillage ST and DPDT considerably saved fuel and labor in land preparation. ST and DPDT saved 43-68% fuel in land preparation compared to CT. Minimum tillage like ST and DPDT indicated environment friendly tillage technology but labor requirement is higher in transplanting due to unpuddled land. Minimum tillage could not provide yield advantage over conventional tillage. Minimum tillage (ST, BP and DPDT) may be adaptable to establish unpuddled transplanting of dry season rice in high barind tract.

Keywords: Minimum tillage, fuel, labor, weed, yield

Introduction

Puddling makes land preparation difficult for the following wheat or other winter crops, resulting in cloddy soil structure, loss of soil moisture, delayed planting and inadequate seed-soil contact (Sharma *et al.*, 1995). Puddling should preferably be avoided as it is unfavorable practice for the succeeding upland crops. Transplanting of rice in unpuddled soils do not change agronomic and crop management practices significantly for getting the higher rice yield. Rice grown after minimum tillage can produce yields similar to that under conventional puddling with minimized expenses on field preparation (Sharma *et al.*, 1988). Minimum tillage in production systems can improve soil physical, chemical, and biological properties (Rice and Smith, 1984 and Franzluebbers *et al.*, 1994) and decrease the input costs for labor, fuel, tractors, and other equipment (Raper *et al.*, 1994). Minimum tillage has been evaluated in rice in the United States (Watkins *et al.*, 2004 and Linquist *et al.*, 2008) and in the Philippines (Mabbayad and Buensosa, 1967). These authors reported similar yields in some seasons but not in others between minimum and conventional tillage. One of the requirements of an efficient rice based production system is to decrease energy inputs. Plowing of puddled soil after rice results in the formation of large clods, having high breaking strength (Sharma and Bhagat, 1993) and very large amounts of energy and time are consumed in producing fine seed beds. Bhagat *et al.* (2003) have indicated that energy input in a conventional tillage was about 276 kWh more than that in a no-till system.There is a need for finding suitable rice establishing option that avoids field puddling. Considerable research works have been done on direct rice seeding but there is almost limited data available on unpuddled rice transplanting. Therefore, this experiment was conducted to explore the possibility of avoiding field puddling through unuddled rice transplanting under minimum tillage options in Boro season.

Materials and methods

The experiment was conducted in High Barind Tract (HBT) at the farmer's field, Khejurtala, Godagari, Rajshahi in dry season during 2010. In the HBT grey terrace soils are predominant (Brammer, 1996). These soils are mostly of silty clay surface horizons. The study area lies at 24°31'9.49"N and 88°22'14.18"E. The unit plot size was 128 m^2. Initial bulk density in 0-7.5 cm depth was 1.23 (g cm^{-3}) at 14.46 % gravimetric water content and bulk density in 7.5-15 cm depth was 1.49 (g cm^{-3}) at 14.29 % gravimetric water content. Properties of soil from upper 15 cm were pH 7.75 and organic carbon 7.15 g kg^{-1}. The treatments were as in puddle condition (i) conventional puddling (CT)and in unpuddled condition (ii) strip tillage (ST) (iii) bed planting (BP) and (iv) double pass dry tillage (DPDT). Treatments were arranged in a RCB design with three replications. Conventional puddling consisted of primary tillage using two passes by two wheel tractor (WT) and exposed to sun for two days followed by inundating whole plot and puddling by 2WT with two passes. ST and BP were done by versatile multicrop planter (VMP) in single pass operation. DPDT was done two passes dry tillage by 2WT (Photo 1). During final land preparation all cares were taken for uniform leveling of the land. Seeding was done in seedbed on 10 December 2009 and transplanting was done on 2 February 2010. Fifty-two-day-old seedling of BRRI dhan28 was hand transplanted in rows during dry season. Seedling age was higher due to excessive cold in January. Seedlings were transplanted into puddled conditions in CT whereas in unpuddled condition in ST, BP and DPDT (Photo 2). Land was inundated before one day of transplanting operation for making the land soft to transplant seedling in ST, BP and DPDT. In BP, the width of bed and furrow were 35 and 20 cm, respectively. The seedling spacing for CT, BP and DPDT was 25 x 15 cm and 20 x 15 cm for ST. Fuel consumption was measured by filling the machine's fuel tank twice, before and after each operation. Carbon dioxide emission was calculated from fuel consumption in tillage operation using the conversion factor of 2.6 kg of CO_2 per kg of diesel consumed (Grace, 2003). Post-emergence herbicide pretilachlor was applied at seven days after transplanting in all the plots to control weeds. Farmers applied fertilizer dose of 118, 174, 72, 118 and 12 kg as diammonium phosphate, urea, muriate of potash, gypsum and zinc sulfate, respectively. Photos 3-5 show the crop condition under tillage practices at different days after transplanting (DAT). At maturity, 12 hills were sampled diagonally to determine above ground total biomass, harvest index, and yield components. Panicle number of each hill was counted to determine the panicle number per m^2. Plant samples were separated into straw and panicles. The dry weight of straw was determined after oven-drying at 70°C to constant weight. Grain yield were recorded from 10 m^2 sampling area within each plot and adjusted to moisture content of 14%. The data were analyzed by statistical software Mstat-C. Least significant difference (LSD) test was performed to determine the significant differences among the treatments. Price of the input and produce was collected from the local market. Land value and interest on investment was considered to calculate the total input cost.

Bed formation Irrigation in bed

Photo 1 Bed formation and irrigation before transplanting


Strip tillage

Double pass dry tillage


Bed

Conventional plot

Photo 2 Manual transplanting in puddled and unpuddled field

Conventional tillage

Double pass dry tillage

Strip tillage

Bed

Photo 3 Crop condition at 20 DAT

Conventional tillage

Double pass dry tillage

Strip tillage

Bed

Photo 4 Crop condition at 35 DAT

Conventional tillage

Double pass dry tillage

Strip tillage

Bed

Photo 5 Crop condition at 80 DAT

Results and discussion

Fuel consumption and labor requirement

Tillage treatment showed significant effect on field capacity, fuel consumption, labor requirement for land preparation and transplanting and cost of land preparation (Table 1). Field capacity of two wheel tractor in CT was the highest due to riding type facility and the lowest of VMP in ST and BP due to walking type. ST showed the lowest fuel consumption among the tillage treatments. The lowest fuel consumption in case of ST, compared to BP may be due to negative draft and comparatively higher field capacity. Fuel consumption was the highest in BP among the minimum tillage practices due to use 24 tynes in rototiller to till and throw the soil inward for bed formation indicating more energy is needed to accomplish the task. ST and DPDT saved 68 and 43% fuel in land preparation compared to CT. CO_2 emission is directly proportional to the fuel consumption; therefore, BP incurred the highest CO_2 emission in land preparation and the lowest in ST. ST reduced 69% CO_2 emission compared to CT. Labor requirement for land preparation in ST was 62% less than in CT. The highest time was required to transplant seedlings in ST i.e. almost double the time needed compared to CT, BP and DPDT due to difficulties to locate the strip in muddy field. Labor did not face any problem to transplant seedlings in unpuddled field.

Weed infestation

In CT and DPDT, weed infestation was very low throughout the growing period due to better efficacy of pre-emergence herbicides. Therefore weeding was not required in those fields (Table 1). Weed infestation was the highest in ST and BP due to the fact that, in ST, surface of tilled portion was dry and stubble was present and in BP surface was dry and indicating that minimum tillage created favorable environment to grow weed. Pretilachlor worked well in wet condition.

Table 1 Tillage effect in land preparation, transplanting and weeding

Parameter	CT	ST	BP	DPDT	$LSD_{0.05}$	CV,%
Field capacity, ha hr^{-1}	0.14 a	0.07 c	0.05 c	0.10 b	0.02	9.5
Fuel consumption, l ha^{-1}	36 a	11 b	39 a	21 b	13.6	16.7
CO_2 emission, kg ha^{-1}	95 a	30 b	102 a	54 b	35.4	16.7
Labor requirement in land preparation, man-hr ha^{-1}	29 a	11 c	19 b	20 b	6.2	10.4
Land preparation cost, Tk ha^{-1}	2525 a	845.1 b	2314 a	1523 b	711.6	13.1
Labor requirement in transplanting, man-hr ha^{-1}	95 b	238 a	102 b	113 b	37	13.9
Labor requirement in weeding, man-hr ha^{-1}	-	386 a	182 b	-	185	65.0
Weeding cost, Tk ha^{-1}	-	9657 a	4557 b	-	4614	65.0

Plant height

Plant height was not significantly affected by tillage options at different DAT (Fig. 1). Plant height followed the increasing trend with DAT. Plant height increased progressively overtime attaining the highest at 85 DAT and thereafter decreased at maturity stage due to leaf senescence. Plant height followed rapid growth from 55to 85 DAT.

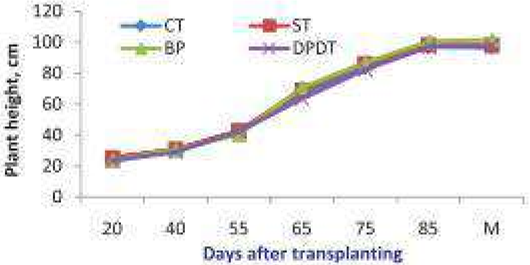

Fig. 1 Effect of tillage on plant height at different days after transplanting

Tillering pattern

Figure 3 shows the effect of tillage on tillering pattern of dry season rice. Irrespective of the tillage treatment, tillering pattern followed increasing trend upto 75 DAT and then it was decreased gradually due to tiller mortality. Tillage treatment showed significant effect on tiller production throughout the crop cycle. ST produced remarkably higher tillers than the other treatments.

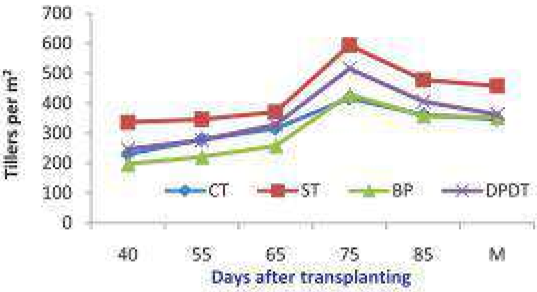

Fig. 2 Effect of tillage on tiller production at different days after transplanting

Stage-wise tiller production

Figure 3 shows the stage-wise tiller production under different treatments. ST produced the highest tillers at all the growth stages and it was more pronounced at maximum tillering stage and flowering initiation stage. Irrespective of tillage treatment, tiller number was reduced at flowering stage and maturity stage due to leaf senescence.

Yield and yield contributing character

Table 2 shows data on yield and yield contributing character. At maturity, tiller production and effective tiller was significantly affected by tillage options. ST produced maximum number of tiller and panicles while the BP gave the lowest number of panicles. Grain and straw yield was not significantly affected by tillage options although effective tiller was the highest in ST. Grain yield in unpuddled DPDT is more comparable to CT indicating that tillage intensity can be reduced to establish transplanted rice without sacrificing yield.

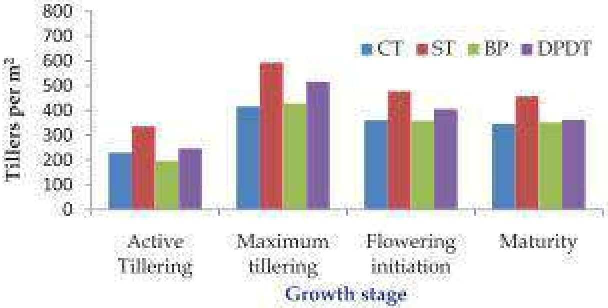

Fig. 3: Effect of tillage on tiller production at different growth stages

Table 2 Yield and yield contributing character

Tillage option	Tiller, no. m^{-2}	Effective tiller, no. m^{-2}	Grain yield, t ha^{-1}	Straw yield, t ha^{-1}
CT	346 b	255 b	5.92	5.69
ST	457 a	317 a	5.45	5.24
BP	352 b	240 b	5.17	4.97
DPDT	362 b	254 b	5.66	5.44
$LSD_{0.05}$	64.2	39.7	NS	NS
CV, %	8.47	7.45	6.02	6.02

Economic analysis

Economic productivity of unpuddled transplanting of dry season rice is shown in Table 3. Inputs cost included fuel, labor, machine rental charge and other expenses from land preparation to harvesting operation including transportation. Seed, fertilizer, insecticide and irrigation water were applied equally in all the plots. The number of passes and operation charges in terms of fuel and time consumption are different in tillage options. Land value and interest on investment was considered to calculate the total input cost.Total input cost was the highest in ST due to higher transplanting time and the lowest in DPDT. CT and DPDT showed the highest gross margin due to low input cost. BCR was similar and the highest in CT and DPDT due to less input cost, higher grain and straw yield. Rice grown in unpuddled transplanting under DPDT is more profitable than ST and BP.

Table 3 Economic productivity of unpuddled transplanted Boro rice as affected by tillage options

Tillage option	Economic productivity			
	Input cost, Tk ha^{-1}	Gross return, Tk ha^{-1}	Gross margin, Tk ha^{-1}	BCR
CT	59,173	93,315	34,142	1.58
ST	70,879	85,268	14,389	1.20
BP	61,674	81,012	19,338	1.31
DPDT	57,318	88,861	31,543	1.55

Limitation

- Difficult to find out the strip to transplant seedling manually due to poor visibility in muddy field
- As a new technology, farmers showed the reluctance to transplant seedling in unpuddled plot.
- Weed infestation is severe in unpuddled than puddle plot

Conclusion

Minimum tillage like ST and DPDT saved 43-68% fuel and 31-62% labor in land preparation. DPDT provided lower cost compared to other tillage treatment due to less fuel and labor used in land preparation. Minimum tillage could not provide yield advantage over conventional tillage. BCR obtained the highest in CT and DPDT whereas lowest in ST and BP. The results of this study indicated that minimum tillage (ST, BP and DPDT) may be adaptable to establish unpuddled transplanting of *boro* season rice in this region.

Recommendation

- It is needed to find out the weed management practices in unpuddled transplanting
- Transplanting can be done using mechanical transplanter in unpuddled field
- It is needed to change the mindset of the farmers to transplant seedling in unpuddled field
- This experiment should be carried out in Aus and Aman season and in other location to make final conclusion

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Mechanical rice transplanting

Abstract

This experiment was conducted to evaluate the performance of mechanical rice transplanter in unpuddled condition under minimum tillage practices in drought prone zone representing sandy loam soil in wet season 2012. Tillage treatments were (i) conventional puddling (CT) in puddled condition and (ii) no tillage (NT) (iii) bed planting (BP) (iv) and strip tillage (ST) in unpuddled condition. Results indicated that unpuddled transplanting saved fuel, time and labor remarkably in land preparation. Mechanical transplanting reduced farmers'drudgery and ensured timely operation. Transplanting time was higher in unpuddled plot than puddled one. Floating hill was also higher in unpuddled plot due to increase in soil hardness and unable to provide proper anchorage and gripping force to seedlings. Grain yield of unpuddled transplanting was similar to puddled transplanting. Water productivity was the lowest in unpuddled than puddled transplanting. Input cost was higher in conventional puddling than unpuddled transplanting. Mechanical transplanting overcome the constraints of manual transplanting in unpuddled condition. It might be an effective technology in rice production with limited seedling floating (9-17%) in sandy loam soil.

Keywords: Bed planting, strip tillage, floating hill, yield

Introduction

Puddling makes land preparation difficult for the following wheat or other winter crops, resulting in cloddy soil structure, loss of soil moisture, delayed planting and inadequate seed-soil contact (Sharma *et al.*, 1995). Continuation of soil puddling for rice transplanting will negate the benefits of minimum tillage in other crops in the rotation as is reported for the rice-wheat system (Sharma *et al.*, 2011). Puddling should preferably be avoided as it is an unfavorable practice for the succeeding upland crops. Sharma *et al.* (1988) revealed that rice grown after minimum tillage produced yields similar to that under conventional puddling with minimized expenses on field preparation. Alternate to puddling, unpuddled transplanting is a new concept of rice cultivation. Transplanting rice in unpuddled condition is an emerging issue in crop cultivation. Islam *et al.*, (2012) stated that rice grown in unpuddled condition in bed and strip tillage saved fuel, labor and time remarkably and produced yield similar to conventional puddling. Islam *et al.*, (2010) mentioned that almost double time was needed to transplant seedling in unpuddled than puddled plot due to poor visibility of strips under muddy flood water caused difficulties for people when transplanting seedlings in the hard surface of untilled soils. Sandy soil may regain high strength after wetting much faster than clay soils and this hampered manual transplanting in unpuddled land if it was delayed (White *et al.*, 1997). This problem can be offset by using mechanical transplanter. Moreover, timeliness of transplanting is essential for optimizing the yield and this can only be achieved through mechanical transplanting. Optimizing plant density and timeliness of operation in paddy is considered essential for optimizing paddy yield, which may be possible if dependence on hired labor is minimized (Chaudhury *et al.*, 2005). For the operation of rice transplanter, the soil flow caused by sinkage is the most critical factor affecting the performance of transplanter. Thus, if the desirable sinkage at which a particular transplanter work effectively is known, operator can take quick decision regarding machine operation at any time (Garg *et al.*, 1997). Therefore, the present study was performed to investigate the constraints to operate the mechanical transplanter in unpuddled field and to compare the economics of transplanted rice grown in puddled and unpuddled condition.

Materials and Methods

The experiment was conducted at the regional station, Bangladesh Rice Research Institute (BRRI), Rajshahi, Bangladesh representing the sandy loam soil during wet season 2012. The study area lies at 24°22´7.73″ N and 88°39´33.16″ E. Agro-climatic (rainfall, evapotranspiration and thermal condition) data were collected from the BRRI weather station (Fig. 1). Tillage treatments in the experiment were (i) conventional puddling by two wheel tractor (CT) as puddled condition and (ii) no tillage (NT) (iii) bed formed by versatile multi-crop planter (VMP) in single pass (BP) (iv) strip tillage by VMP in single pass (ST) as unpuddled condition. The treatments were arranged in a randomized complete block (RCB) design with three replications. Conventional puddling consisted of primary tillage using two passes by two WT and exposed to sun for two days followed by inundating whole plot and puddling by 2WT with two passes.

Fig 1 Mean monthly minimum and maximum temperature and rainfall during experimental period

Before land preparation, cores of undisturbed soil (0-7.5 cm and 7.5-15 cm layers) were taken with a 7.5 cm long cylinder made from cold rolled steel tubing having a 5.6 cm inside diameter. One end of the cylinder was sharpened to a knife edge. The cylinder was forced into the soil (by pounding on a piece of wood placed over the cylinder when the cylinder could no longer be manually forced into the soil) until the top edge of the cylinder was in level with the adjacent ground surface. The core then was removed with a tiling spade, the cutting knife inserted, excess soil trimmed off the bottom edge, and the 0 to 7.5 and 7.5 to 15 cm cores gently placed into separate containers. Soil samples were taken randomly in three places in each plot between rows of crops and top of beds. Weight of wet material of cores was recorded and placed in dry, clean pan and kept in the oven. The material was dried to a constant weight. Constant weight was achieved when two successive periods of drying indicate no change in the weight of the material. Soil samples were oven dried in the laboratory for the calculation of bulk density using methods described by Blake and Hartge, 1986. Hand penetrometer was used to measure the soil penetration resistance (Model: Ejkelkemo, Serial no. 27180909, Netherlands). The apparatus has a mean deviation of + and - 8%. Soil strength was measured from the soil surface to a depth of 15 cm at 2.5 cm depth increments from three points of each plot. Penetrometer readings were taken randomly in three places in subplots between rows of crops and top of bed. During final land preparation, all cares were taken for uniform leveling of the land. A fertilizer dose of 19 kg P, 33 kg K, 10kg S and 3 kg Zn as triple super phosphate, muriate of potash, gypsum and zinc sulfate, respectively was applied at final land preparation. Fuel consumption was measured by filling the machine's fuel tank twice, before and after each operation. Derived carbon dioxide emission was calculated from fuel consumption in tillage operation using the conversion factor of 2.6 kg of CO_2 per litre of diesel (Grace, 2003).

Transplanting was done by using walking type 4-row mechanical transplanter (Model DP-480, made in Korea). Mechanical transplanting required a special method of seedling raising. Seedlings were raised in tray. Rice seed BR11 was used in this experiment. In each tray, 120 gm seeds were used. Seeds were soaked on 23 June 2012 and seeding on tray was done on 26 June 2012. Sprouted seeds were spread uniformly on the tray, pressed gently and covered with another layer of soil. Water was sprinkled everyday by sprayer until complete emergence of seedlings. Seedlings were ready to transplant at 2-3 leaf stage. Fifteen-day-old seedling was transplanted mechanically during 11 July 2012. Land was inundated before one day of transplanting for maintaining soil softness to transplant seedling in unpuddled plot. The spacing was set as 30 x 14 cm. Water level in the field was kept at 2 cm only to avoid floating of seedlings. Observations on operation speed, placement depth of seedlings, number of seedlings per hill, number of missed hills, number of floating hill, total time taken for transplanting, total area covered and quantity of fuel consumed for the operation were recorded.

Photo 1 Transplanting rice in unpuddled bed

After seedling establishment, the operations such as fertilizing, weeding, pesticide application and irrigation were performed at the same time and same dose on all plots to reduce the significance of differential fertility on crop yield. A knapsack-powered blower (sprayer) was used to apply fertilizer and pesticides. Nitrogen was top dressed at 60 kg ha^{-1} as urea in three equal splits at 10 days after transplanting (DAT), 30 DAT and panicle initiation (PI) stage. First weeding was done at 25 DAT, urea and weeds were incorporated to the soil. Adequate measures were taken to keep the insect infestation to a minimum. Irrigation frequencies was counted to calculate the volume of water required for crop production. The number and duration of operations, the seed, fertilizer and pesticide rates, and the amount of human labor involved in each operation were investigated through field measurements. Water use efficiency was calculated according to Viets (1962) formula. Number of tillers in the selected hills was counted at each growth stage. Based on successive tiller count data, tillering rate and tiller mortality was calculated. Number of panicle per m^2 was measured. Grain yield was recorded from pre-selected 10 m^2 land area and adjusted moisture content of 14% moisture level. Border areas of all sides of the plot were excluded to avoid border competition effects. Statistical analysis was done by using software Mstat-C. Means were compared with least significant difference (LSD) test.

Results and discussion

Soil physical properties

Figure 2 shows the soil bulk density under different tillage treatment. It was observed that bulk density under no tilled plot was higher than the other tillage treatment.

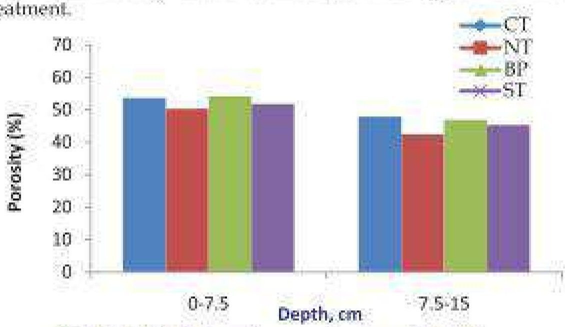

Fig. 2 Soil Bulk density according to soil depth

Soil penetration resistance

Figure 3 shows the value of penetration resistance of different tillage plots. Penetration resistance was observed the highest in NT plot compared to other tillage trial plots. In all tillage trial plots, penetration resistance was increased at a faster rate with the increase in depth.

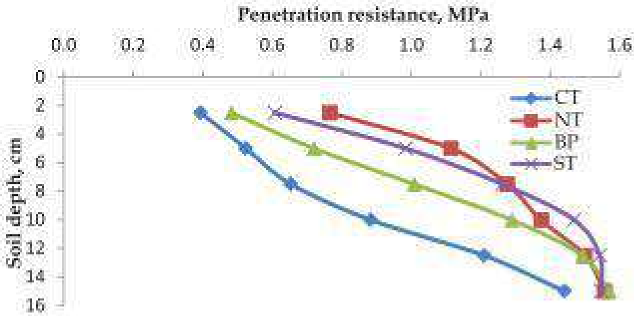

Fig. 3 Soil penetration resistance (MPa)

Fuel consumption

Tillage treatment showed significant difference in diesel fuel consumption in land preparation (Table 1). The highest the fuel was required to prepare the land in CT than the other treatments. Unpuddled plot significantly reduced the fuel consumption in land preparation i.e. 45-100% fuel can be saved in land preparation compared to CT. Minimum tillage method indicated fuel saving tillage technology in land preparation.

Labor requirement in land preparation, transplanting and weeding

Table 1 shows the labor requirement in land preparation, transplanting and weeding. Tillage treatment showed significant difference in labor requirement for land preparation. Labor requirement for land preparation was the highest in CT. BP and ST saved 71% and 83% labor, respectively in land preparation. Tillage treatment showed significant difference in labor requirement for transplanting. The highest time was required for transplanting in BP i.e. almost double the time needed compared to CT. The operator faced difficulties to operate the transplanter for seedling placement on both edges of the bed. It was observed that weeding time in unpuddled and puddled field was statistically similar. It might be due to use of herbicide (glyphosate) before land preparation as mentioned in Natarajan and Kuppuswarmy (1999) for transplanted rice.

Table 1 Tillage effect on fuel consumption, labor requirement in land preparation, transplanting and weeding

Tillage option	Fuel consumption ($l\ ha^{-1}$)	Labor requirement (man-hr ha^{-1})		
		Land preparation	Transplanting	Weeding
CT	50 a	69 a	3.52 c	344
NT	0 d	0 d	5.28 b	622
BP	27 b	20 b	7.54 a	432
ST	23 c	12 c	5.03 b	429
CV, %	1.90	3.62	10.26	8.01
$LSD_{0.05}$	0.95	1.81	1.09	NS

Floating hills

It was observed that the average floating hills were higher in unpuddled than puddled transplanting (Fig. 4). During operation of transplanter in puddle plot, water wave displaced the seedlings which influence the floating hill in CT. The higher floating hills in unpuddled soil were due to poor anchorage of seedlings. In NT and ST, it was due to increased bulk density (Fig. 2) and soil penetration resistance (Fig. 3) compared to other tillage plots. In case of BP, in some places, picker was unable to touch the edge of bed due to uneven shape of BP leading to increased floating hill. Desired planting depth is very important for proper anchorage of seedling and floating hill may be increased with the decrease in planting depth. In NT and ST, previous crop residue also hampered the release of seedling from the gripper and proper placement into the soil which ultimately increased the floating hill (16-17%) in those tillage practices. Unpuddled soil increased the hardness and could not provide proper anchorage and gripping force to seedlings resulting higher floating. Floating hills can be minimized with the optimum period of inundation. There is need to quantify the soil bearing capacity to the unpuddled soil. It was observed that unpuddled soil provided sufficient bearing capacity to prevent sinking or floating of transplanter. Gap filling was done after one day of transplanting.

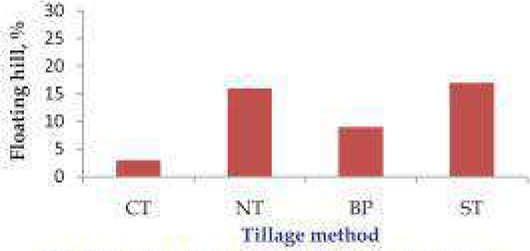

Fig. 4 Floating hills as affected by tillage options

Plant height

Figure 5 shows the changes in plant height of transplanted seedling under different tillage practices. During the crop cycle, the highest plant height was observed in CT. Although the plant height of conventional and bed planting method over time was similar but significantly differed from strip method. The lowest plant height was found in no-tilled plot probably due to lower root growth and activity in unpuddled soil condition. Plant height followed rapid growth from 42 to 94 DAT.

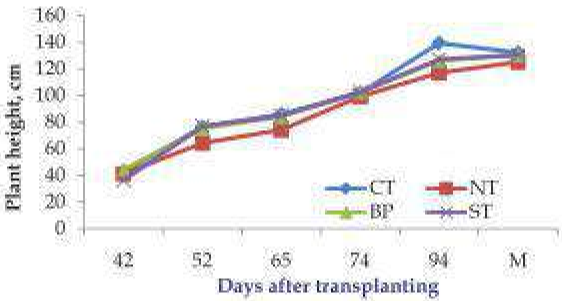

Fig. 5: Effect of tillage on plant height at different days after transplanting

Tillering pattern

Figure 6 shows the effect of tillage on tillering pattern of wet season rice. Tillage treatment did not influence the plant population throughout the crop cycle. Tillering pattern also behaved similar pattern throughout the production period. Irrespective of the tillage, tillering pattern followed increasing trend upto 40 DAT. In all the treatments, the tiller production sharply increased from 42 DAT and the maximum tillering stage reached in 52 DAT then it was decreased gradually due to tiller mortality. Strip tillage produced remarkably higher tillers than the other treatments although; the difference in tiller production at later stage was not distinguished significantly by tillage options. The result indicated that seedling establishment was equally effective both in puddled and unpuddled soil for tiller production.

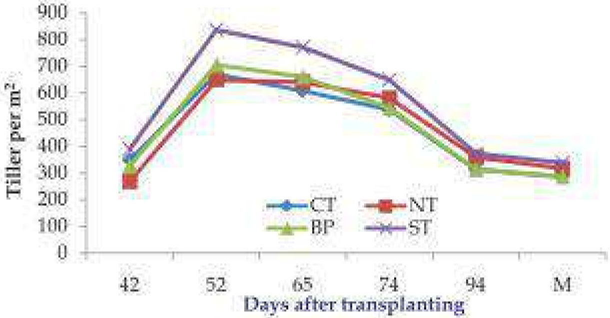

Fig. 6 Effect of tillage on tiller production at different DAT

Figure 7 shows the stage-wise tiller production under different treatments. ST produced higher tillers at all the studied stages and it was more pronounced at maximum tiller and panicle initiation stages. Irrespective of tillage, tiller number was reduced at flowering and maturity stages due to leaf senescence.

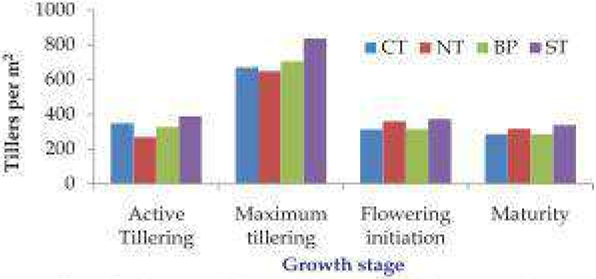

Fig. 7 Effect of tillage on tiller production at different growth stages

Percent productive tiller production

Among the yield components, productive tillers are very important because the final yield is mainly a function of the number of panicle bearing tillers per unit area. Figure. 8 presents the percent productive tiller at maturity stage under different tillage methods. It was reported that although the tiller production was higher, but all the tillers did not produce panicle. At maturity stage, tiller was aborted due to intra competition. Although the plant population under strip method was higher at both maximum tillering and maturity stage, percent productive tiller was the lowest in strip method. It might be due to dense population in strip method resulting higher competition within tillers for food and less translocation of assimilates into panicle. Tillage treatment CT, NT, BP and ST produced 39%, 44%, 37%, 36% productive tiller, respectively. It indicated a high degree of tiller mortality suggesting that rice varieties produce almost double the tillers than they need or can support. Data also indicated that tiller number was negatively correlated with percent productive tiller which was in agreement with Zhong *et al.*, (2001).

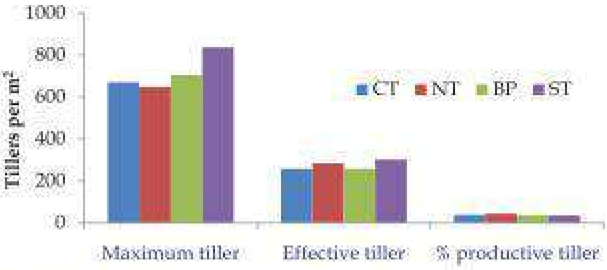

Fig. 8 Tillage effect on maximum tiller and percent productive tiller production

Water inputs and productivity

Table 2 presents the grain yield and water productivity with respect to irrigation plus rainfall. The present findings showed that grain yield in unpuddled transplanting of rice was statistically similar to conventional puddling indicating that tillage intensity can be reduced to establish transplanted rice without sacrificing yield. This was coincided with the findings as stated by Islam *et al*., (2010). Total effective rainfall during the growing season (July-December 2012) was 862 mm. Irrigation amounts varied with tillage. The highest water productivity occurred in CT (5.76 kg grain/mm water input), and the lowest was found in NT with a water productivity of 4.94 kg grain/mm water. In this experiment, average grain yield was comparable with all the tillage treatments but water productivity was 14%, 9%, and 8% lower in NT, BP and ST, respectively.

Table 2 Water productivity as affected by average grain yield and water inputs

Tillage option	Average grain yield (kg ha^{-1})	Water input (mm ha^{-1})			Water productivity (kg grain mm water^{-1})
		Irrigation	Rain fall	Total	
CT	5,365	70	862	932	5.76
NT	4,620	74	862	936	4.94
BP	4,886	66	862	928	5.27
ST	4,945	67	862	929	5.32
CV, %	8.65	5.81	-	0.43	8.54
$LSD_{0.05}$	NS	NS	-	NS	NS

Cost of land preparation and transplanting, weeding and irrigation under different tillage systems

Table 3 shows the cost of major items in crop production. Tillage treatment showed significant effect in land preparation cost. Land preparation cost was the highest in CT due to more labor requirement and fuel usage. Tillage treatment gave significant effect on transplanting cost. BP incurred the highest transplanting cost due to difficulties to operate the transplanter on the bed. Weeding and irrigation cost was statistically similar in puddled and unpuddled plot.

Table 3 Cost (Tk ha⁻¹) of land preparation and transplanting, weeding and irrigation under different tillage systems

Tillage	Land preparation	Transplanting	Weeding	Irrigation
CT	9811 a	1,087 b	10,333	516
NT	0.00 d	1,275 b	18,676	543
BP	3839 b	1,822 a	12,967	489
ST	2769 c	1,214 b	12,877	491
CV, %	1.93	10.13	8.01	5.86
$LSD_{0.05}$	158	273	NS	NS

In a row, means followed by a common letter(s) are not significantly different at 5 % level by LSD test.

Economic productivity

Input cost was the highest in BP and CT due to higher weed infestation (Table 4). The lowest variable cost was observed in ST and NT. The highest BCR was observed in CT followed by ST, NT and BP. This was due to less variable cost, higher grain and straw yield.

Table 4 Economic productivity of *aman* rice as affected by tillage options

Tillage option	Input cost ($Tk\ ha^{-1}$)	Gross return ($Tk\ ha^{-1}$)	Gross margin ($Tk\ ha^{-1}$)	BCR
CT	69,237	1,08,083	38,846	1.56
NT	69,929	94,624	24,694	1.35
BP	66,990	98,475	31,485	1.47
ST	65,995	99,627	33,631	1.51

Limitation

- In sandy loam soil, unpuddled field could not provide proper anchorage and gripping force to seedlings resulting higher floating hills
- Shape of the bed damaged due to movement of transplanter
- Difficult to dispense seedling in line with strip tilled plot

Conclusion

Unpuddled transplanting saved fuel remarkably compared to puddle transplanting. Transplanting cost was higher in BP due to difficulties to operate the transplanter on the bed. Water productivity was higher in puddled than unpuddled transplanted rice. Grain yield was statistically similar in puddled and unpuddled transplanting. Transplanting rice under no-tillage condition was less profitable than conventional puddling.

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CHAPTER IV

CONSERVATION AGRICULTURE
The cost effectiveness of rice-maize cropping systems

Abstract

Conservation agriculture practices in cereal system are gaining attention to the farmers of Bangladesh. Over the last two decades, rice (*Oryza sativa* L.)-maize (*Zea mays* L.) cropping systems have become one of the most dominant cropping systems in Bangladesh. This has coincided with the expansion in use of two-wheel tractors, which has facilitated options for minimum tillage. A three-year trial examined the prospects of conservation agriculture practices for rice-maize cropping in Bangladesh, with respect to minimum tillage and residue retention. Main plot tillage treatments of conventional full tillage, single pass wet tillage in rice (rotated with zero tillage in maize), bed planting and strip tillage were combined with residue retention treatments of 0, 50 and 100% in sub-plots. Compared to conventional tillage, minimum tillage saved 60-66% of fuel and 70-74% of labor required for land preparation. Although minimum tillage reduced the land preparation cost significantly through saving fuel and labor, weed infestation was higher compared to conventional tillage, which influenced the production cost. Rice seedlings transplanted under unpuddled strip tillage required more time than in conventional or single pass wet tillage due to poor visibility of strips and the hard surface of untilled soil. Bed planting incurred the lowest production cost. Tillage methods and residue treatment gave no significant grain yield differences. Rice grown with single pass wet tillage and maize grown with strip tillage gave the highest gross margin over time. Despite lack of treatment effects on yields, the results suggest that profitability of rice-maize cropping could be increased with minimum tillage, provided there is adequate weed control by herbicides.

Keywords: Minimum tillage, residue retention, unpuddled transplanting, fuel, labor, weeds

Introduction

Conservation agriculture (CA) is an approach to cropping that involves minimal soil disturbance for placing seeds and fertilizers, practicing diverse crop rotations and maintaining permanent soil cover using crop residues or plant canopies (Hobbs *et al.*, 2008; Kassam *et al.*, 2009). It is aimed at maintaining or improving crop yields while improving the soil resource base, minimizing inputs and increasing profitability (Baker and Saxton, 2007). Tillage was questioned for the first time in the Midwest, United States during 1930s when millions of tons of topsoil were blown away by the wind or washed into rivers. Farmers abandoned the traditional plowing system, left the crop residues on the soil surface and planted the crop directly into the stubble. In South America, farmers sowed cover crops to protect the soil, and rotated crops in order to maintain soil fertility. Brazil started no-tillage farming in the early 1970s and West Africa also tested the no-tillage and mulching. Seeding machinery developments works started in 1940s to seed directly without any soil tillage. The benefit of CA spread exponentially from farmer to farmer. By the year 2000, conservation agriculture was practiced on about 60 million hectares of land worldwide, mainly in North and South America (IIRR and ACT, 2005). The key points of conservation agriculture are to protect from soil erosion and to develop farm machinery like minimum tillage seeder, bed planter, zero-tillage seeder and strip tillage seeder. There has been widespread adoption of these practices in large-scale commercial farming around the world and possibilities for use of CA in smallholder farming are now emerging (Johansen *et al.*, 2012). Table 1 also shows the widespread practices of CA in the world.

Table 1 Conservation agriculture* by country as percent of arable land

Country	Year of report	Area under CA (1000 ha)	CA as % of arable land*
Argentina	2011	27000	71.0%
Paraguay	2013	3000	68.0%
Uruguay	2013	1072	61.0%
Brazil	2012	31811	43.8%
Canada	2013	18313	39.9%
Australia	2014	17695	37.6%
USA	2009	35613	22.5%
Chile	2008	180	13.8%
Zimbabwe	2013	332	8.3%
Colombia	2011	127	8.0%
Spain	2013	792	6.4%
China	2013	6670	6.3%
Zambia	2011	200	5.6%
Mozambique	2011	152	2.7%
Malawi	2013	65	1.7%
India	2013	1500	1.0%

(Source: FAO Conservation Agriculture Program and FAO AQUASTAT, 2014)

*Conservation agriculture defined here as disturbed soil <25% of cropped area combined with ground cover >30%. Arable land is land under temporary crops and meadows or fallow less than five years.

A major cropping system that has evolved in Bangladesh over the last two decades is transplanted monsoon season rice followed by irrigated maize in the winter season (Ali, 2008). Although this system is high yielding, it is input intensive, exploitative of the soil and subject to declining factor productivity and profitability. CA system is proven for the establishment of non-rice crop elsewhere in the world. The challenge of the rice scientists in Bangladesh is to fit the CA system in rice based cropping system as 90% rice is transplanted in puddled field. There is a need to evaluate the various minimum tillage options for the rice–maize rotation in Bangladesh, in comparison with the conventional practice. Residue retention is also an important component of CA, however, rice and maize straw are usually removed from fields in Bangladesh at harvest for such uses as fodder, fuel and building material. Nevertheless, the efficacy of retaining at least some crop residue, in combination with minimum tillage needs to be assessed. This study was designed to determine the extent to which minimum tillage options combined with crop residue retention affect input requirements, yield and profitability of a rice-maize cropping system in Bangladesh over three cropping cycles.

Materials and methods

Experimental site

A field experiment with a rice-maize rotation was conducted during 2009-2012 at the regional station of Bangladesh Rice Research Institute (BRRI), Rajshahi, Bangladesh (24°69´N and 88°30´E). The soil is classified as high Ganges river flood plain-soil type is calcareous dark grey and soil texture sandy loam (Brammer, 1996). Initial bulk density at 0-0.75 m depth was 1.24 Mg m^{-3} at 39.7 % gravimetric water content and bulk density at 0.75-1.5 m depth was 1.51 Mg m^{-3} at 26.3 % gravimetric water content. The soil pH in the experimental field was 7.96 and organic carbon was 7.9 g kg^{-1}. The soil exchangeable potassium (m equivalent 100 gm $soil^{-1}$), total nitrogen (%) and available phosphorus (mg gm $soil^{-1}$) at initiation of the experiment were 0.28, 0.05 and 15.1. Figure 1 presents the monthly rainfall and mean maximum and minimum temperature at the experimental location during the course of the study.

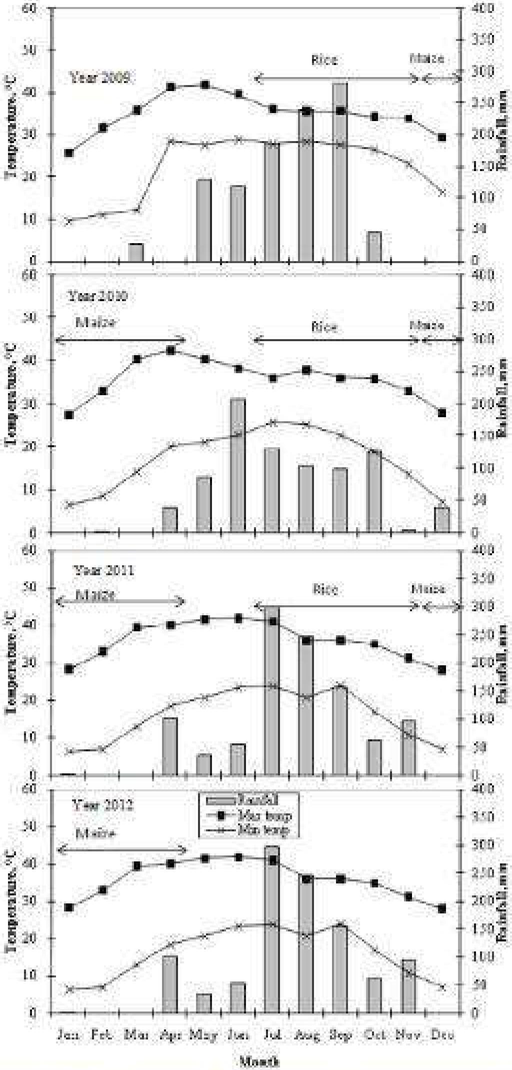


Fig 1 Mean monthly minimum and maximum temperature and rainfall at the experimental site at Rajshahi (2009-2012)

Experiment design

The experiment was laid out in a strip plot design (Gomez and Gomez, 1984) with tillage options as main plot treatments and crop residue retention in subplots, with three replications, to explore the interaction between tillage and residue retention. The tillage treatments were:

- Puddled conventional tillage (CT) for rice; CT for maize
- Puddled single pass wet tillage (SPWT) for rice; zero tillage (ZT) for maize
- Unpuddled bed planting (BP) for rice; dry BP for maize
- Unpuddled strip tillage (ST) for rice and dry ST for maize

The crop residue retention treatments in subplots were 100 % (CR_{100}), 50 % (CR_{50}) and 0 % (CR_0).Subplot size was 8.5 x 8 m. There was a 1 m wide trench between blocks to allow irrigation.

Land preparation

For rice cultivation, CT consisted of two passes of primary rotary tillage by 2WT, inundating the whole plot after two days and puddling with two passes of rotary tillage. In SPWT, there was one pass of 2WT rotary tillage after inundating the field. ST and BP for rice were done by VMP in a single pass operation, but without placing seed and fertilizer, before inundating the field. In maize cultivation, CT consisted of two passes of primary rotary tillage by 2WT and after two days, another two passes of secondary tillage. ZT, BP and ST were done in a single pass operation by VMP.

Crop agronomy

The land in unpuddled plots was fully inundated one day before transplanting of rice seedlings, which were transplanted into both puddled (CT and SPWT) and unpuddled (BP and ST) treatments. Seedling spacings were (cm): for CT 25 x 15, SPWT 25 x 15, BP 29 x 15 and ST 20 x 15. Maize seeding was done manually at a between row spacing of 60 cm and within row spacing of 20 cm. Rice variety BR11 and maize variety NK40 were grown in this experiment. Table 2 presents the dates of transplanting, age of rice seedlings, date of sowing maize seed and harvest of both the crops. As per treatment sequence, previous crop residue was spread in between rows of rice and maize at 20 days after transplanting/seeding. Residue treatments began after the first rice crop.

Table 2 Date of transplanting/seeding and harvesting of rice and maize

Crop	Date of transplanting/seeding	Seedling age (day)	Date of harvesting
1st rice	19 Aug 2009	27	30 Nov 2009
1st maize	18 Dec 2009		15 May 2010
2nd rice	09 Jul 2010	25	9 Nov 2010
2nd maize	16 Dec 2010		25 May 2011
3rd rice	12 Jul 20011	30	11 Nov 2011
3rd maize	20 Nov 2011		28 Apr 2012

Table 3 presents the fertilizer application rates for rice and maize following the recommendations of BRRI (2011) and Mondal *et. al.*, (2011). In both the crops fertilizer was applied manually. In rice cultivation, the entire amount of triple super phosphate (TSP), muriate of potash (MP), gypsum and zinc sulphate was broadcast and incorporated into the soil at final land preparation. In BP and ST, fertilizers were broadcast before tillage operation. Urea was top dressed in three equal installments. In maize cultivation, one third urea and full dose of other fertilizers were applied during last ploughing. In case of ZT, BP and ST, fertilizer was applied carefully in rows by hand after seeding at one centimeter distance from seed to avoid seed and fertilizer contact. One third of urea was applied at the 8-10 leaf stage and the rest at the 20-22 leaf stage. Weed infestation was severe in all the plots during first rice and maize crop. Hand weeding was done twice in rice and maize crops. Roundup® (a.i. 73.3% glyphosate and 2.9% diquat) was applied @ 3.75 L ha^{-1} from the second rice and maize crop one day before land preparation. Roundup® reduced the severity of weed infestation in all tillage trials, but it did not reduce the number of weeding operations in rice and maize crops. In the second and third rice crop, pre-emergence weedicide Rifit® (a.i. 50% pretilachlore) was applied @ 1 L ha^{-1} at four days after transplanting. The insecticide Sabion® (a.i. 10% diazinion) was applied @ 16 kg ha^{-1} at the vegetative stage to control stem borer (*Scirpophaga incertudas*) in rice cultivation. In rice cultivation, irrigation water was applied when needed, in measured quantities. In maize cultivation, the first, second and third irrigation was applied at the 3-5, 8-10 and 20-22 leaf stages, respectively. The fourth irrigation was applied 15-20 days after the third irrigation. Photo 1-6 show the transplanting, land preparation for maize, root development and crop condition at different growth stages. Grain yield was recorded after harvest from a pre-selected, but randomly chosen, 10 m^2 area and was adjusted to 14% moisture content for both rice and maize. Border areas of all sides of the plot were excluded from samples to avoid edge effects.

Table 3 Fertilizer application rate (kg ha^{-1}) for rice and maize

Crop	Urea	MoP	TSP	Zinc sulphate	Gypsum
Rice	175	110	80	10	100
Maize	185	277	277	17	185

Economic analysis

A simple economic analysis was done based on the total production. Production cost included rental charge of the land and input cost. The input cost was calculated by considering cost of seed, fuel, fertilizers, weedicide, hiring charges of manual labor and machine use for land preparation and sowing, irrigation and fertilizer application, plant protection, harvesting, and threshing. Fuel consumption was measured by filling the fuel tank twice, before and after each operation, with the re-filled volume being the actual fuel consumption. The gross income and net returns were calculated on the basis of market price for rice and maize grain, straw and stover. Price of the produce was based on that in the local market to compute total production cost, gross return, gross margin and benefit-cost ratio. The net returns were calculated by subtracting total variable costs from the gross income. Rice equivalent yield (REY) is an indicator of the total system productivity of the cropping system and was computed by converting the yield of maize into yield of rice on the basis of prevailing market price of the individual crops with the following equation (1):

$$REY = \frac{Y_{maize} \times P_{maize}}{P_{rice}} + Y_{rice} \qquad (1)$$

where, Y_{maize} is the yield of maize (t ha^{-1}), P_{maize} is the price of maize (Tk t^{-1}), Y_{rice} is the yield of rice (t ha^{-1}) and P_{rice} is the price of rice (Tk t^{-1}).

Statistical analysis

Statistical analysis as a one way analysis of variance was done according to Gomez and Gomez (1984). Data were analysed by using statistical software Mstat-C. Means were compared using least significant difference (LSD).

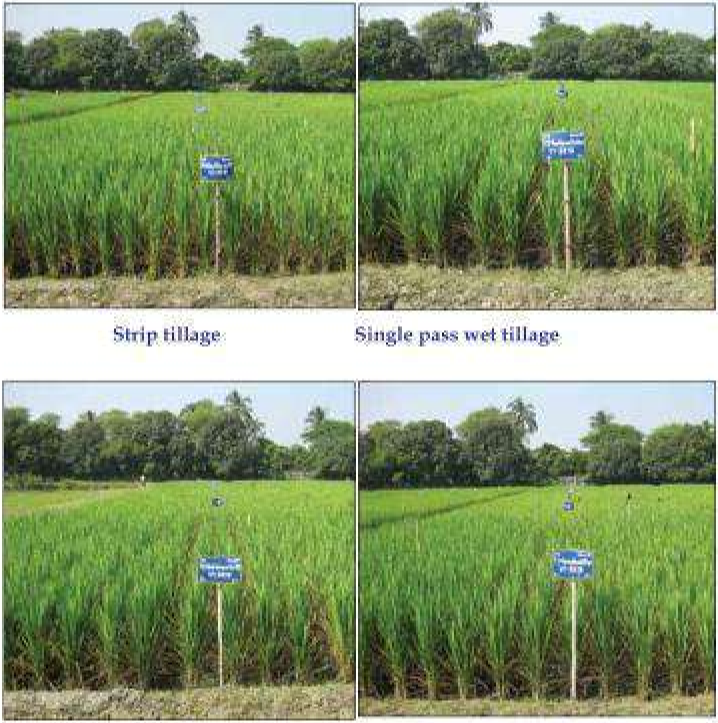
Strip tillage

Single pass wet tillage

Bed

Conventional tillage

Photo 1 Rice seedling transplanting



Strip tillage

Single pass wet tillage

Bed

Conventional tillage

Photo 2 Rice crop condition at 70 DAT


Strip tillage **Single pass wet tillage**


Bed **Conventional tillage**

Photo 3 Rice crop condition at maturity

Bed making

Zero tillage

Strip tillage

Conventional tillage

Photo 4 Land preparation for maize seeding

Conventional/bed tillage **Zero tillage**

Strip tillage **Zero tillage**

Photo 5 Root development


Bed planting Zero tillage


Strip tillage Conventional tillage

Photo 6 Maize crop condition at maturity

Results

Fuel consumption

Tillage treatment showed a significant effect on fuel consumption in land preparation in rice and maize cultivation over three seasons (Table 4). Fuel consumption was the highest in CT (39-50 L ha^{-1} for rice and 35-49 L ha^{-1} for maize) and the lowest in ST (10-24 L ha^{-1}) for rice and ZT (6-9 L ha^{-1}) for maize. Fuel consumption followed a similar trend in all rice and maize seasons. Averaged over three years, the fuel consumption for minimum tillage operations saved 66 % compared to CT for ST in both crops and SPWT in rice and 60 % for ZT in maize. BP saved the least amount (38%) of fuel compared to CT.

Table 4 Tillage effect on fuel consumption (L ha^{-1}) in land preparation in rice-maize cropping sequences, from 2009 to 2012

Tillage	Rice 2009	Maize 2010	Rice 2010	Maize 2011	Rice 2011	Maize 2012
CT	39	49	37	35	50	45
SPWT/ZT	40	0	18	6	23	9
BP	27	28	24	20	27	23
ST	10	17	19	8	24	15
CV (%)	10.4	17.6	10.6	4.3	3.1	2.4
$LSD_{0.05}$	6.0	8.2	5.1	1.5	1.9	1.1

CT = Conventional tillage, SPWT = Single pass wet tillage, ZT = Zero tillage, BP = Bed planting, ST = Strip tillage

Labor requirement in land preparation

Minimum tillage procedures significantly reduced labor requirement for land preparation in rice-maize cropping systems (Table 5). In rice cultivation, labor requirement was the highest in CT (70-100 man-hr ha^{-1}) followed by SPWT (39-60 man-hr ha^{-1}), BP (16-20 man-hr ha^{-1}) and ST (9-12 man-hr ha^{-1}). In maize cultivation land preparation included tillage, seeding and leveling, whereas in rice cultivation land preparation included tillage only. The labor requirement for land preparation for maize varied between seasons due to labor efficiency and field condition. BP and ST by VMP saved 73 and 61% labor in land preparation compared to CT. SPWT in rice followed by ZT in maize saved most labor (39%) compared to CT in land preparation.

Labor requirement in transplanting

The time required for transplanting seedlings in unpuddled ST (174-296 man-hr ha^{-1}) was almost double the time needed in CT and SPWT (Table 5). Transplanting time was lower in the second and third seasons due to improved labor efficiency.

Table 5 Labor requirement (person-hr ha^{-1}) in land preparation and transplanting in rice-maize cropping systems

Tillage	Rice 2009	Maize 2010	Rice 2010	Maize 2011	Rice 2011	Maize 2012
			Land preparation			
CT	77	275	100	243	70	354
SPWT/ZT	69	202	60	114	39	195
BP	16	61	17	89	20	102
ST	9	71	11	118	12	223
CV (%)	19.2	17.6	7.5	9.1	2.4	5.6
$LSD_{0.05}$	16.4	53.6	7.1	25.7	1.7	24.8
			Transplanting			
CT	151		107		102	
SPWT/ZT	168		107		111	
BP	201		122		111	
ST	296		187		174	
CV (%)	27.3		3.4		2.5	
$LSD_{0.05}$	15.7		8.9		6.1	

CT = Conventional tillage, SPWT = Single pass wet tillage, ZT = Zero tillage, BP = Bed planting, ST = Strip tillage, NS = Not si

Labor requirement in weeding

Weeding time for maize was the highest in the first year as no herbicide was used (Table 6). In the second rice crop, herbicide was applied during cloudy weather and rain occurred after applying herbicide, which resulted in ineffective weed control . Weeding time was the highest in unpuddled BP and ST in the rice crop and in ZT and ST in maize cultivation. Weed infestation in rice cultivation was more severe in unpuddled plots (BP and ST) than puddled plots (CT and SPWT). Crop residue retention did not significantly affect weeding time in rice cultivation, whereas in maize cultivation weeding time decreased as the level of crop residue retention increased.

Table 6 Effect of tillage and residue retention on weeding time (person-hr ha^{-1}) in rice-maize cropping systems

Tillage	Year 1							
	Rice2009				Maize 2010			
	CR_{100}	CR_{50}	CR_0	Mean	CR_{100}	CR_{50}	CR_0	Mean
				Year 1				
CT				229	613	659	685	653
SPWT/ZT				202	1,370	1,576	2,762	1,903
BP				680	639	847	1,025	837
ST				582	916	1,160	2,258	1,444
Mean					885	1,061	1,683	
$LSD_{0.05}$	Tillage (T) = 221.9				Tillage (T) = 617 Residue (CR) = 84.7 T X CR = 160.2			
CV (%)	18.67				7.45			
				Year 2				
	Rice2010				Maize 2011			
CT	578	576	555	570	156	165	175	166
SPWT/ ZT	599	622	558	594	364	357	354	359
BP	609	670	614	631	318	325	330	325
ST	659	635	621	639	127	130	126	128
Mean	611	626	587		241	244	246	
$LSD_{0.05}$	Tillage (T) = NS Residue (CR) = NS T X CR = NS				Tillage (T) = 130 Residue (CR) = NS T X CR = NS			
CV (%)	5.4				8.7			
				Year 3				
	Rice2011				Maize 2012			
CT	283	289	278	283	185	254	374	271
SPWT/ ZT	460	446	450	452	215	221	407	281
BP	476	477	461	471	199	205	341	248
ST	370	394	381	382	197	221	437	285
Mean	397	402	393		199	225	390	
$LSD_{0.05}$	Tillage (T) = 66.8 Residue (CR) = NS T X CR = NS				Tillage (T) = 26.9 Residue (CR) = 96.1 T X CR = 86.3			
CV (%)	3.42				17.89			

CT = Conventional tillage, SPWT = Single pass wet tillage, ZT = Zero tillage, BP = Bed planting, ST = Strip tillage, CR = Previous crop residue retention, CR_{100}, CR_{50} and CR_0 corresponds to 100%, 50% and 0% previous crop residue retention, NS = Not significant

Water productivity

Table 7 presents water productivity with respect to irrigation plus rainfall. Tillage treatment showed an inconsistent effect on water productivity in rice cultivation. Water productivity for rice was the highest in BP and ST in the first year, in SPWT and BP in the second year and in CT and ST in the third year. Water productivity increased as the tillage passes decreased in maize cultivation. Water productivity in maize was the highest in BP in the first year, and in ST in the second and third years.

Grain yield of rice and maize

There were no significant effects of tillage treatment or residue retention, or interaction between them, on rice or maize yields, or rice equivalent yield, in any season (Table 8).

Table 7 Water productivity (kg grain mm water^{-1}) in rice-maize cropping systems

Tillage	Year 1		Year 2		Year 3	
	Rice	Maize	Rice	Maize	Rice	Maize
CT	4.73	98.01	4.66	57.42	7.20	66.55
SPWT/ZT	4.87	89.27	5.49	64.03	6.91	67.68
BP	6.59	108.34	5.09	56.66	6.56	64.66
ST	6.16	95.84	4.37	68.36	7.03	79.26

CT = Conventional tillage, SPWT = Single pass wet tillage, ZT = Zero tillage, BP = Bed planting, ST = Strip tillage

Economic analysis

Economic analysis of rice-maize cropping systems under different tillage practices was done based on the total cost of production and average grain and straw yield (Table 9). The total cost of production was the highest in CT in the second and third seasons. Over three years, BP incurred the lowest cost in the overall rice-maize cropping systems. Gross return was the highest in BP in the first year, SPWT followed by ZT in the second year and ST in the third year due to higher grain yield. Gross margin was the highest in BP in the first year, and in ST in the second and third year. In the third year, benefit cost ratio (BCR) was increased in all the tillage options due to higher yield in that year. The highest BCR was observed in BP (1.43) in the first year and ST (1.41 and 2.27) in the second and third years because of higher gross return and lower total cost of production.

Table 8 Rice and maize grain yields and rice equivalent yield (REY) ($t\ ha^{-1}$) in rice-maize cropping systems

Tillage	Rice				Maize				REY			
	CR_{100}	CR_{50}	CR_{0}	Mean	CR_{100}	CR_{50}	CR_{0}	Mean	CR_{100}	CR_{50}	CR_{0}	Mean
Year 1												
CT	4.61	4.48	4.19	4.43	7.21	8.38	7.67	7.75	9.53	10.19	9.42	9.71
SPWT/ZT	4.66	5.21	3.82	4.56	7.17	7.51	6.32	7.00	9.55	10.33	8.13	9.33
BP	4.64	5.10	3.90	4.55	8.43	8.71	8.29	8.48	10.39	11.04	9.58	10.33
ST	4.47	4.65	3.80	4.30	6.43	7.62	7.53	7.19	8.85	9.85	8.93	9.20
Mean	4.60	4.86	3.93		7.31	8.06	7.45		9.58	10.36	9.01	
$LSD_{0.05}$	Tillage (T) = NS				Tillage (T) = NS Residue (CR) = NS T × CR = NS				Tillage (T) = NS Residue (CR) = NS T × CR = NS			
CV (%)	7.9				9.1				6.1			
Year 2												
CT	4.27	3.71	3.68	3.89	7.15	7.34	7.15	7.22	9.15	8.71	8.56	8.81
SPWT/ZT	5.06	4.37	3.86	4.43	7.65	7.77	7.54	7.66	10.28	9.67	9.00	9.65
BP	4.42	4.05	4.04	4.17	7.08	7.46	7.19	7.24	9.25	9.14	8.94	9.11
ST	3.94	3.87	4.00	3.94	7.80	7.83	7.88	7.84	9.26	9.21	9.37	9.29
Mean	4.42	4.00	3.90		7.42	7.60	7.44		9.48	9.18	8.97	
$LSD_{0.05}$	Tillage (T) = NS				Tillage (T) = NS Residue (CR) = NS T × CR = NS				Tillage (T) = NS Residue (CR) = NS T × CR = NS			
CV,%	8.8				3.7				3.7			
Year 3												
CT	7.00	6.69	6.70	6.80	11.33	11.28	11.19	11.27	14.73	14.38	14.33	14.48
SPWT/ZT	6.69	6.45	6.52	6.55	11.34	11.24	11.09	11.22	14.42	14.11	14.08	14.20
BP	6.57	6.26	6.20	6.34	11.00	10.86	11.12	10.99	14.07	13.66	13.78	13.83
ST	6.69	6.62	6.39	6.57	12.99	12.93	13.00	12.97	15.55	15.44	15.25	15.41
Mean	6.74	6.51	6.45		11.66	11.58	11.60		14.69	14.41	14.36	
$LSD_{0.05}$	Tillage (T) = NS				Tillage (T) = NS Residue (CR) = NS T × CR = NS				Tillage (T) = NS Residue (CR) = NS T × CR = NS			
CV (%)	6.3				6.3				4.7			

CT = Conventional tillage, SPWT = Single pass wet tillage, ZT = Zero tillage, BP = Bed planting, ST = Strip tillage, CR = Previous crop residue retention, CR_{100}, CR_{50} and CR_{0} corresponds to 100%, 50% and 0% previous crop residue retention, NS = Not significant

Table 9 Economic productivity of rice-maize cropping systems as affected by tillage treatment

Treatment	Total cost (US$ ha⁻¹)*	Gross return (US$ ha⁻¹)	Gross margin (US$ ha⁻¹)	BCR
		Year 1		
CT	1,690	2,371	681	1.40
SPWT/ZT	1,942	2,295	353	1.18
BP	1,753	2,523	757	1.43
ST	1,841	2,270	416	1.23
		Year 2		
CT	1,703	2,157	454	1.26
SPWT/ZT	1,703	2,346	643	1.38
BP	1,677	2,220	542	1.32
ST	1,627	2,295	668	1.41
		Year 3		
CT	1,690	3,519	1,841	2.09
SPWT/ZT	1,652	3,481	1,829	2.11
BP	1,614	3,368	1,741	2.08
ST	1,665	3,771	2,106	2.27

CT = Conventional tillage, SPWT = Single pass wet tillage, ZT = Zero tillage, BP = Bed planting, ST = Strip tillage; NS = Not significant

*1 US$ = 80 Tk

Discussion

Minimum tillage consumed less fuel compared to CT. Hernánz *et al.*(1995) and Sijtsma *et. al.*, (1998) similarly reported that a decrease in tillage intensity resulted in significant fuel savings. The time required for transplanting seedlings in unpuddled ST (174-296 person-hr ha^{-1}) was almost double the time needed in CT and SPWT. Poor visibility of strips under muddy flood water caused difficulties for labor when transplanting seedlings in the hard surface of untilled soil. Laborers complained that they had to apply more pressure to place seedlings in unpuddled fields than the puddled ones. In the first year, transplanting time was the highest in unpuddled than the puddled plots due to inexperience in transplanting seedlings in unpuddled condition. From the next rice crop, transplanting time was reduced due to experience gained from the first year. Similar problems were encountered when transplanting seedlings in BP. The whole plot was inundated one day before transplanting so the soil was not soft enough to push the seedling roots into the soil easily. Sandy soil may regain high strength after wetting much faster than clay soils and this hampered manual transplanting in unpuddled land if it was delayed (White *et al.*, 1997).

Weed infestation was more severe in unpuddled than puddled plots of rice. Weeds also more severely infested in less intensive tillage (ZT and ST) of maize. Pre-planting post-emergence herbicide was not applied before the first rice and maize crop. Weed infestation was drastically reduced due to herbicide application (glyphosate) after first rice and maize cultivation. Crop residue retention had no significant effect on weeding time in rice cultivation with application of pre-emergence weedicide (pretilachlore) at four days after transplanting. The effect of crop residue retention on weed infestation was significant in maize cultivation. Weeding time was decreased as the level of crop residue retention increased. Crop residue acted as mulch, which suppressed weeds. Weed control was a major determinant in conservation tillage. Proper selection of herbicide and its application time might reduced the weed severity.

Yield variation was inconsistent with no significant treatment differences due to tillage in three rice crops and there was no significant yield difference between puddled and unpuddled transplanting. Watkins *et al.,* (2004) and Linquist *et al.,* (2008) reported similar rice yields in some seasons but not in others between reduced/zero and conventional tillage. Yield variation was also not significantly affected by tillage in three maize crops. Research in Iowa, USA found no consistent difference in maize yields between strip till and no-till (Pierce *et al.,* 1992). On the other hand, Ghuman and Sur (2001) reported that maize grain yield increased with minimum tillage and residue retention after a production period of two years when compared with conventional tillage. In the second year of the current study, an overall decrease in grain yield was observed as compared to the first year. In this year, the application of crop residue had variable effects and maize yield appeared higher in 50% residue retention plot but this was not significant. Although residue retention had an inconsistent effect on maize yield, it had a positive effect on rice yield. In the third year, rice and maize yield was higher than in earlier years in all the treatments. This could be attributed to favorable weather, increased soil fertility due to residual effects of previously applied fertilizers and low pest and disease infestation. Maize was grown immediately after harvesting rice, which enabled it to escape cold injury.

In this study, effects of treatment on soil chemical properties were studied and will be reported in a subsequent publication. Islam (2012) observed that minor changes occurred in soil chemical properties (organic matter, nitrogen, phosphorus and potassium) in minimum tillage with residue retention after three years trial in rice-maize cropping systems. Xu *et al.* (2010) found that crop residue retention as well as changes in tillage may alter the availability of soil N, which could affect the timing and rate of N fertilization for an optimal supply of N to rice.

The total cost of production was the highest in CT in the two latter seasons. In the first rice and maize crop, weed infestation was severe and weeding cost influenced the total production cost. In other seasons, weed infestation was drastically reduced due to application of preplanting post-emergence herbicide (glyphosate). It was observed that minimum tillage reduced the land preparation cost significantly through saving fuel and labor, whereas the weed infestation was higher with less intensive tillage compared to conventional tillage causing an increase in production cost. Gross return was the highest in BP in the first year, SPWT followed by ZT in the second year and ST in the third year due to higher grain yield. In the third year, as compared with previous years, BCR was increased in all tillage options due to higher yield. The highest BCR was observed in BP in the first year and ST in the second and third years because of higher gross return and lower total cost of production. Where weeds can be managed by use of herbicides, minimum tillage treatments are generally more remunerative than conventional tillage, with strip tillage appearing most promising. However, in the third year the SPWT/ZT and BP treatments were not superior to CT.

Constraints

- Poor visibility of strips under muddy flood water caused difficulties to transplant
- Farmers showed reluctance to transplant seedling in hard surface of untilled strip tillage field
- Weed infestation is high in unpuddled bed, strip and zero tillage
- Encourage the use of post and pre-emergence herbicide
- Farmers got pain in leg during transplanting of rice seedling in unpuddled plot due to existence of previous maize roots in rice-maize cropping systems

Conclusion

Rice and maize yield did not differ significantly among various tillage and residue retention treatments during the three years of the study. Minimum tillage (SPWT, ZT, BP and ST) with residue retention saved fuel (38-61%) and labor (39-73%) in rice-maize cropping systems. Transplanting and weeding costs were highest in unpuddled than puddled plots. Unpuddled transplanting of rice did not show a yield advantage over conventional puddling. Although, no yield advantage of minimum tillage over conventional tillage was apparent in this study, production costs can generally be lowered, and profitability increased, with minimum tillage, provided there is effective herbicide to control weeds.

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CHAPTER V

SOIL HEALTH IN CONSERVATION AGRICULTURE

Soil bulk density

Abstract

Wet land rice (*Oryza sativa* L.) and dry land maize (*Zea mays* L.) are often growing in rice-maize (RM) cropping systems in different parts of Bangladesh. Tillage and residue management are among the important factors influencing the soil physical properties and crop yield. Bulk density and associated moisture content were the useful parameters for evaluating the soil quality under various tillage and residue retention in RM cropping systems. A three-year field experiment with five tillage practices namely conventional tillage (CT), single pass wet tillage (SPWT) in rice rotated with zero tillage (ZT) in maize, bed planting (BP) and strip tillage (ST) combined with three levels of previous crop residue retention (100%, 50% and 0%) were conducted to investigate the effects of various tillage practices and residue retention on soil bulk density and water content in RM cropping systems. The experiment was carried out in strip plot design with three replications. Rice was transplanted in CT and SPWT as puddle condition whereas in BP and ST as unpuddled condition. After rice harvest, minimum tillage treatments tended to decrease bulk density compared to the conventional tillage. Residue retention showed positive effect on soil physical health as it resulted in decreased bulk density. Downward trend was observed in bulk density whereas, upward trend was observed in volumetric water content with the increase in level of residue retention after three years of crop cultivation. Bulk density was the highest after harvesting maize than after harvesting rice. Soil bulk density increased with increasing depth for all tillage systems. Bulk density values were the lowest in unpuddled than puddled plot. Soil porosity in bed planting of rice and conventional tillage in maize was higher than the other treatments. Porosity in unpuddled plot was higher than puddled plot. The porosity was increased by residue retention, but the change in porosity due to residue retention was too small to be distinguished.

Keywords: Unpuddled transplanting, bulk density, porosity, moisture content

Introduction

Changes in soil physical properties due to use of reduced tillage depend on several factors including differences in soil properties, weather conditions, history of management, intensity and type of tillage (Fabrizzi *et al.*, 2005; Osunbitana *et al.*, 2005). The physical properties of the seedbed have considerable effect on seedling emergence, plant stand establishment, plant growth and yield (Ozpinar and Cay, 2006). Tillage operations increases soil porosity by loosening and reduces bulk density and mechanical impedance (Rizvi*et al.*, 1987). Tillage also increases the total soil porosity by increasing the pore size distribution and pores (Linden, 1982). An ideal soil contains about 50% solid particles and 50% pore space by volume (Hillel, 1982). Soil porosity characteristics are closely related to soil physical behavior, root penetration and water movement (Pagliai and Vignozzi 2002; Sasal *et al.*, 2006). Husnjak *et al.*, (2002) mentioned that strong direct dependence was found between crop yield and total porosity. Pores are of different size, shape and continuity and these characteristics influence the infiltration, storage and drainage of water, the movement and distribution of gases, and the ease of soil penetration by growing roots (Kay and Vanden Bygaart, 2002). Bulk density is attributable to the relative proportion and specific gravity of solid organic and inorganic particles and to the porosity of the soil. Bulk density varies with soil structural conditions, especially related to soil packing. The bulk density of a typical mineral soil is about 1.3 Mg m^{-3} (Singh *et al.*, 1992). A bulk density greater than 1.2 Mg m^{-3} (clayey soil), 1.6 Mg m^{-3} (loam soil) and 1.8 Mg m^{-3} (sandy loam soil) may adversely affect the paddy root growth (Kar *et al.*, 1976). Grossman and Berdainer (1982) proposed root limiting bulk densities of 1.47 Mg m^{-3} for clayey and 1.85 Mg m^{-3} for sandy soils to most of the feed and fiber crops of temperate regions. Bulk density is nearly always altered by tillage operations. Seedling emergence and the rate or speed of emergence was influenced by bulk density and aggregate size of the seedbed. Increases in bulk density and aggregate size of the seedbed decreased and delayed emergence. Successful stand establishment is achieved by providing the seed with an environment, which encourages early germination and emergence. Early-emerging plants contribute more to crop yield than later emerging plants (Gan *et al.*, 1992). Bulk density affected emergence through changes in the volume and continuity of pores in the seedbed (Nasr and Selles, 1995).

Conservation tillage improved soil properties *e.g.* soil water content (Moreno *et al.*, 1997) and aggregate stability and soil aggregation (McQuaid and Olson, 1998). Reduced tillage operations with elimination of ploughing may decrease soil bulk density due to less soil compaction (Maurye, 1988). Straw returning could increase the total porosity of soil (Lal *et al.*, 1980), while minimal and no tillage would decrease the soil porosity for aeration, but increase the capillary porosity; as a result, it enhances the water capacity of soil (Glab and Kulig, 2008). The effects of tillage systems and residue retention on soil properties are very important to be investigated because little information is available on this subject in Bangladesh. The physical conditions are quite reverse for RM systems. Maize is grown in dry conditions and rice is grown in puddled condition. It was hypothesized that conservation tillage with residue retention under dry and wet condition changed soil physical properties in RM cropping systems. Therefore, the present study was undertaken to focus on the changes in soil bulk density, moisture content and porosity due to combined effect of various tillage and residue retention in unpuddled RM cropping systems.

Methodology

A field experiment with a rice-maize rotation was conducted during 2009-2012 at the regional station of Bangladesh Rice Research Institute (BRRI), Rajshahi, Bangladesh (24°69´N and 88°30´E). The soil is classified as high Ganges river flood plain – soil type is calcareous dark grey and soil texture sandy loam (Brammer, 1996). Initial bulk density at 0-0.75 m depth was 1.24 Mg m^{-3} at 39.7 % gravimetric water content and bulk density at 0.75-1.5 m depth was 1.51 Mg m^{-3} at 26.3 % gravimetric water content. The experiment was laid out in a strip plot design with tillage options as main plot treatments and crop residue retention in subplots, with three replications, to explore the interaction between tillage and residue retention. The tillage treatments were:

- Puddled conventional tillage (CT) for rice; CT for maize
- Puddled single pass wet tillage (SPWT) for rice; zero tillage (ZT) for maize
- Unpuddled bed planting (BP) for rice; dry BP for maize
- Unpuddled strip tillage (ST) for rice and dry ST for maize

The crop residue retention treatments in subplots were 100 % (CR_{100}), 50 % (CR_{50}) and 0 % (CR_0). Subplot size was 8.5 x 8 m. In rice cultivation, CT consisted of two passes primary tillage by 2WT and exposed to sun for two days followed by inundating whole plot and puddling by 2WT with two passes to complete land preparation. In SPWT, one pass tillage by 2WT after inundating the field. ST and BP were done by VMP in single pass operation before inundating the field. The land was fully inundated one day before transplanting in unpuddled plots. In maize cultivation, CT consisted of two passes primary tillage by 2WT and exposed to sun for two days followed by two passes secondary tillage by 2WT to complete land preparation. ZT, BP and ST were done in single pass operation by VMP. As per treatment sequence, previous crop residue was spread in between rows of rice and maize at 20 days after transplanting/seeding. Residue incorporation was started after first rice crop. Rice variety BR11 and maize variety NK40 were grown in this experiment.

Cores of undisturbed soil (0-7.5 cm and 7.5-15 cm layers) were taken with a 7.5 cm long cylinder made from cold rolled steel tubing having a 5.6 cm inside diameter. One end of the cylinder was sharpened to a knife edge. The cylinder was forced into the soil (by pounding on a piece of wood placed over the cylinder when it could no longer be manually forced into the soil until it top edge was in level with the adjacent ground surface (Photo 1 and 2). The core then was removed with a tiling spade, the cutting knife inserted, excess soil trimmed off the bottom edge, and the 0 to 7.5 and 7.5 to 15 cm cores gently placed into separate containers. Soil samples were taken randomly in three places in subplots between rows of crops and top of bed. Weight of wet material of cores was recorded and placed in dry, clean pan and kept in the oven. The material was dried to a constant weight. Constant weight was achieved when two successive periods of drying indicate no change in the weight of the material. Moisture content was determined with the following equation.

$$Moisture\ content, \% = \frac{Weight\ of\ wet\ soil, g - Weight\ of\ dry\ soil, g}{Weight\ of\ dry\ soil, g} X\ 100 \quad (1)$$

Photo 1 Soil core

Photo 2 Measuring weight of core sampler with soil

Soil samples were oven dried in the laboratory for the calculation of bulk density and total porosity using methods described by Blake and Hartge, 1986. The total porosity of the soil was obtained from its bulk density and particle density by the following formula described by Lowery *et al.*, (1996). Particle density of soil was taken as 2.65 (Mg m^{-3}) for calculation (Freeze and Cherry, 1979).

$$Porosity, \% = 1 - \frac{Bulk\ density}{Particle\ density} \quad (2)$$

Gravimetric moisture content was multiplied by soil bulk density to obtain volumetric moisture content. Statistical analysis as a one way analysis of variance was done according to Gomez and Gomez (1984). Data were analysed by using statistical software Mstat-C. Means were compared with the least significant difference (LSD) test.

Results

Bulk density

(a) After rice harvest

Table 1 peresents soil bulk density in three seasons after rice harvest. The tillage × residue retention demonstrated no significant interaction on soil bulk density in all the three seasons after rice harvest. Tillage showed significant effect on bulk density after second rice crop at 0-7.5 cm layer only. The non-significant effect of tillage methods on soil bulk density may be attributed to low soil organic matter. Residue management had no statistical significant effect on soil bulk density. Irrespective of tillage and residue management, bulk density at the 0 – 7.5 cm depth was lower than that at 7.5 – 15 cm depth. Apparently, bulk density after third season of rice demonstrated lower value than the first or second season. At 0 – 7.5 cm and 7.5-15 cm depths, bulk density in the minimum tillage treatments tended to decrease compared to the conventional tillage consistently in second and third seasons. However, the difference was significant only in the second season as mentioned earlier. In the third season, all the tillage treatments had lower bulk density receiving 100% residue incorporation compared to the no residue incorporation. Data were averaged over three years after rice harvest with respect to crop residue retention and (Fig. 1). Irrespective of tillage, the graphs showed that bulk density values decreased with increased level of residue incorporation at two layers. The effect was more visible at 7.5-15 cm depth.

After maize harvest

Table 2 shows soil bulk density with respect to tillage and residue retention in three seasons after maize harvest. The interaction of tillage × residue retention showed insignificant effect on bulk density in all the three maize seasons. Tillage practices demonstrated insignificant effect on bulk density except in the third season at two depths. Soil bulk density increased with increasing depth for all tillage systems. After three years of maize cultivation, neither tillage nor residue incorporation (CR_{100}, CR_{50} and CR_0) had profound effect on bulk density. Data were averaged over three years after maize harvest with respect to CR (Fig. 2). In 0-7.5 cm depth, the graphs showed that downward trend was observed in bulk density with the increase in CR level. However, effect of bulk density on CR was inconsistent at 7.5-15 cm depth.

Table 1 Effect of tillage and residue retention on bulk density (Mg m^{-3}) after rice harvestin Aman season at two soil depths

Tillage	Aman 2009				Aman 2010				Aman 2011			
	CR_{100}	CR_{50}	CR_0	Mean	CR_{100}	CR_{50}	CR_0	Mean	CR_{100}	CR_{50}	CR_0	Mean
					0-7.5 cm depth							
CT				1.26	1.32	1.33	1.30	1.32	1.24	1.27	1.26	1.26
SPWT				1.26	1.30	1.33	1.34	1.32	1.23	1.25	1.23	1.24
BP				1.25	1.26	1.26	1.26	1.26	1.19	1.20	1.22	1.20
ST				1.27	1.29	1.30	1.30	1.30	1.21	1.24	1.24	1.23
Mean					1.29	1.31	1.30		1.22	1.24	1.24	
$LSD_{0.05}$	Tillage (T) = NS				Tillage (T) = 0.04 Residue (CR) = NS T × CR = NS				Tillage (T) = NS Residue (CR) = NS T × CR = NS			
CV(%)	2.58				3.03				1.60			
					7.5-15 cm depth							
CT				1.47	1.44	1.47	1.48	1.46	1.35	1.35	1.38	1.36
SPWT				1.42	1.44	1.48	1.51	1.48	1.37	1.38	1.36	1.37
BP				1.45	1.42	1.42	1.42	1.42	1.32	1.33	1.33	1.33
ST				1.47	1.44	1.47	1.50	1.47	1.33	1.36	1.38	1.36
Mean					1.44	1.46	1.48		1.34	1.36	1.36	
$LSD_{0.05}$	Tillage (T) = NS				Tillage (T) = NS Residue (CR) = NS T × CR = NS				Tillage (T) = NS Residue (CR) = NS T × CR = NS			
CV(%)	5.01				2.57				1.35			

CT = Conventional tillage, SPWT = Single pass wet tillage, BP = Bed planting, ST = Strip tillage, CR = Previous crop residue retention, CR_{100}, CR_{50} and CR_0 corresponds to 100%, 50% and 0% previous crop residue retention, NS = Non-significant

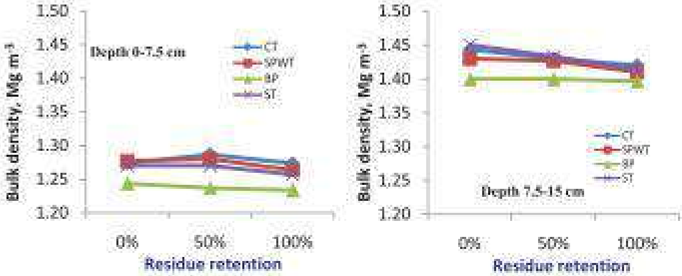

Fig. 1 Effect of residue retention on bulk density after rice harvest (average of over three years)

Table 2 Effect of tillage and residue retention on bulk density (Mg m^{-3}) after maize harvest at two soil depths

Tillage	Maize 2010				Maize 2011				Maize 2012			
	CR_{100}	CR_{50}	CR_0	Mean	CR_{100}	CR_{50}	CR_0	Mean	CR_{100}	CR_{50}	CR_0	Mean
					0-7.5 cm depth							
CT	1.20	1.23	1.24	1.22	1.29	1.29	1.27	1.28	1.25	1.33	1.21	1.26
ZT	1.25	1.32	1.30	1.29	1.30	1.33	1.27	1.30	1.23	1.31	1.27	1.27
BP	1.24	1.26	1.27	1.26	1.26	1.30	1.28	1.28	1.21	1.18	1.27	1.22
ST	1.27	1.31	1.30	1.29	1.27	1.28	1.29	1.28	1.31	1.25	1.29	1.29
Mean	1.24	1.28	1.28		1.28	1.30	1.28		1.25	1.27	1.26	
$LSD_{0.05}$	Tillage (T) = NS Residue (CR) = NS T X CR = NS				Tillage (T) = NS Residue (CR) = NS T × CR = NS				Tillage (T) = 0.04 Residue (CR) = NS T × CR = NS			
CV (%)	2.10				3.30				2.81			
					7.5-15 cm depth							
CT	1.38	1.40	1.39	1.39	1.39	1.38	1.34	1.37	1.34	1.54	1.43	1.44
ZT	1.42	1.45	1.41	1.43	1.34	1.26	1.32	1.30	1.40	1.52	1.44	1.45
BP	1.40	1.43	1.44	1.42	1.26	1.30	1.28	1.28	1.40	1.35	1.46	1.40
ST	1.45	1.46	1.50	1.47	1.39	1.34	1.40	1.38	1.52	1.44	1.45	1.47
Mean	1.41	1.44	1.44		1.35	1.32	1.34		1.41	1.46	1.45	
$LSD_{0.05}$	Tillage (T) = NS Residue (CR) = NS T × CR = NS				Tillage (T) = NS Residue (CR) = NS T × CR = NS				Tillage (T) = 0.05 Residue (CR) = NS T × CR = NS			
CV (%)	1.67				3.99				4.00			

CT = Conventional tillage, ZT = Zero tillage, BP = Bed planting, ST = Strip tillage, CR = Previous crop residue retention, CR_{100}, CR_{50} and CR_0 corresponds to 100%, 50% and 0% previous crop residue retention, NS = Non-significant

Soil bulk density

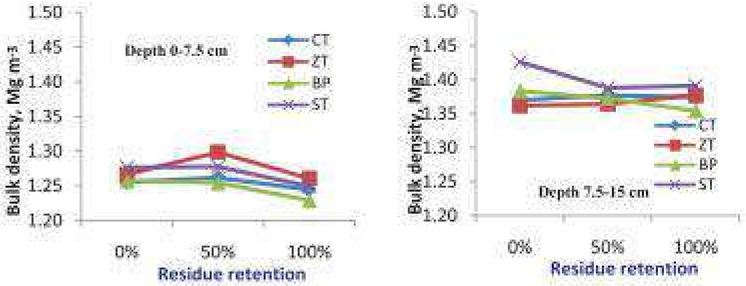

Fig. 2 Effect of residue retention on bulk density after maize harvesting (average of over three years)

Volumetric moisture content

After rice harvest

Table 3 presents the effect of tillage and residue retention on volumetric moisture content (VMC) in three rice seasons at two depths. The tillage × residue retention demonstrated not significant interaction on VMC in all the three rice season in both the layers. The effect of tillage on VMC was not significant in all the three rice seasons. VMC was the highest in all tillage during the first rice crop, decreased in during the second and increased in the third. Unpuddled BP and ST showed the lowest VMC at two depths after rice harvest. This may be due to lower water holding capacity in unpuddled than the puddlled plot. The changes in VMC for the 0-7.5 and 7.5-15 cm depths recorded after harvesting rice were the highest in SPWT and CT followed by ST and BP. The effect of CR on VMC was also found insignificant at two depths in three rice seasons. Data were averaged over three years with respect to CR (Fig. 3). In all tillage systems, there was a tendency to increase VMC with the increase in level of CR in both layers.

After maize harvest

Tillage and residue retention effect on volumetric moisture content after maize harvest in three seasons at two depths (Table 4). The tillage × residue retention had no significant effect on VMC in all the three maize seasons at two depths. The effect of tillage on VMC was significant after first maize harvest at top layer whereas, insignificant effect in the succeeding years. During second and third maize crop, ST showed the highest VMC at 0-7.5 depths. Crop residue incorporation on VMC was also non-significant in all the season. Residue retention effect on VMC was inconsistent in all the maize seasons. In all tillage systems, upward trend was observed in VMC with the increase in CR level in the both layers. Data were averaged over three years with respect to CR (Fig. 4). In all tillage systems, upward trend was observed in VMC with the increase in crop residue incorporation in both the layers.

Table 3 Effect of tillage and residue retention on volumetric moisture content (%) after rice harvest in Aman season at two soil depths

Tillage	Aman 2009				Aman 2010				Aman 2011			
	CR_{100}	CR_{50}	CR_0	Mean	CR_{100}	CR_{50}	CR_0	Mean	CR_{100}	CR_{50}	CR_0	Mean
0-7.5 cm depth												
CT				45	38	35	37	37	38	38	39	38
SPWT				44	36	37	34	36	38	37	38	38
BP				43	34	30	36	33	37	34	35	35
ST				45	36	33	36	35	38	35	39	37
Mean				44	36	34	36		38	36	38	
$LSD_{0.05}$	Tillage (T) = NS				Tillage (T) = NS Residue (CR) = NS T × CR = NS				Tillage (T) = NS Residue (CR) = NS T × CR = NS			
CV (%)	4.81				6.26				5.08			
7.5-15 cm depth												
CT				41	37	33	35	35	35	35	34	35
SPWT				41	35	36	33	35	34	31	34	33
BP				38	35	31	34	34	33	31	31	31
ST				41	34	32	34	33	31	31	32	32
Mean				40	35	33	34		33	32	33	
$LSD_{0.05}$	Tillage (T) = NS				Tillage (T) = NS Residue (CR) = NS T × CR = NS				Tillage (T) = NS Residue (CR) = NS T × CR = NS			
CV (%)	17.43				8.52				6.48			

CT = Conventional tillage, SPWT = Single pass wet tillage, BP = Bed planting, ST = Strip tillage, CR = Previous crop residue retention, CR_{100}, CR_{50} and CR_0 corresponds to 100%, 50% and 0% previous crop residue retention, NS = Non-significant

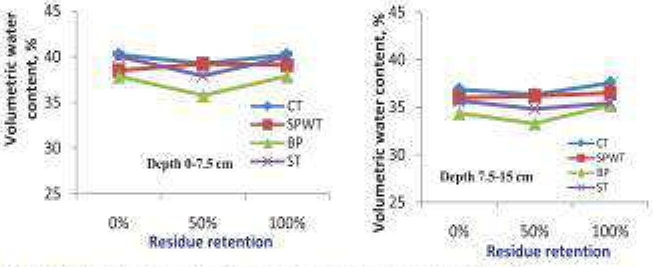

Fig. 3 Effect of residue retention on volumetric water content after rice (average of over three years)

Table 4 Effect of tillage and residue retention on volumetric moisture content (%) after maize harvest at two soil depths

Tillage	Maize 2010				Maize 2011				Maize 2012			
	CR_{100}	CR_{50}	CR_0	Mean	CR_{100}	CR_{50}	CR_0	Mean	CR_{100}	CR_{50}	CR_0	Mean
					0-7.5 cm depth							
CT	32	32	33	32	36	32	35	34	11	25	17	18
ZT	38	35	37	37	31	27	35	31	15	28	24	22
BP	33	34	33	33	36	31	34	34	18	24	21	21
ST	36	34	35	35	35	36	36	36	26	20	22	23
Mean	35	34	34		35	32	35		18	24	21	
$LSD_{0.05}$	Tillage (T) = 2.14 Residue (CR) = NS T × CR = NS				Tillage (T) = NS Residue (CR) = NS T × CR = NS				Tillage (T) = NS Residue (CR) = NS T × CR = NS			
CV (%)	7.74				13.40				17.50			
					7.5-15 cm depth							
CT	36	34	36	35	31	30	38	33	27	23	24	24
ZT	37	33	35	35	27	33	29	30	25	25	27	25
BP	36	35	34	35	33	35	30	32	29	27	21	26
ST	34	32	32	33	33	37	32	34	21	23	26	23
Mean	36	34	34		31	34	32		25	24	24	
$LSD_{0.05}$	Tillage (T) = NS Residue (CR) = NS T × CR = NS				Tillage (T) = NS Residue (CR) = NS T × CR = NS				Tillage (T) = NS Residue (CR) = NS T × CR = NS			
CV (%)	4.20				14.73				15.91			

CT = Conventional tillage, ZT = Zero tillage, BP = Bed planting, ST = Strip tillage, CR = Previous crop residue retention, CR_{100}, CR_{50} and CR_0 corresponds to 100%, 50% and 0% previous crop residue retention, NS = Non-significant

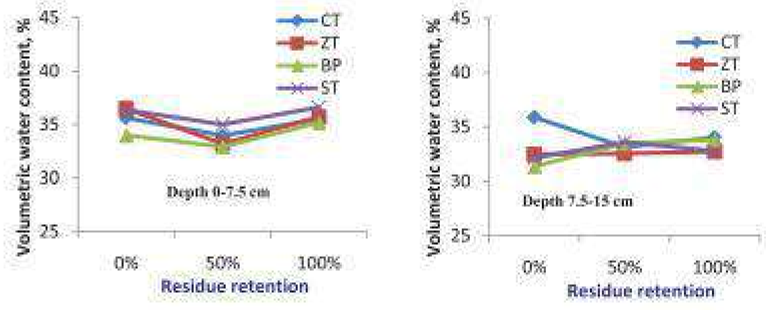

Fig. 4 Effect of residue retention on volumetric water content after maize harvest (average of over three years)

Porosity

After rice harvest

Table 5 presents the effect of tillage and residue retention on porosity at rice harvest in two depths. The tillage × residue retention demonstrated no significant interaction on porosity in the top and bottom layer during three rice seasons. The soil porosity was not affected significantly by tillage practices at 0-7.5 and 7.5-15 cm depths. Crop residue retention had no significant effect on porosity in all the years. At 0-7.5 cm depth, porosity was same at all CR levels in the second rice crop and the highest in the third. Porosity was same in all levels of CR after third rice crop at 7.5-15 cm depth. However, change in porosity due to CR was too small to be distinguished. Difference in total porosity among CR in three years was not consistent (Fig. 5). Porosity followed slightly increasing trend with the increase in level of previous crop residue retention in both the layers indicating that there might have some influence of residue retention on the porosity.

After maize harvest

Table 6 presents the soil porosity in three seasons after maize harvest. The interactive effect of tillage × residue retention in the top and bottom layer demonstrated no significance in all three maize seasons. The total soil porosity was not affected significantly by tillage methods at 0-7.5 and 7.5-15 cm depths. Crop residue retention had no significant effect on porosity in all the maize seasons. The results of this study showed that the effect of CR on soil porosity was varied to the depth. Effect of CR on porosity was not consistent at three seasons. Figure 6 shows that porosity followed slightly increasing trend with the increase in level of crop residue incorporation in both the layers indicating that residue retention level increases the porosity.

Table 5 Effect of tillage and residue retention on porosity after rice harvest at two soil depths

Tillage	Aman 2009				Aman 2010				Aman 2011			
	CR_{100}	CR_{50}	CR_0	Mean	CR_{100}	CR_{50}	CR_0	Mean	CR_{100}	CR_{50}	CR_0	Mean
0-7.5 cm depth												
CT				52	50	50	51	50	53	52	53	53
BP1/ SPWT				52	51	50	50	50	54	53	54	53
BP				53	53	53	53	53	55	55	54	55
ST				52	51	51	51	51	54	53	53	54
Mean					51	51	51		54	53	53	
$LSD_{0.05}$	Tillage (T) = NS				Tillage (T) = NS Residue (CR) = NS T × CR = NS				Tillage (T) = NS Residue (CR) = NS T × CR = NS			
CV (%)	2.34				2.91				1.38			
7.5-15 cm depth												
CT				45	46	45	44	45	49	49	48	49
BP1/ SPWT				46	46	44	43	44	48	48	49	48
BP				45	46	47	46	46	50	50	50	50
ST				45	46	44	43	45	50	49	48	49
Mean					46	45	44		49	49	49	
$LSD_{0.05}$	Tillage (T) = NS				Tillage (T) = NS Residue (CR) = NS T × CR = NS				Tillage (T) = NS Residue (CR) = NS T × CR = NS			
CV (%)	6.08				3.13				1.41			

CT = Conventional tillage, BP1 = CT+ bed formed manually, SPWT = Single pass wet tillage, BP = Bed planting, ST = Strip tillage, CR = Previous crop residue retention, CR_{100}, CR_{50} and CR_0 corresponds to 100%, 50% and 0% previous crop residue retention, NS = Non-significant NB. Treatment BP1 was used in the first year and SPWT was used in the succeeding year

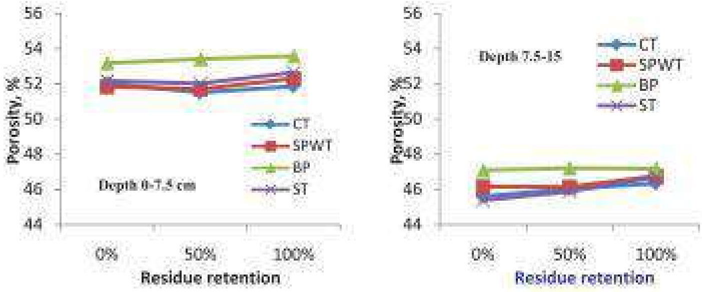

Fig. 5 Effect of residue retention on porosity after rice harvest (average of over three years)

Table 6 Effect of tillage and residue retention on porosity after maize harvest at two soil depths

Tillage	Maize 2010				Maize 2011				Maize 2012			
	CR_{100}	CR_{50}	CR_0	Mean	CR_{100}	CR_{50}	CR_0	Mean	CR_{100}	CR_{50}	CR_0	Mean
					0-7.5 cm depth							
CT	55	54	53	54	52	51	52	52	53	50	54	52
ZT	53	50	51	51	51	50	52	51	54	51	52	52
BP	53	53	52	53	53	51	52	52	54	56	52	54
ST	52	51	51	51	52	52	51	52	50	53	51	51
Mean	53	52	52		52	51	52		53	52	52	
$LSD_{0.05}$	Tillage (T) = NS Residue (CR) = NS T × CR = NS				Tillage (T) = NS Residue (CR) = NS T × CR = NS				Tillage (T) = 1.63 Residue (CR) = NS T × CR = NS			
CV (%)	1.92				3.10				2.54			
					7.5-15 cm depth							
CT	48	47	47	48	48	48	49	48	49	42	46	46
ZT	46	45	47	46	50	52	50	51	47	43	46	45
BP	47	46	46	46	49	49	48	49	47	49	45	47
ST	45	45	44	45	48	49	47	48	43	46	45	45
Mean	47	46	46		49	50	49		47	45	45	
$LSD_{0.05}$	Tillage (T) = NS Residue (CR) = NS T × CR = NS				Tillage (T) = NS Residue (CR) = NS T × CR = NS				Tillage (T) = 2.14 Residue (CR) = NS T × CR = NS			
CV (%)	1.94				4.17				4.76			

CT = Conventional tillage, ZT = Zero tillage, BP = Bed planting, ST = Strip tillage CR = Previous crop residue retention, CR_{100}, CR_{50} and CR_0 corresponds to 100%, 50% and 0% previous crop residue retention, NS = Non-significant

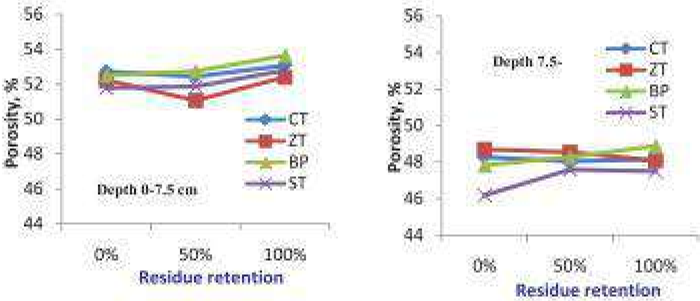

Fig. 6 Effect of residue retention on porosity after maize harvest (average of over three years)

Discussion

Bulk density values were the highest after harvesting maize than after harvesting rice might be due to swelling of pores in wet land rice cultivation. The BP treatment showed progressiv decrease in bulk density with the increase in residue amounts. However, the consistent effect of residue incorporation was too low to be significant statistically. Literature suggested that the settlement of aggregate after puddling and formation of crust in puddled layer increase soil bulk density (Schwartz *et al.*, 2003). Shrinkage of soils after puddling may contribute to the increase in bulk density. The bulk density values in 0-15 cm soil layer did not differ much amongst the treatments. This may be attributed to minimum changes in the structure of ST and maximum in CT due to intense puddling and consequent maximum re-aggregation in CT. Ishaq *et al.*, (2002) also observed no significant effect of tillage methods on soil bulk density. In the top layer, bulk density was the highest under minimum tillage and the lowest in CT. Diaz-Zorita (2000) observed a decrease in bulk density with increase in tillage intensity especially deep tillage decreased the bulk density. Moreno *et al.*, (1997) reported higher bulk density in conservation tillage than conventional tillage systems. However, reduced tillage operations with elimination of plowing may decrease soil bulk density due to less soil compaction (Maurye, 1988). In contrast, Grant and Lafond (1993) reported that bulk density was higher in conventional tillage than in minimum tillage at a depth of 0-5 cm, but bulk density was higher in minimum tillage than in conventional tillage in the deeper layers. The climatic differences (rainfall distribution pattern) may produce some contradictory results. In the present study, ST showed the highest bulk density in all the years at 7.5-15 cm depth. Scheiner and Lavado (1998) reported higher soil bulk density in case of no-tillage. The results of the present study coincided with Soane (1990) and Felton and Ali (1992). Vyn and Raimbault (1993) reported higher bulk density for no-tillage compared with moldboard tillage during early maize growth. The effect of residue incorporation on bulk density was also found non-significant in all the three seasons after maize harvest. Receiving 100% residue, all the tillage treatments had lower bulk density compared to no residue incorporation. This may be due to increase in the organic matter from decomposition of residue in top soil. Increase in soil organic matter usually decreases bulk density (Ishaq *et al.*, 2002). A slight increase in bulk density due to incorporation of 50% residue compared to no residue incorporation was observed after second and third maize crop. After third maize harvest, bulk density value with respect to tillage ranged from 1.22-1.29 Mg m^{-3} and 1.40-1.47 Mg m^{-3} in 0-7.5 cm and 7.5-15 cm depth, respectively. Bulk density values with respect to CR ranged from 1.25-1.27 Mg m^{-3} and 1.41-1.46 Mg m^{-3} in 0-7.5 cm and 7.5-15 cm depth, respectively. Kar *et al.*, (1976) reported that bulk density greater than 1.6 Mg m^{-3} for loam soil adversely affected the root growth. Erbach (1987) mentioned that the magnitude of bulk density for agricultural soils commonly varied from 0.9 to 1.8 Mg m^{-3}. The present bulk density values were below as mentioned in Kar *et al.*, (1976) and Erbach (1987). The bulk density value obtained from this study did not restrict the root development.

The soil porosity after rice and maize harvest was not affected significantly by tillage practices at 0-7.5 and 7.5-15 cm depths. Similar finding was obtained from Borresen and Njos (1993). The porosity was the highest in the top layer compared to the bottom layer in all the tillage treatments. Porosity in the top layer was decreased in the second year and increased in the third. In BP and ST, similar trend was observed at the bottom layers. Katsvairo *et al.*, (2002) reported similar effect of moldboard (51%), chisel (51%) and ridge tillage (49%) on soil porosity. Porosity in unpuddled plot was higher than puddled plot in both the layers. This might be due to settlement of aggregate and shrinkage of soil pores in puddling. Cassel *et al.*, (1995) reported that the tillage intensity caused increase in porosity especially chisels and moldboards plow tillage when compared with no-tillage, which is in contrast to this finding. Conventional and deep tillage have greater porosity compared with minimum tillage during early maize growth (Cassel *et al.*, 1995). Tillage increased the total soil porosity by increasing the pore size distribution and pores (Linden, 1982). Crop residues are supposed to enhance total soil porosity because organic matter increases the pore-size distribution and pore-number and improved soil aggregation.

Conclusion

Bulk density values were the highest after harvesting maize than after harvesting rice. The bulk density values in 0-15 cm soil layer did not differ much amongst the treatments. Bulk density was the highest under minimum tillage and the lowest in conventional tillage. Bulk density was the lowest in unpuddled than the puddled soil. The effect of residue incorporation on bulk density was also found non-significant in all the three seasons. All the tillage treatments receiving 100% residue had lower bulk density compared to no residue incorporation. The bulk density values obtained from this study were below the critical level and did not restrict the root development. Porosity in unpuddled plot was higher than puddled plot. Tillage and residue retention improved soil porosity in RM cropping systems. Upward trend was observed in porosity with the increase in level of residue retention after three years of crop cultivation in RM cropping systems.

Recommendation

The experiment on the changes in soil physical properties due to tillage and residue retention should be continued for more years to get the consistent effect.

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Soil penetration resistance

Abstract

Soil penetration resistance may restrict the root to move into the deeper soil layers. However, information on penetration resistance in unpuddled rice-maize cropping system is lacking. This experiment was conducted to investigate the effects of various tillage practices and residue retention on soil penetration resistance in rice-maize cropping system. In this cropping system, rice was transplanted in irrigated condition and maize was sown in dry condition. Soil manipulation system is different in rice-maize cropping system. ZT plot in maize was converted to SPWT during rice cultivation. The highest penetration resistance was obtained from ST and the lowest was detected in CT. Downward trend was observed in penetration resistance with the increase in level of residue retention after three years of crop cultivation in rice-maize cropping systems. Penetration resistance increased in minimum tillage practices. However, residue retentions had little effect on penetration resistance in this cropping system. Penetration resistance values under different tillage residue retention level in rice-maize cropping systems were below the critical value regarded as sufficient to promote the root growth.

Keywords: Unpuddled transplanting, strip tillage, bed planting, zero tillage, residue retention, soil strength

Introduction

Penetration resistance is a common measure of soil strength and an indicator of how easily roots can penetrate into soil, and thus a measure of plant growth and crop yield (Singh *et al.*, 1992). Several studies have negatively correlated root development with increasing resistance (Hasegawa *et al.*, 1985; Martino and Shaykewich, 1994; Busscher *et al.*, 2000). Soil compaction is known to restrict plant root growth, reduce water and nutrient uptake, and thereby impede plant development (Carr and Dodds 1983; Ishaq *et al.*, 2001). These detrimental effects subsequently reduce crop yields (de Willigen and van Noordwijk 1987). Wilkens *et al.* (2002) reported similar results for no-tillage and conventional tillage on a silt loam soil. They also reported that the conversion from a tilled to no-tilled cropping system caused an increase in soil strength significantly. Soil penetration resistance was greater under reduced tillage and no-tillage than conventional tillage (Hill and Cruse, 1985). It is important that there is adequate seed soil contact to facilitate water movement into the seed, and that there is adequate aeration. Most commonly, adequate seed-soil contact is obtained by light packing with rollers or press-wheels. However, excessive pressure can lead to compaction of the seedbed, which may delay germination (Dexter, 1988). Rickman *et al*. (1965) reported that maize growth and yield potential were well related with soil bulk density and penetration resistance. Bauder *et al*., (1981) reported that penetration resistance ranked as follows: moldboard plow < chisel plow < spring disk = no till in a clay loam soil. Bowen (1981) mentioned that poor plant growth and reduction of crop yields due to soil compaction have been recognized as early as plowing was practiced and encouraged. Moreno *et al*., (1997) reported higher bulk density and penetration resistance in conservation tillage than conventional tillage systems.

Soil strength is affected by soil type, clay content, voids, water content, bulk density, soil depth, and soil tillage systems. Carter *et al*., (1965) found that seed cotton yield decreased linearly from 3.6 to 1.45 Mg ha^{-1} as soil strength increased from 0.3 to 4 MPa. Penetration resistance above the 2-3 MPa level is generally considered slow for root growth (Bengough and Mullins, 1990; Vepraskas, 1994). Soils with more clay than sand tend to show more cohesion and strength (Lal and Shukla, 2004). Several studies have found penetration resistance increases with depth, whereas the tillage system is less influential as depth increases (Erbach *et al*., 1992; Unger and Jones, 1998; Vyn and Raimbault, 1993). Shallow hardpans are very common in the rainfed lowland and appear to impede root penetration (Kundu *et al*., 1996; Wade *et al*., 1999). Mielke *et al*., (1984) and Erbach *et al*., (1992) obtained the lowest penetration resistance from moldboard plow. Many experiments have shown that crop yields decreased as the strength of soil layers increased. The reduction of crop growth and yield is attributed to penetration resistance. There is a need to combine tillage practices with recycling of crop residues in energy conscious world. The effects of tillage systems and residue retention on soil physical properties are very important to be investigated because there is little information on this subject in Bangladesh. The physical conditions are quite reverse for RM systems. Maize is grown in dry conditions and rice is grown in puddled condition. Alternate to minimum tillage component of conservation tillage, unpuddled transplanting of rice is appeared as resource saving technology and gaining attention to the farmers in Bangladesh (Islam *et al*., 2010 and Haque *et al*., 2016). It was hypothesized that conservation tillage with residue retention changed the penetration resistance in unpuddled RM cropping systems. Therefore, the present study was proposed to study the combined effect of tillage and residue retention on penetration resistance in unpuddled rice-maize cropping system.

Methodology

A field experiment with a rice-maize rotation was conducted during 2009-2012 at the Bangladesh Rice Research Institute (BRRI), Regional Station, Rajshahi, Bangladesh (24°69´N and 88°30´E). The soil is classified as high Ganges river flood plain – soil type is calcareous dark grey and soil texture sandy loam (Brammer, 1996). Initial bulk density at 0-0.75 m depth was 1.24 Mg m^{-3} at 39.7 % gravimetric water content and bulk density at 0.75-1.5 m depth was 1.51 Mg m^{-3} at 26.3 % gravimetric water content. The experiment was laid out in a strip plot design with tillage options as main plot treatments and crop residue retention in subplots, with three replications, to explore the interaction between tillage and residue retention.

The tillage treatments were:

- Puddled conventional tillage (CT) for rice; CT for maize
- Puddled single pass wet tillage (SPWT) for rice; zero tillage (ZT) for maize
- Unpuddled bed planting (BP) for rice; dry BP for maize
- Unpuddled strip tillage (ST) for rice and dry ST for maize

The crop residue retention treatments in subplots were 100% (CR100), 50% (CR50) and 0 % (CR0). Subplot size was 8.5 x 8 m. Rice was grown in wet season (Aman) and maize is grown in dry season (rabi). In rice cultivation, CT consisted of two passes primary tillage by 2WT and exposed to sun for two days followed by inundating whole plot and puddling by 2WT with two passes to complete land preparation. In SPWT, one pass tillage by 2WT after inundating the field. ST and BP were done by versatile multi-crop planter (VMP) in single pass operation before inundating the field. The land was fully inundated one day before transplanting in unpuddled plots. Seedlings were transplanted into puddled conditions (CT and SPWT) and unpuddled conditions (BP and ST). In maize cultivation, CT consisted of two passes primary tillage by 2WT and exposed to sun for two days followed by two passes secondary tillage by 2WT to complete land preparation. ZT, BP and ST were done in single pass operation by VMP. As per treatment sequence, previous crop residue was spread in between rows of rice and maize at 20 days after transplanting/seeding. Residue incorporation was started after first rice crop. Rice variety BR11 and maize variety NK40 were grown in this experiment. Handpenetrometer was used to measure the soil penetration resistance (Model: Ejkelkemo, Serial no. 27180909, Netherlands). The apparatus has a mean deviation of + and - 8%. Soil strength was measured from the soil surface to a depth of 15 cm at 2.5 cm depth increments from three points of each plot after harvesting rice and maize. Penetrometer readings were taken randomly in three places in subplots between rows of crops and top of bed (Photo 1).

Photo 1 Measurement of soil penetration resistance

Result

After rice harvest

Table 1 shows the effect of tillage intensity and residue retention on penetration resistance (PR) after rice harvest. The effect of tillage × residue retention on PR showed no significant effect in all the three seasons. Tillage practices demonstrated insignificant effect on PR in all the three rice seasons upto 15 cm depth except 5, 7.5, 12.5 cm depth after second rice crop and 5, 7.5 and 10 cm depth after third rice crop. PR value was the highest in unpuddled BP and ST and the lowest in puddled CT and SPWT. PR was the lowest in CT followed by SPWT, BP and ST up to 10 cm depth. PR in puddled CT and SPWT increased at slow rate upto 7.5 cm depth after that PR increased at faster rate. CR showed insignificant effect of PR up to 15 cm depth in all three rice crops after harvest. PR value with all levels of residue retention was the lowest under puddled than unpuddled plot. PR followed the decreasing trend as the level of residue retention increases upto 10 cm depth. In most of the cases, PR increased with the increased level of CR. Rate of change in PR was slow up to 7.5 cm depth. After 7.5 cm depth, PR increased with faster rate. Below 12.5 cm, PR value was almost similar with all levels of CR. The trend is almost similar at all tillage depth. Data were averaged over three years after rice harvest with respect to CR in (Fig. 1). The graphs showed that downward trend was observed in PR with the increase in level of CR up to 10 cm depth. Figures 2 and 3 indicate that the penetration resistance reduced due to residue incorporation and increased in minimum tillage after rice harvest.

Table 1 Effect of tillage and residue retention on penetration resistance (MPa) after rice harvest at different soil depths

Tillage	Aman 2009				Aman 2010				Aman 2011			
	CR_{100}	CR_{50}	CR_{0}	Mean	CR_{100}	CR_{50}	CR_{0}	Mean	CR_{100}	CR_{50}	CR_{0}	Mean
					2.5 cm depth							
CT	0.41	0.39	0.41	0.40	0.63	0.72	0.56	0.64	0.43	0.44	0.48	0.45
SPWT	0.44	0.44	0.57	0.49	0.73	0.84	0.82	0.80	0.53	0.52	0.49	0.51
BP	0.38	0.56	0.57	0.51	0.71	0.88	1.02	0.87	0.47	0.54	0.54	0.52
ST	0.40	0.48	0.44	0.44	0.85	1.09	1.13	1.02	0.57	0.51	0.46	0.52
Mean	0.41	0.47	0.50		0.73	0.88	0.88		0.50	0.50	0.49	
$LSD_{0.05}$	Tillage (T) = NS Residue (CR) = NS T × CR = NS				Tillage (T) = NS Residue (CR) = 0.10 T × CR = NS				Tillage (T) = NS Residue (CR) = NS T × CR = NS			
CV (%)	24.16				14.36				11.44			
					5 cm depth							
CT	0.51	0.45	0.48	0.48	0.59	0.66	0.60	0.62	0.44	0.44	0.49	0.46
SPWT	0.46	0.48	0.62	0.52	0.72	0.91	0.87	0.83	0.50	0.52	0.52	0.51
BP	0.40	0.57	0.58	0.52	0.77	0.94	0.93	0.88	0.49	0.59	0.61	0.56
ST	0.45	0.53	0.65	0.55	0.98	1.20	1.24	1.14	0.66	0.73	0.61	0.67
Mean	0.46	0.51	0.58		0.77	0.93	0.91		0.52	0.57	0.56	
$LSD_{0.05}$	Tillage (T) = NS Residue (CR) = NS T × CR = NS				Tillage (T) = 0.28 Residue (CR) = 0.11 T × CR = NS				Tillage (T) = 0.12 Residue (CR) = NS T × CR = NS			
CV (%)	24.16				15.93				11.79			
					7.5 cm depth							
CT	0.55	0.56	0.57	0.56	0.56	0.81	0.65	0.67	0.41	0.45	0.46	0.44
SPWT	0.53	0.50	0.80	0.61	0.80	0.97	0.99	0.92	0.50	0.55	0.52	0.52
BP	0.43	0.57	0.55	0.52	0.93	1.15	1.06	1.04	0.63	0.75	0.82	0.73
ST	0.63	0.57	0.82	0.68	1.19	1.25	1.33	1.25	0.94	1.02	0.93	0.96
Mean	0.54	0.55	0.69		0.87	1.05	1.01		0.62	0.69	0.68	
$LSD_{0.05}$	Tillage (T) = NS Residue (CR) = NS T × CR = NS				Tillage (T) = 0.37 Residue (CR) = NS T × CR = NS				Tillage (T) = 0.11 Residue (CR) = NS T × CR = NS			
CV (%)	28.54				14.38				12.96			

Table 1 Continued

Tillage	Aman 2009				Aman 2010				Aman 2011			
	CR_{100}	CR_{50}	CR_0	Mean	CR_{100}	CR_{50}	CR_0	Mean	CR_{100}	CR_{50}	CR_0	Mean
					10 cm depth							
CT	0.67	0.82	0.92	0.80	0.97	1.04	0.85	0.95	0.46	0.54	0.65	0.55
SPWT	0.67	0.65	0.93	0.75	0.93	1.03	1.22	1.06	0.87	0.85	0.80	0.84
BP	0.60	0.68	0.76	0.68	0.98	1.25	1.18	1.14	1.01	1.05	1.13	1.06
ST	0.91	0.81	0.91	0.88	1.29	1.36	1.40	1.35	1.25	1.23	1.16	1.22
Mean	0.71	0.74	0.88		1.04	1.17	1.16		0.90	0.92	0.94	
$LSD_{0.05}$	Tillage (T) = NS Residue (CR) = NS T × CR = NS				Tillage (T) = NS Residue (CR) = NS T × CR = NS				Tillage (T) = 0.24 Residue (CR) = NS T × CR = NS			
CV (%)	33.31				13.58				21.76			
					12.5 cm depth							
CT	1.13	1.32	1.04	1.16	1.39	1.24	1.36	1.33	0.94	0.99	1.34	1.09
SPWT	1.18	1.11	1.19	1.16	1.18	1.26	1.34	1.26	1.32	1.22	1.03	1.20
BP	0.88	1.28	1.09	1.08	1.25	1.36	1.34	1.32	1.38	1.39	1.28	1.35
ST	1.40	1.24	1.15	1.26	1.46	1.40	1.42	1.43	1.40	1.27	1.37	1.35
Mean	1.15	1.24	1.12		1.32	1.32	1.37		1.26	1.22	1.26	
$LSD_{0.05}$	Tillage (T) = NS Residue (CR) = NS T × CR = NS				Tillage (T) = 0.09 Residue (CR) = NS T × CR = NS				Tillage (T) = NS Residue (CR) = NS T × CR = NS			
CV(%)	22.29				7.83				17.63			
					15 cm depth							
CT	1.32	1.32	1.15	1.26	1.39	1.33	1.39	1.37	1.46	1.46	1.45	1.46
SPWT	1.20	1.21	1.23	1.21	1.31	1.37	1.39	1.36	1.43	1.23	1.34	1.33
BP	1.18	1.32	1.24	1.25	1.38	1.36	1.36	1.37	1.46	1.45	1.48	1.46
ST	1.42	1.24	1.29	1.32	1.44	1.40	1.42	1.42	1.47	1.50	1.49	1.49
Mean	1.28	1.27	1.23		1.38	1.37	1.39		1.46	1.41	1.44	
$LSD_{0.05}$	Tillage (T) = NS Residue (CR) = NS T × CR = NS				Tillage (T) = NS Residue (CR) = NS T × CR = NS				Tillage (T) = NS Residue (CR) = NS T × CR = NS			
CV(%)	17.38				4.31				5.04			

CT = Conventional tillage, SPWT = Single pass wet tillage, BP = Bed planting, ST = Strip tillage, CR = Previous crop residue retention, CR_{100}, CR_{50} and CR_0 corresponds to 100%, 50% and 0% previous crop residue retention, NS = Non-significant

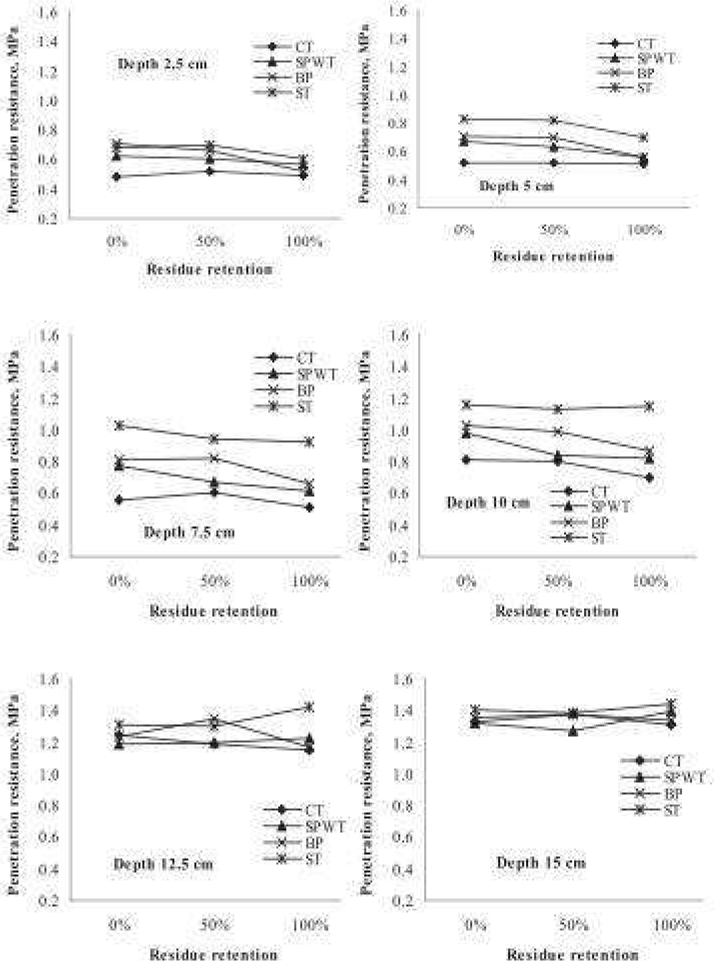

Fig. 1 Effect of residue retention with respect to tillage on penetration resistance after rice harvest (average of over three years)

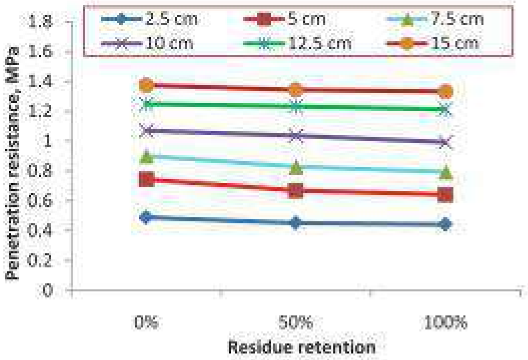

Fig. 2 Effect of residue retention on penetration resistance after rice harvest (average over three years and four tillage)

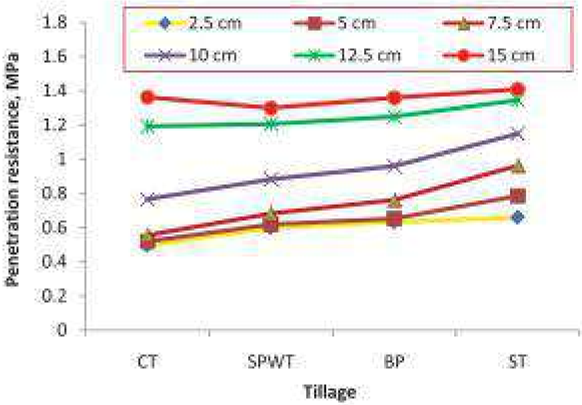

Fig. 3 Effect of tillage on penetration resistance after rice harvest (average over three and three levels of residue retention)

After maize harvest

Penetration resistance in three seasons after maize harvest is given in table 1. The combined effect of tillage × residue retention was not significant in all the three maize seasons. Tillage practices showed significant effect on PR after maize harvest. PR in ZT and ST was detected as the highest with any levels of CR than other tillage treatments. Data were averaged over three years with respect to CR and presented in Fig. 4. The data showed that downward trend was observed in PR with the decrease in level of CR upto 7.5 cm depth. Figures 5 and 6 indicate that the penetration resistance reduced due to residue incorporation and increased in minimum tillage after maize harvest.

Table 2 Effect of tillage and residue retention on penetration resistance after maize harvest at different soil depths

Tillage	Maize 2010				Maize 2011				Maize 2012			
	CR_{100}	CR_{50}	CR_0	Mean	CR_{100}	CR_{50}	CR_0	Mean	CR_{100}	CR_{50}	CR_0	Mean
					2.5 cm depth							
CT	0.24	0.29	0.30	0.28	0.26	0.26	0.33	0.28	0.44	0.34	0.40	0.39
ZT	0.67	0.54	0.71	0.64	0.41	0.45	0.36	0.41	0.73	0.79	0.78	0.77
BP	0.36	0.39	0.35	0.37	0.22	0.28	0.32	0.27	0.50	0.48	0.46	0.48
ST	0.68	0.62	0.70	0.67	0.35	0.36	0.43	0.38	0.57	0.52	0.73	0.61
Mean	0.49	0.46	0.52		0.31	0.34	0.36		0.56	0.53	0.59	
$LSD_{0.05}$	Tillage (T) = 0.21 Residue (CR) = NS T × CR = NS				Tillage (T) = NS Residue (CR) = NS T × CR = NS				Tillage (T) = 0.225 Residue (CR) = NS T × CR = NS			
CV (%)	27.84				16.34				15.46			
					5 cm depth							
CT	0.39	0.46	0.55	0.47	0.34	0.36	0.40	0.37	0.59	0.49	0.50	0.52
ZT	0.82	0.90	1.10	0.94	0.63	0.61	0.57	0.60	1.00	1.25	1.09	1.11
BP	0.50	0.56	0.52	0.53	0.33	0.42	0.46	0.41	0.69	0.67	0.80	0.72
ST	0.94	0.94	1.06	0.98	0.53	0.58	0.68	0.60	0.93	0.81	1.20	0.98
Mean	0.66	0.72	0.81		0.46	0.49	0.53		0.80	0.81	0.90	
$LSD_{0.05}$	Tillage (T) = 0.35 Residue (CR) = NS T × CR = NS				Tillage (T) = 0.13 Residue (CR) = NS T × CR = NS				Tillage (T) = 0.31 Residue (CR) = NS T × CR = NS			
CV (%)	16.9				11.84				14.19			
					7.5 cm depth							
CT	0.57	0.70	0.72	0.66	0.39	0.48	0.55	0.47	0.75	0.60	0.61	0.65
ZT	0.93	1.00	1.11	1.01	0.67	0.67	0.66	0.67	1.18	1.40	1.25	1.28
BP	0.64	0.69	0.69	0.67	0.45	0.53	0.57	0.52	0.89	0.98	1.15	1.01
ST	1.04	1.15	1.22	1.14	0.68	0.71	0.86	0.75	1.19	1.19	1.41	1.26
Mean	0.80	0.89	0.94		0.55	0.60	0.66		1.00	1.04	1.11	
$LSD_{0.05}$	Tillage (T) = 0.30 Residue (CR) = NS T × CR = NS				Tillage (T) = 0.20 Residue (CR) = NS T × CR = NS				Tillage (T) = 0.31 Residue (CR) = NS T × CR = NS			
CV (%)	11.50				11.67				12.00			

Table 2 Continued

Tillage	Maize 2010				Maize 2011				Maize 2012			
	CR_{100}	CR_{50}	CR_0	Mean	CR_{100}	CR_{50}	CR_0	Mean	CR_{100}	CR_{50}	CR_0	Mean
					10 cm depth							
CT	0.98	1.12	1.04	1.05	0.54	0.67	0.66	0.63	0.99	0.85	0.81	0.88
ZT	1.00	1.17	1.15	1.10	0.78	0.80	0.84	0.81	1.25	1.46	1.41	1.37
BP	0.85	0.94	0.90	0.90	0.66	0.69	0.75	0.70	1.20	1.21	1.45	1.29
ST	1.17	1.29	1.26	1.24	0.91	0.92	1.04	0.96	1.39	1.49	1.53	1.47
Mean	1.00	1.13	1.09		0.72	0.77	0.82		1.21	1.25	1.30	
$LSD_{0.05}$	Tillage (T) = 0.24 Residue (CR) = NS T × CR = NS				Tillage (T) = NS Residue (CR) = NS T × CR = NS				Tillage (T) = 0.27 Residue (CR) = NS T × CR = NS			
CV (%)		5.67				14.34				10.57		
					12.5 cm depth							
CT	1.19	1.28	1.22	1.23	0.71	1.05	1.01	0.92	1.26	1.23	1.14	1.21
ZT	1.21	1.23	1.18	1.21	1.00	1.06	1.01	1.02	1.39	1.56	1.55	1.50
BP	1.01	1.14	1.13	1.09	1.06	0.92	1.04	1.01	1.38	1.56	1.54	1.49
ST	1.23	1.29	1.27	1.26	1.24	1.27	1.33	1.27	1.51	1.55	1.56	1.54
Mean	1.16	1.24	1.20		1.00	1.08	1.10		1.39	1.48	1.45	
$LSD_{0.05}$	Tillage (T) = 0.10 Residue (CR) = NS T × CR = NS				Tillage (T) = 0.24 Residue (CR) = NS T × CR = NS				Tillage (T) = NS Residue (CR) = NS T × CR = NS			
CV (%)		6.88				10.82				7.38		
					15 cm depth							
CT	1.23	1.28	1.25	1.25	1.06	1.39	1.27	1.24	1.42	1.50	1.41	1.44
ZT	1.30	1.27	1.25	1.27	1.27	1.22	1.43	1.31	1.45	1.64	1.58	1.56
BP	1.24	1.27	1.31	1.28	1.37	1.48	1.46	1.44	1.58	1.56	1.57	1.57
ST	1.25	1.29	1.28	1.28	1.35	1.38	1.45	1.39	1.53	1.55	1.57	1.55
Mean	1.26	1.28	1.27		1.26	1.37	1.40		1.49	1.56	1.53	
$LSD_{0.05}$	Tillage (T) = NS Residue (CR) = NS T × CR = NS				Tillage (T) = NS Residue (CR) = NS T × CR = NS				Tillage (T) = NS Residue (CR) = NS T × CR = NS			
CV (%)		4.03				6.39				5.17		

CT = Conventional tillage, ZT = Zero tillage, BP = Bed planting, ST = Strip tillage, CR = Previous crop residue retention. CR_{100}, CR_{50} and CR_0 corresponds to 100%, 50% and 0% previous crop residue retention. NS = Non-significant

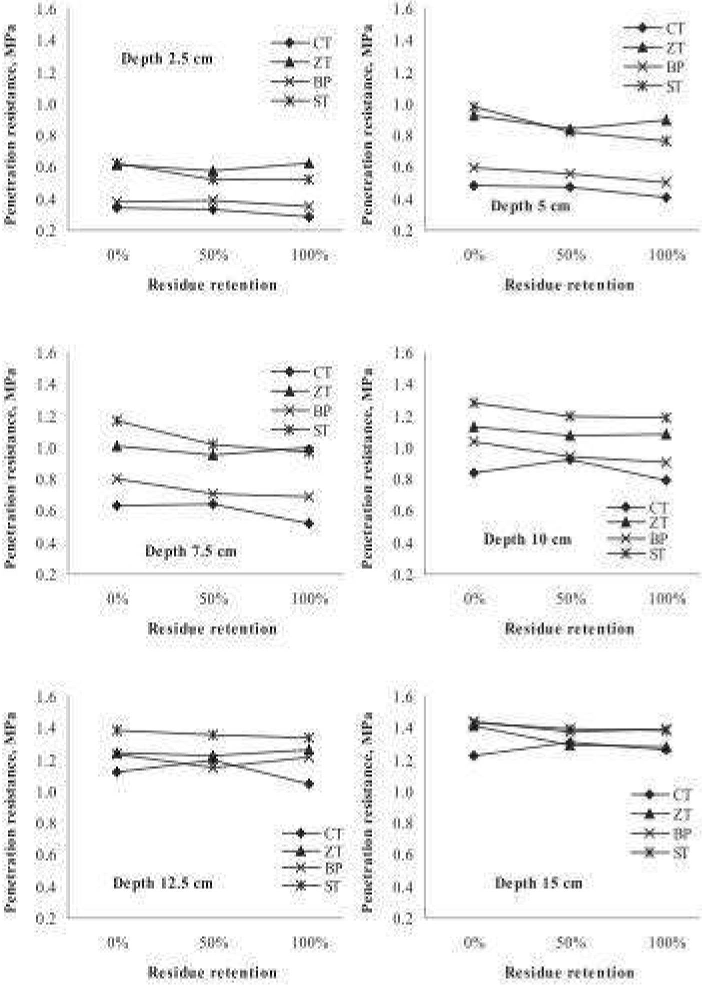

Fig. 4 Effect of residue retention with respect to tillage on penetration resistance after maize harvest (average over three years)

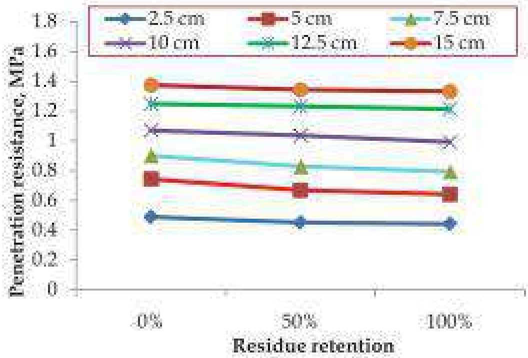

Fig. 5 Effect of residue retention on penetration resistance after maize harvest (average over three years and four tillage)

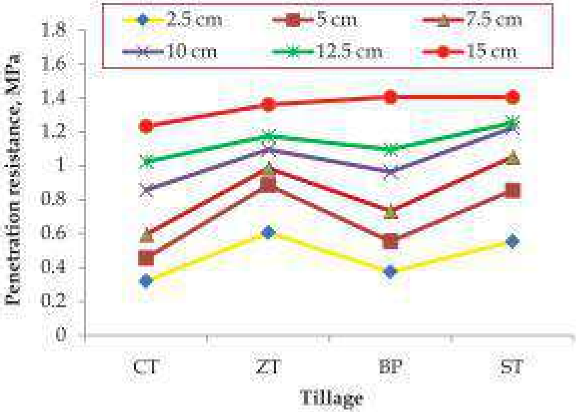

Fig. 6 Effect of tillage on penetration resistance after maize harvest (average over three years and three levels of residue retention)

Discussion

Penetration resistance (PR) in puddled CT and SPWT increased at slow rate up to 7.5 cm depth after that PR increased at faster rate. This trend might be progressive settlement of heavier particles at the lower part of the puddle layer. Previous workers (Painuli *et al.*, 1988; Bhagat *et al.*, 1994; Painuli, 2000) reported that PR decreased with puddling and increased with depth. This may be attributed to progressive consolidation of the puddled layers due to a layer-wise settling of soil particles and re-aggregation. PR in ST always higher than other tillage treatment due to transplant seedling in less disturbance unpuddled soil. PR value was the lowest in puddled plot than unpuddled plot. This might be due to loose particles and saturated soil condition. PR changed with depth faster in ST. Unpuddled BP also behaved the same. Since, ST and BP were not exposed to puddling there was no major structural change in this treatment. Several studies have found that penetration resistance increases with depth, whereas the tillage system was less influential as depth increased (Erbach *et al.,* 1992; Unger and Jones, 1998; Vyn and Raimbault, 1993). In three years study, tillage (puddled and unpuddled) has profound effect on PR but residue retention have little effect on PR after rice harvest. In maize cultivation, higher penetration resistance in conservation tillage than conventional tillage systems was observed in this study. This was coincided with the findings of Moreno *et al.,* (1997) and Wilkens *et al.* (2002). PR in CT and BP increased at slow rate up to 12.5 cm depth after that PR increased at faster rate. PR changed with depth faster in ST and ZT. The PR in CT was the lowest due to intensity of tillage during maize cultivation. CR showed non-significant effect on PR after maize harvest. PR value was the lowest with 100% residue incorporation than without residue incorporation. PR in ZT and ST was detected the highest with any level of CR than the other tillage treatments due to fewer disturbances of soil. PR with respect to CR increased at slow rate up to 7.5 cm depth and at faster rate after 10 cm depth. Murdock *et al.,* (1995) suggested that penetrometer measurement of 2 MPa generally regarded as sufficient to hinder the growth and development of crops. The PR values of the present findings were below the suggested value.

Conclusion

Penetration resistance was the highest in unpuddled than puddled plot. Penetration resistance reduced due to residue incorporation and increased in minimum tillage after three years RM cropping systems. Values of penetration resistance are below the critical level and did not restrict the crop stand.

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Soil chemical properties

Abstract

Soil organic matter, nitrogen (N), phosphorus (P) and potassium (K) nutrition of rice-maize cropping systems are important for sustaining crop productivity and food security. An experiment was conducted to determine the effects of tillage practices and residue retention on soil chemical properties in rice-maize cropping systems. Conventional tillage, single pass wet tillage in rice (rotated with zero tillage in maize), bed planting (unpuddled rice transplanting) and strip tillage (unpuddled rice transplanting) in vertical plots and residue retention (0, 50 and 100%) in horizontal plot were tested for three consecutive years in rice-maize cropping systems in strip-plot design. Rice was grown as transplanted irrigated crop and maize as upland crop. After third crop, strip tillage increased soil organic matter compared to bed and zero tillage at 0-7.5 cm soil depth. After three years, retention of crop residues, irrespective of tillage treatment, increased SOM at 7.5-15.0 cm soil depth. Tillage practices (puddled or unpuddled) showed no significant changes in SOM. Neither tillage nor residue management had any significant effect on soil pH, total nitrogen available phosphorus and exchangeable potassium in rice-maize cropping system.

Keywords: Tillage, residue retention, pH, organic matter, nitrogen, phosphorus, potassium

Introduction

Organic matter differs in stage of decomposition and degree of association with mineral material (Kay and VandenBygaart, 2002). These different forms of soil organic matter (SOM) collectively represent a reservoir of nutrients that are critical for plant growth. The tillage impacts on SOM varied due to soil type, cropping system, residue management and climatic conditions (Marschner *et al.*, 2008). Tillage systems that reduce soil disturbance and residue incorporation have generally been observed to increase SOM content (Mrabet *et al.*, 2001). Ismail *et al.* (1994) concluded that conservation tillage systems results in significant and positive effects on several chemical soil properties. SOM content declined when soil was tilled to a depth of 10 cm (Stockfisch *et al.*, 1999). Carter (1992) reported that conservation tillage practices may lead to high soil organic carbon (SOC) contents in surface soil than conventional tillage system or moldboard plough. The loss of SOM due to tillage may be considered a function of soil type, climatic condition and cropping practice (Lal *et al.*, 1998). Short term influence of tillage on transfer of soil carbon to atmospheric CO_2 in semi-arid soil is small (Ellert and Janzen, 1999). Therefore, long term conservation tillage practices were highly effective in improving SOC under semi-arid environment (Moreno *et al.*, 1997). The conversion to no-till may increase SOC pool by about 10 Mg ha^{-1} in 5-20 years (Paustian *et al.*, 1997). Conflicting results also exist regarding tillage practices and SOM content in surface soil. Dick (1983) reported higher organic C and N contents in no-tillage than conventional tillage system. Conventional tillage practices have resulted in lower carbon contents of agricultural soils due to increased decomposition rates and carbon redistribution (Christensen, 1996). The SOM largely contributes to nutrient cycling and thus supply of N, S and other elements as well (Saleque *et al.*, 2009). Soil cultivation reduces organic matter and alters distribution and stability of soil aggregates (Six *et al.*, 1999). The decreased soil crusting, bulk density, runoff and erosion are also attributed for increased SOM levels. The most common method to enhance SOM is crop rotation, residue management and the application of farm manure (Kirchmann and Witter, 1992). The ability of soil to retain nutrients is increased by addition of organic materials and this play a major role in reducing soil erosion and maintaining long term soil health and productivity. Improved nutrient management and soil conservation practices are gaining importance in research and policy communities (Khan *et al.*, 2007). Verma and Bhagat (1992) reported that the incorporation of rice straw in wheat caused a slight increase in an availability of P, Mn and Zn and a marked increase in the availability of K. There is a need to combine tillage practices with nutrient management practices, including recycling of crop residues in energy conscious world. The effects of tillage systems and residue retention on soil properties are very important to be investigated because there is little information on this subject in Bangladesh. Physical conditions are quite reverse for rice-maize system. Maize is grown in dry conditions, whereas rice is grown in wet land conditions. Rice grown in minimum tillage unpuddled transplanting decreased the production cost and increased the profitability (Islam *et al.*, 2014). Unpuddled transplanting is gaining attention to the rice growing farmers in Bangladesh. It was hypothesized that minimum tillage with residue retention under dry and wet conditions would change chemical properties in rice-maize cropping systems. Therefore, the objective of present investigation is to determine the effects of tillage and residue management on soil chemical properties in rice-maize cropping systems.

Materials and methods

A field experiment with a rice-maize rotation was conducted during 2009-2012 at the regional station, BRRI, Rajshahi, Bangladesh (24°69´N and 88°30´E). The soil is classified as high Ganges river flood plain – soil type is calcareous dark grey and soil texture sandy loam (Brammer, 1996). The soil pH in the experimental field was 7.96 and organic carbon 7.9 g kg^{-1}. The soil exchangeable potassium (m equivalent 100 gm $soil^{-1}$), total nitrogen (%) and available phosphorus (mg gm $soil^{-1}$) at initiation of the experiment were 0.28, 0.05 and 15.1. The experiment was laid out in a strip plot design with tillage options as main plot treatments and crop residue retention in subplots, with three replications, to explore the interaction between tillage and residue retention. The tillage treatments were:

- Puddled conventional tillage (CT) for rice; CT for maize
- Puddled single pass wet tillage (SPWT) for rice; zero tillage (ZT) for maize
- Unpuddled bed planting (BP) for rice; dry BP for maize
- Unpuddled strip tillage (ST) for rice and dry ST for maize

The crop residue retention treatments in subplots were 100% (CR_{100}), 50% (CR_{50}) and 0 % (CR_0). Subplot size was 8.5 x 8 m. In rice cultivation, CT consisted of two passes primary tillage by 2WT (wheel tractor) and exposed to sun for two days followed by inundating whole plot and puddling by 2WT with two passes to complete land preparation. In SPWT, one pass tillage by 2WT after inundating the field. ST and BP were done by versatile multi-crop planter (VMP) in single pass operation before inundating the field. The land was fully inundated one day before transplanting in unpuddled plots. In maize cultivation, CT consisted of two passes primary tillage by 2WT and exposed to sun for two days followed by two passes secondary tillage by 2WT to complete land preparation. ZT, BP and ST were done in single pass operation by VMP. As per treatment sequence, previous crop residue was spread in between rows of rice and maize at 20 days after transplanting/seeding. Residue incorporation was started after first rice crop. Rice variety BR11 and maize variety NK40 were grown as indicator crops. Table 1 presents fertilizer application rates for rice and maize following the recommendations of BRRI (2011) and Mondal *et al.*, (2011). In both crops fertilizer was applied manually. In rice cultivation, the entire amount of triple super phosphate (TSP), muriate of potash (MP), gypsum and zinc sulphate was broadcast and incorporated into the soil at final land preparation. In BP and ST, fertilizers were broadcast before tillage operation. Urea was top dressed in three equal installments. In maize cultivation, one third urea and full dose of other fertilizers were applied during last plowing. In case of ZT, BP and ST, fertilizer was applied carefully in rows by hand after seeding at one centimeter distance from seed to avoid seed and fertilizer contact. One third of urea was applied at the 8-10 leaf stage and the rest at the 20-22 leaf stage. Weed infestation was severe in all the plots during first rice and maize crop. Hand weeding was done twice in rice and maize crops. Roundup® (a.i. 73.3% glyphosate and 2.9% diquat) was applied @ 3.75 L ha^{-1} from the second rice and maize crop one day before land preparation. Roundup® reduced the severity of weed infestation in all tillage trials but it did not reduce the number of weeding operations in rice and maize crops. In the second and third rice crop, pre-emergence weedicide Rifit® (a.i. 50% pretilachlore) was applied @ 1 L ha^{-1} at four days after transplanting. The insecticide Sabion® (a.i. 10% diazinion) was applied @ 16 kg ha^{-1} at the vegetative stage to control stem borer (*Scirpophaga incertulas*) during rice cultivation. In rice cultivation, irrigation water was applied when needed, in measured quantities. In maize cultivation, the first, second and third irrigation was done at the 3-5, 8-10 and 20-22 leaf stages, respectively. The fourth irrigation was done 15-20 days after the third irrigation.

Table 1 Fertilizer application rate (kg ha^{-1}) for rice and maize

Crop	Urea	MoP	TSP	Zinc sulphate	Gypsum
Rice	175	110	80	10	100
Maize	185	277	277	17	185

Soil samples were taken randomly in three places in subplots between rows of crops and top of bed at a depth of 0-7.5 cm and 7.5-15 cm before starting the next crop. Chemical analysis was done in Soil Resource Development Institute (SRDI) laboratory, Rajshahi.

Measurement of soil pH in water

First 10 g soil was taken into a small beaker, 25 ml water was added and frequently stirred for 50 minutes. Then the beaker was left for 10 minutes without stirring. The pH meter electrode was rinsed with soil suspension and the electrode was immersed in soil suspension and measurement was taken when display was stable. For each 10-soil sample or less; pH meter was checked in one of the buffer solutions. Calibration procedure was repeated as and when necessary.

Determination of organic matter

In soil samples without $CaCO_3$, the content of total carbon was determined with the help of LECO C-200 Analyzer. In soil samples with a content of $CaCO_3$, a correction of total carbon content, as determined with LECO C-200 Analyzer, is required to obtain the content of organic carbon. All soil samples to be analyzed for organic carbon were checked for $CaCO_3$ by adding a small amount of the soil to a dish or beaker containing 10 % hydrochloric acid. If effervescence occurs, the soil contains $CaCO_3$ and the content of $CaCO_3$ must be determined. The content of organic carbon is calculated as follows.

$$\% \text{ organic C} = \% \text{ total C} - 0.12 \times \% \ CaCO_3 \quad (1)$$
$$\% \text{ organic matter} = \% \text{ organic C} \times 1.724 \quad (2)$$

Determination of potassium

Soil extraction

First 2.50 g soil was taken into a dry conical flask. Then 25 ml 1 M ammonium acetate was added (using a pipette). Shaking for 30 minutes and left for overnight. Care was taken to avoid evaporation from the flask. Using filter paper whatman no. 42 the extract was filter using a dry funnel into a dry beaker or flask.

Calculations

$$\text{Cmol(+) K per kg soil} = \text{meq K per 100 g soil} = \frac{a \times 25}{g} \quad (3)$$

Where,

a = cmol(+) K per l measured on the flame photometer,
g = g soil used for the analysis

Determination of phosphorus

The content of available P was determined by Olsen method. All P was determined colorimetrically after neutralization when necessary with dilute HCl and NaOH and the neutral pH indicated by the light yellow color of the solution in the presence of P-nitro phenol indicator. Absorbance for P was determined at a wavelength of 710 nm by double beam spectrophotometer.

Determination of total nitrogen

Three steps processes were followed to determine total nitrogen. First digestions of the soil sample second distillation of the sample and third step titration of the sample.

Digestion First 3 g soil was taken into a tube. Then one-gram catalyst mixture and 5 ml conc. H_2SO_4 was added to the tube. Digestion was continued for two hours at 390ºC temperature. The exhaust pump was started and the regulating valve was opened fully. After about five minutes the suction rate was reduced by almost closing the regulating valve. The digester was turned off, the rack with the tubes was removed from the digester and placed it beside the digester for cooling. Suction was continued for five minutes, the exhaust manifold was removed from the tubes, and the exhaust pump was turned off.

Distillation of Samples From a burette or a dispenser 20 ml 0.05 M HCl was taken/measured into a conical flask, and place the flask on the platform in the distill. The platform was pushed up. Twnety-five ml water was added to the digestion tubes from the digestion rack. The addition of water was done carefully while shaking, because the mixture becomes very hot. Then 25 ml 33% NaOH was dispensed into the digestion tube. The content in the flask which was removed from the distill, was titrated with 0.05 M NaOH as described below.

Titration After removal of the receiver flask from the distill, four drops of indicator solution was added to the content in the flask, and titrate with 0.05 NaOH until the color changes from violet to green.

Calculations

$$\% \text{ N in the soil} = \frac{a\ x\ M_{HCL} - bxM_{NaOH}}{c}\ x\ 1.401 \qquad (4)$$

Where,

a = ml HCl measured into the conical flask in the distill (usually 20.00 ml),
b = ml NaOH used for titration of the content in the conical flask,
M_{HCl} = molarity of the HCl measured into the conical flask,
M_{NaOH} = molarity of the NaOH used for titration,
c = g soil used for the analysis.

If M_{HCl} = M_{NaOH} = 0.0500 and if 20.00 ml 0.0500 M HCl is measured into the conical flask, the calculation will be simplified to:

$$\% \text{ N in the soil} = \frac{(20.00 - b)\ x\ 0.07005}{c} \qquad (5)$$

Results and discussion

Soil pH

At the end of three-year trial, soil pH was compared to initial value for all tillage practices (Table 2). There was no influence of tillage practices on pH due to variations in soil depth. Apparently, pH values were the lowest in unpuddled treatment (BP and ST) than puddled ones (CT and SPWT). The effect of residue incorporation on soil pH was also insignificant. In top layer, pH values were the lowest with 100% residue incorporation than no residue use after first maize and second rice crop. However, reverse trend was observed in second maize and third rice crop.

Table 2 Effect of tillage and residue retention on soil pH at two soil depths

Tillage	Aman 2009				Maize 2010				Aman 2010			
	CR_{100}	CR_{50}	CR_0	Mean	CR_{100}	CR_{50}	CR_0	Mean	CR_{100}	CR_{50}	CR_0	Mean
					0-7.5 cm depth							
CT				8.63	7.37	8.07	7.37	7.60	8.46	8.28	8.40	8.38
SPWT/ZT				8.63	7.40	7.57	8.03	7.67	8.41	8.46	8.46	8.44
BP				8.67	7.27	7.30	7.60	7.39	8.33	8.41	8.43	8.39
ST				8.63	7.30	7.30	7.70	7.43	8.39	8.42	8.43	8.41
Mean					7.34	7.56	7.68		8.40	8.39	8.43	
$LSD_{0.05}$	Tillage (T) = NS				Tillage (T) = NS Residue (CR) = NS T × CR = NS				Tillage (T) = NS Residue (CR) = NS T × CR = NS			
CV (%)	0.75				8.50				0.65			
	Maize 11				Aman 11							
CT	8.27	8.30	8.30	8.29	8.33	8.33	8.30	8.32				
SPWT/ZT	8.30	8.20	8.30	8.27	8.37	8.30	8.37	8.34				
BP	8.30	8.30	8.33	8.31	8.33	8.33	8.27	8.31				
ST	8.30	8.27	8.17	8.24	8.33	8.33	8.33	8.33				
Mean	8.29	8.27	8.28		8.34	8.32	8.32					
$LSD_{0.05}$	Tillage (T) = NS Residue (CR) = NS T × CR = NS				Tillage (T) = NS Residue (CR) = NS T × CR = NS							
CV (%)	1.13				0.65							
					7.5-15 cm depth							
	Aman 2009				Maize 2010				Aman 2010			
CT				8.57	8.27	8.20	7.97	8.14	8.18	8.29	8.50	8.32
SPWT/ZT				8.67	8.10	8.23	7.53	7.96	8.31	8.49	8.50	8.43
BP				8.60	8.23	7.97	8.30	8.17	8.27	8.44	8.47	8.39
ST				8.63	7.97	8.23	8.30	8.17	8.11	8.39	8.45	8.32
Mean					8.14	8.16	8.03		8.22	8.40	8.48	
$LSD_{0.05}$	Tillage (T) = NS				Tillage (T) = NS Residue (CR) = NS T × CR = NS				Tillage (T) = NS Residue (CR) = NS T × CR = NS			
CV (%)	1.28				4.24				2.30			
	Maize 2011				Aman 2011							
CT	8.33	8.33	8.40	8.36	8.47	8.53	8.53	8.51				
SPWT/ZT	8.30	8.33	8.33	8.32	8.53	8.50	8.50	8.51				
BP	8.40	8.33	8.37	8.37	8.50	8.47	8.43	8.47				
ST	8.30	8.40	8.40	8.37	8.50	8.50	8.50	8.50				
Mean	8.33	8.35	8.38		8.50	8.50	8.49					
$LSD_{0.05}$	Tillage (T) = NS Residue (CR) = NS T × CR = NS				Tillage (T) = NS Residue (CR) = NS T × CR = NS							
CV (%)	1.36				0.63							

CT = Conventional tillage, SPWT = Single pass wet tillage, ZT = Zero tillage, BP = Bed planting, ST = Strip tillage, CR = Previous crop residue retention, CR_{100}, CR_{50} and CR_0 corresponds to 100%, 50% and 0% previous crop residue retention, NS = Non-significant

Soil organic matter

The effect of tillage on soil SOM was insignificant after crop harvest (Table 3). There was a decline in SOM with soil depth irrespective of tillage practices. SOM increased in the succeeding crop harvest in both the layers.

Table 3 Effect of tillage and residue retention on soil organic matter (%) at two soil depths

Tillage	Aman 2009				Maize 2010				Aman 2010			
	CR_{100}	CR_{50}	CR_0	Mean	CR_{100}	CR_{50}	CR_0	Mean	CR_{100}	CR_{50}	CR_0	Mean
					0-7.5 cm depth							
CT				1.30	1.41	1.52	1.25	1.38	1.58	1.50	1.55	1.54
SPWT/ ZT				1.20	1.20	1.25	1.59	1.35	1.59	1.50	1.51	1.53
BP				1.24	1.48	1.36	1.52	1.42	1.70	1.37	1.47	1.51
ST				1.30	1.33	1.29	1.36	1.33	1.61	1.54	1.62	1.59
Mean					1.36	1.33	1.43		1.62	1.48	1.54	
$LSD_{0.05}$	Tillage (T) = NS				Tillage (T) = NS Residue (CR) = NS T × CR = NS				Tillage (T) = 0.06 Residue (CR) = NS T × CR = NS			
CV (%)	12.70				16.50				12.55			
	Maize 2011				Aman 2011							
CT	1.39	1.30	1.30	1.33	1.42	1.30	1.49	1.40				
ZT/SPWT	1.38	1.28	1.28	1.31	1.25	1.40	1.41	1.41				
BP	1.27	1.25	1.29	1.27	1.17	1.42	1.35	1.31				
ST	1.32	1.18	1.43	1.31	1.56	1.57	1.59	1.57				
Mean	1.34	1.25	1.33		1.36	1.42	1.51					
$LSD_{0.05}$	Tillage (T) = NS Residue (CR) = NS T × CR = NS				Tillage (T) = NS Residue (CR) = NS T × CR = NS							
CV (%)	14.32				17.23							
					7.5-15 cm depth							
	Aman 2009				Maize 2010				Aman 2010			
CT				0.50	0.80	1.02	0.80	0.88	1.33	1.12	0.82	1.09
SPWT/ ZT				0.52	0.67	0.88	0.59	0.71	0.88	0.92	1.14	0.98
BP				0.48	0.80	0.72	0.74	0.75	1.12	1.22	0.95	1.10
ST				0.45	0.74	0.81	0.69	0.55	1.00	0.99	1.28	1.09
Mean					0.76	0.86	0.71		1.08	1.06	1.05	
$LSD_{0.05}$	Tillage (T) = NS				Tillage (T) = NS Residue (CR) = NS T × CR = NS				Tillage (T) = NS Residue (CR) = NS T × CR = NS			
CV (%)	39.40				22.95				32.19			
	Maize 2011				Aman 2011							
CT	0.86	0.77	1.13	0.92	1.25	0.92	1.10	1.09				
ZT/SPWT	1.26	1.39	1.17	1.27	1.08	1.20	0.95	1.08				
BP	1.08	0.94	1.24	1.09	1.10	1.17	0.96	1.07				
ST	0.76	0.31	1.15	0.75	1.17	1.23	0.95	1.12				
Mean	0.99	0.85	1.17		1.15	1.15	0.99					
$LSD_{0.05}$	Tillage (T) = NS Residue (CR) = NS T × CR = NS				Tillage (T) = NS Residue (CR) = 0.12 T × CR = NS							
CV (%)	55.77				15.28							

CT = Conventional tillage, SPWT = Single pass wet tillage, ZT = Zero tillage, BP = Bed planting, ST = Strip tillage. CR = Previous crop residue retention, CR_{100}, CR_{50} and CR_0 corresponds to 100%, 50% and 0% previous crop residue retention, NS = Non-significant

After third crop, strip tillage increased soil organic matter compared to bed and zero tillage at 0-7.5 cm soil depth. Initially, soil of the experimental plot contained less amount of organic matter. The values measured at the end of the trial showed that there was an improvement in soil organic matter in all the tillage trials. Staley et al., (1988) reported that intensive tillage operations result in more or less even distribution of SOM in topsoil, but in minimum tillage the concentration of organic matter was in the surface (0-5 cm) soil. Paustian et al., (1997) reported increased organic matter content with conservation tillage. Conventional tillage practices have resulted in lower carbon contents of agricultural soils due to increased decomposition rates and carbon redistribution (Christensen, 1996). Cultivation also stimulates soil carbon losses due to accelerated oxidation of soil carbon by microbial action. In conventionally tilled soils, the organic matter was fairly distributed throughout the plow layer due to the evenly incorporation of crop residues in the plowed layer. Examining the depth effect under tillage practices, there was a decline in SOM with depth. Accumulation of organic carbon in the upper soil layer is evident under long-term no-tillage conditions (Singh et al., 1994). After three years, retention of crop residues, irrespective of tillage treatments, increased SOM at 7.5–15.0 cm soil depth. Increase in organic matter in the 7.5-15 cm compared to upper layer may be attributed to the restricted decomposition. SOM value was the highest in all the tillage treatments receiving 100% residue incorporation than no residue incorporation except in second and fifth crop. It was due to the fact that organic matter increases due to decomposition of crop residue. Tillage systems (no tillage or minimum tillage) that reduce soil disturbance and residue incorporation have generally been observed to increase SOM (Mrabetet al., 2001). The findings of the study showed benefits by the application of residue incorporation. Ghoshal and Singh (1995) largely attributed these beneficial effects to enhanced microbial activity and soil organic matter.

Nitrogen

Table 4 shows the effect of tillage and residue incorporation on soil N at two depths. Interaction effect of tillage and residue retention on N was not significant at two depths in all the crop harvest. Tillage practices had insignificant effect on soil N after all the crop harvest. The total N content was the highest in top layer than bottom layer. The total N concentration was fairly similar in all the tillage treatments. Soil N was not affected significantly by residue incorporation in three years study. After three years crop production, residue retention showed no influence on total nitrogen in the top layer. However, residue incorporation increased total nitrogen in the bottom layer. Increase in total N may be explained by increase in soil organic matter. Balesdent et al. (2000) concluded that mineralizable nitrogen in the surface soil (0-10 cm) was more in case of no-tillage as compared with CT. The higher amount of mineralizable nitrogen under no-till than under conventional till may be attributed to greater pool of labile nitrogen with a slow decomposition rate (Germonet al., 1991; Balesdent et al., 2000) related this to higher biomass production.

Table 4 Effect of tillage and residue retention on soil nitrogen (%) at two soil depths

Tillage	Aman 2009				Maize 2010				Aman 2010			
	CR_{100}	CR_{50}	CR_0	Mean	CR_{100}	CR_{50}	CR_0	Mean	CR_{100}	CR_{50}	CR_0	Mean
0-7.5 cm depth												
CT				0.05	0.07	0.08	0.06	0.07	0.08	0.07	0.08	0.08
SPWT/ ZT				0.06	0.06	0.08	0.08	0.07	0.08	0.07	0.07	0.07
BP				0.06	0.07	0.06	0.06	0.07	0.08	0.07	0.07	0.07
ST				0.05	0.06	0.06	0.06	0.06	0.08	0.08	0.08	0.08
Mean					0.07	0.07	0.07		0.08	0.07	0.08	
$LSD_{0.05}$	Tillage (T) = NS				Tillage (T) = NS Residue (CR) = NS T × CR = NS				Tillage (T) = NS Residue (CR) = NS T × CR = NS			
CV (%)	13.58				18.33				13.72			
	Maize 2011				Aman 2011							
CT	0.07	0.06	0.06	0.06	0.07	0.06	0.07	0.07				
ZT/SPWT	0.07	0.06	0.06	0.06	0.06	0.07	0.08	0.07				
BP	0.07	0.06	0.06	0.06	0.07	0.07	0.06	0.07				
ST	0.06	0.06	0.07	0.06	0.08	0.08	0.08	0.08				
Mean	0.07	0.06	0.06		0.07	0.07	0.07					
$LSD_{0.05}$	Tillage (T) = NS				Tillage (T) = NS Residue (CR) = NS T × CR = NS							
CV (%)	14.13				26.84							
7.5-15 cm depth												
	Aman 2009				Maize 2010				Aman 2010			
CT				0.03	0.04	0.05	0.04	0.04	0.06	0.05	0.04	0.05
SPWT/ZT				0.03	0.03	0.05	0.03	0.04	0.04	0.05	0.05	0.05
BP				0.03	0.04	0.04	0.04	0.04	0.05	0.06	0.05	0.05
ST				0.03	0.04	0.04	0.03	0.04	0.05	0.05	0.06	0.05
Mean					0.04	0.05	0.04		0.05	0.05	0.05	
$LSD_{0.05}$	Tillage (T) = NS				Tillage (T) = NS Residue (CR) = NS T × CR = NS				Tillage (T) = NS Residue (CR) = NS T × CR = NS			
CV (%)	35.92				21.15				32.62			
	Maize 2011				Aman 2011							
CT	0.04	0.04	0.05	0.04	0.06	0.04	0.05	0.05				
ZT/SPWT	0.06	0.07	0.06	0.06	0.05	0.06	0.05	0.05				
BP	0.05	0.04	0.06	0.05	0.06	0.06	0.05	0.05				
ST	0.04	0.02	0.05	0.04	0.06	0.06	0.05	0.06				
Mean	0.05	0.04	0.06		0.06	0.05	0.05					
$LSD_{0.05}$	Tillage (T) = NS Residue (CR) = NS T × CR = NS				Tillage (T) = NS Residue (CR) = 0.01 T × CR = NS							
CV (%)	14.33				17.12							

CT = Conventional tillage, SPWT = Single pass wet tillage, ZT = Zero tillage, BP = Bed planting, ST = Strip tillage, CR = Previous crop residue retention, CR_{100}, CR_{50} and CR_0 corresponds to 100%, 50% and 0% previous crop residue retention, NS = Non-significant

Phosphorus

Table 5 shows the effect of tillage and crop residue retention on P concentration. Before hosting the trial, the soil enjoyed poor amount of P concentration. The data demonstrated that soil phosphorus was not affected significantly by the combined action of tillage systems and residue retention at two depths in all the crop harvest. The phosphorus level was the highest in the top layer than the bottom layers. Effect of tillage on soil phosphorus concentration was not significant after crop harvest. Irrespective of tillage practice, phosphorus level was increased from initial condition to the end of the experiment. Effect of CR on soil P was not significant after crop harvest.

In the end of three-year trial, P concentration was also increased irrespective of level of residue incorporation at 0-7.5 cm depth.

Table 5 Effect of tillage and residue retention on soil phosphorus (μg g soil[-1]) at two soil depths

Tillage	Aman 2009				Maize 2010				Aman 2010			
	CR_{100}	CR_{50}	CR_0	Mean	CR_{100}	CR_{50}	CR_0	Mean	CR_{100}	CR_{50}	CR_0	Mean
0-7.5 cm depth												
CT				11.77	14.50	17.90	25.03	19.14	18.88	18.13	20.10	19.03
SPWT/ ZT				12.70	9.67	15.60	13.47	12.91	19.98	17.20	14.85	15.94
BP					12.50	14.20	11.83	12.85	20.93	20.77	26.17	22.62
ST				10.98	12.13	6.47	7.77	8.79	20.93	15.87	18.97	17.92
Mean				11.90	10.21	13.97	14.48		19.88	16.90	19.82	
$LSD_{0.05}$	Tillage (T) = NS				Tillage (T) = NS Residue (CR) = NS T × CR = NS				Tillage (T) = NS Residue (CR) = NS T × CR = NS			
CV (%)	10.31				32.92				22.26			
	Maize 2011				Aman 2011							
CT	9.09	10.81	10.27	10.06	15.93	19.23	19.53	18.23				
ZT/SPWT	8.19	8.95	7.83	8.12	17.87	15.93	15.90	16.57				
BP	11.89	7.52	8.56	9.32	18.77	19.00	21.93	19.90				
ST	9.52	10.18	13.00	10.90	14.33	15.47	14.83	14.88				
Mean	9.67	9.27	9.87		16.73	17.41	18.05					
$LSD_{0.05}$	Tillage (T) = NS Residue (CR) = NS T × CR = NS				Tillage (T) = NS Residue (CR) = NS T × CR = NS							
CV (%)	24.38				14.57							
7.5-15 cm depths												
	Aman 2009				Maize 2010				Aman 2010			
CT				9.97	7.87	8.27	6.63	7.59	10.43	10.00	14.93	11.79
SPWT/ ZT				11.23	14.17	8.13	6.53	9.61	8.70	13.53	11.90	11.38
BP				10.30	6.77	6.00	8.00	6.92	11.00	10.57	14.23	11.93
ST				8.93	6.20	6.63	7.17	6.67	11.93	11.70	10.27	17.92
Mean					8.75	7.26	7.08		10.52	11.45	12.83	
$LSD_{0.05}$	Tillage (T) = NS				Tillage (T) = NS Residue (CR) = NS T × CR = NS				Tillage (T) = NS Residue (CR) = NS T × CR = NS			
CV,%	20.52				34.13				20.71			
	Maize 2011				Aman 2011							
CT	16.67	12.95	10.42	13.35	16.03	18.10	18.00	18.04				
ZT/SPWT	11.44	9.29	16.99	12.58	20.60	16.67	15.67	17.64				
BP	12.30	18.88	10.95	14.04	15.17	15.43	23.97	18.19				
ST	7.59	7.89	8.71	8.06	17.30	17.27	17.97	17.51				
Mean	12.00	12.25	11.77		17.78	16.87	18.90					
$LSD_{0.05}$	Tillage (T) = Residue (CR) = NS T × CR =				Tillage (T) = NS Residue (CR) = NS T × CR = NS							
CV (%)	26.68				11.20							

CT = Conventional tillage, SPWT = Single pass wet tillage, ZT = Zero tillage, BP = Bed planting, ST = Strip tillage, CR = Previous crop residue retention. CR_{100}, CR_{50} and CR_0 corresponds to 100%, 50% and 0% previous crop residue retention. NS = Non-significant

Potassium

Table 6 shows the effect of tillage and residue retention on soluble K of soil. The tillage practice × residue incorporation demonstrated insignificant effect on K concentration. Effect of tillage on soluble K concentration was not significant in both the layers. Effect of CR on soil K concentration was not significant at two depths in all the crop harvest. In each crop season, the incorporation of crop residue did not influence the available K concentrations significantly.

Table 6 Effect of tillage and residue retention on soil potassium (m equivalent 100 gm soil[-1]) at two soil depths

Tillage	Aman 2009				Maize 2010				Aman 2010			
	CR_{100}	CR_{50}	CR_0	Mean	CR_{100}	CR_{50}	CR_0	Mean	CR_{100}	CR_{50}	CR_0	Mean
						0-7.5 cm depth						
CT				0.18	0.23	0.21	0.21	0.22	0.20	0.21	0.21	0.21
SPWT/ ZT				0.19	0.17	0.20	0.15	0.18	0.20	0.21	0.20	0.21
BP				0.17	0.20	0.18	0.21	0.20	0.21	0.22	0.25	0.21
ST				0.17	0.19	0.17	0.15	0.17	0.20	0.20	0.19	0.20
Mean					0.20	0.19	0.19		0.20	0.21	0.20	
$LSD_{0.05}$	Tillage (T) = NS				Tillage (T) = NS Residue (CR) = NS T × CR = NS				Tillage (T) = NS Residue (CR) = NS T × CR = NS			
CV (%)		4.48				17.59				4.55		
	Maize 2011				Aman 2011							
CT	0.18	0.21	0.19	0.19	0.20	0.21	0.19	0.20				
ZT/SPWT	0.17	0.21	0.15	0.18	0.20	0.23	0.20	0.21				
BP	0.19	0.19	0.17	0.18	0.19	0.20	0.20	0.20				
ST	0.18	0.18	0.15	0.17	0.19	0.20	0.20	0.20				
Mean	0.18	0.20	0.17		0.20	0.21	0.20					
$LSD_{0.05}$	Tillage (T) = NS Residue (CR) = NS T × CR = NS				Tillage (T) = NS Residue (CR) = NS T × CR = NS							
CV (%)		16.03				8.98						
						7.5-15 cm depth						
	Aman 2009				Maize 2010				Aman 2010			
CT				0.19	0.16	0.18	0.16	0.17	0.20	0.21	0.19	0.20
SPWT/ ZT				0.20	0.20	0.19	0.17	0.19	0.21	0.22	0.21	0.22
BP				0.20	0.16	0.16	0.16	0.16	0.21	0.21	0.20	0.21
ST				0.17	0.16	0.17	0.16	0.16	0.20	0.20	0.20	0.20
Mean					0.17	0.18	0.16		0.21	0.21	0.20	
$LSD_{0.05}$	Tillage (T) = NS				Tillage (T) = NS Residue (CR) = NS T × CR = NS				Tillage (T) = NS Residue (CR) = NS T × CR = NS			
CV (%)		4.26				12.04				5.88		
	Maize 2011				Aman 2011							
CT	0.15	0.14	0.14	0.14	0.19	0.21	0.18	0.19				
ZT/SPWT	0.15	0.14	0.14	0.14	0.20	0.22	0.19	0.20				
BP	0.15	0.18	0.16	0.16	0.19	0.21	0.19	0.20				
ST	0.15	0.12	0.12	0.13	0.18	0.19	0.18	0.19				
Mean	0.15	0.15	0.14		0.19	0.21	0.19					
$LSD_{0.05}$	Tillage (T) = NS Residue (CR) = NS T × CR = NS				Tillage (T) = NS Residue (CR) = NS T × CR = NS							
CV (%)		17.33				6.66						

CT = Conventional tillage, SPWT = Single pass wet tillage, ZT = Zero tillage, BP = Bed planting, ST = Strip tillage, CR = Previous crop residue retention, CR_{100}, CR_{50} and CR_0 corresponds to 100%, 50% and 0% previous crop residue retention, NS = Non-significant

In the end of the three-year trial, zero tillage increased K concentration at both the layers. These results supported the earlier findings of Mahboubi *et al.*, (1993) of higher available K concentrations in no-till soils. In the present findings, the K concentration was higher in ZT. Yin and Vyn (2002) also observed more soil K in case of no-tillage as compared to deep tillage. The repeated no-tillage has resulted in vertical stratification of soil K (Holanda *et al.*, 1998; Yin and Vyn, 2002). Only change of the exchangeable K could not capture the full story of the K history. Because incorporation of crop residues added a huge amount of K, some of which may have incorporated into the non-exchangeable form to maintain K equilibrium in soil.

Conclusion

The values measured at the end of trial showed that tillage practices with crop residue retention improved soil chemical properties such as pH, soil organic matter, potassium, phosphorus and nitrogen concentrations.

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CHAPTER VI

ENERGY CONSUMPTION IN CONSERVATION AGRICULTURE

Unpuddled rice-maize cropping systems

Abstract

Energy budget is essential for efficient management of the resources in agricultural production. The energy balance under different conservation tillage management practices in rice-maize cropping systems during 2009-12 was assessed by comparing the parameters: energy input, energy output, energy productivity and energy output-input ratio. Energy input in conventional tillage (CT), single pass wet tillage (SPWT) in rice followed by zero tillage (ZT) in maize, bed planting (BP) and strip tillage (ST) were 48.93, 41.51, 41.89 and 41.05 GJ ha^{-1}, respectively in rice-maize cropping systems. Results revealed that the maximum energy was consumed for chemical fertilizers. Tillage energy ranked second in conventional tillage and ranked fourth in minimum tillage options. The lowest energy input was required for maize and the highest for rice due to less irrigation water requirement in maize. The energy output under all tillage options was two folds higher in maize than rice due to increased grain yield. Energy output was insignificant due to insignificant yield difference. Minimum tillage showed 14-17% increase in energy productivity and 19-26% increase in energy output-input ratio. However, from the energy saving point of view, single pass shallow tillage in rice production followed by zero tillage in maize cultivation may be considered better options depending on the resources availability in rice-maize cropping system.

Keywords: Direct energy, indirect energy, energy productivity, energy ratio

Introduction

Energy is the key inputs in modern agriculture. Effective energy use is one of the conditions for sustainable agricultural production, since it provides financial savings, fossil resources preservation and air pollution reduction (Uhlin, 1998). Energy use has recently increased in agriculture in response to increasing populations, limited supply of arable land and desire for an increasing standard of living. In all societies, these factors have encouraged an increase in energy inputs to maximize yields, minimize labor-intensive practices, or both (Esengun *et al.*, 2007). Productivity of agriculture depends on adequate inputs such as power (farm machines, human labor, animal draft, electrical), improved seeds, fertilizers and irrigation water. The relation between agriculture and energy is very complementary to each other. Crop yield is directly proportional to the energy input (Srivastava, 1982). In comparison to conventional cultivation with plough, the fuel consumption could be reduced for cultivation by two to threefold with a strip tillage system (Islam *et al.*, 2012). Fuel and fertilizers (N and P) account for the largest share (>75%) of all energy expenditures in a mixed cropping system (Safa and Tabatabaeefar, 2002). Bockari-Gevao *et al.*, (2005) reported that the highest average operational energy consumption was for tillage (1747 MJ ha^{-1}), which accounted for about 48.6% of the total operational energy consumption (3596 MJ ha^{-1}), followed by harvesting (1171 MJ ha^{-1}, 32.6%) and planting (563 MJ ha^{-1}, 15.7%) in the low land rice production system in Malaysia. The energy saving of 50% and fuel saving of 30% were achieved by site-specific tillage as compared to uniform-depth tillage in a loamy sand soil type (Alimardani *et al.*, 2007). Due to increasing fuel prices, energy efficiency in plant production became an increasing awareness. Conservation tillage requires less total energy to achieve approximately the same crop production levels as conventional tillage systems (Smith *et al.*, 2002). The primary objectives of mechanizing crop production are to reduce human drudgery and to raise the output of farm by either increasing the crop yield or increasing the area under cultivation. These can only be done by supplementing the traditional energy input i.e. human labor with substantial investments in farm machinery, irrigation equipment, fertilizers, soil and water conservation practices, weed management practices, etc. The energy and agriculture relationship is becoming more and more important with the intensification of the cropping systems. Energy budgets for agricultural production can be used as first step towards identifying crop production processes. The input elements need to be identified in order to prescribe the most efficient methods for controlling them. The benefits of energy analysis are to determine the energy invested in every step of the production process, to provide a basis for conservation and to aid in making sound management and policy decisions for efficient management of scarce resources for improved agricultural production. This would identify cost effective production practices. Therefore, this study was undertaken to expedite the direct and indirect energy consumption under conservation tillage practices in rice-maize cropping system of Bangladesh.

Materials and methods

A field experiment with a rice-maize rotation was conducted during 2009-2012 at the regional station, BRRI, Rajshahi, Bangladesh (24°69´N and 88°30´E). The experiment was laid out in a strip plot design (Gomez and Gomez, 1984) with tillage options as main plot treatments and crop residue retention in subplots, with three replications, to explore the interaction between tillage and residue retention. The tillage treatments were:

- Puddled conventional tillage (CT) for rice; CT for maize
- Puddled single pass wet tillage (SPWT) for rice; zero tillage (ZT) for maize
- Unpuddled bed planting (BP) for rice; dry BP for maize

- Unpuddled strip tillage (ST) for rice and dry ST for maize

The crop residue retention treatments in subplots were 100% (CR_{100}), 50% (CR_{50}) and 0% (CR_0). Subplot size was 8.5 x 8 m. There was a 1 m wide trench between blocks to allow for irrigation.

In rice cultivation, CT consisted of two passes primary tillage by two wheel tractors (2WT) and exposed to sun for two days followed by inundating whole plot and puddling by 2WT with two passes to complete land preparation. In SPWT, one pass tillage by 2WT after inundating the field. ST and BP were done by versatile multi-crop planter (VMP) in single pass operation before inundating the field. The land was fully inundated one day before transplanting in unpuddled plots. Seedlings were transplanted into puddled conditions (CT and SPWT) and unpuddled conditions (BP and ST). In maize cultivation, CT consisted of two passes primary tillage by 2WT and exposed to sun for two days followed by two passes secondary tillage by 2WT to complete land preparation. ZT, BP and ST were done in single pass operation by VMP. As per treatment sequence, previous crop residue was spread in between rows of rice and maize at 20 days after transplanting/seeding. Residue incorporation was started after first rice crop. Rice variety BR11 and maize variety NK40 were grown in this experiment.

Table 1 presents the fertilizer application rates for rice and maize, following the recommendations of BRRI (2011) and Mondal *et. al.,* (2011). In both the crops fertilizer was applied manually. In rice cultivation, the entire amount of triple super phosphate (TSP), muriate of potash (MP), gypsum and zinc sulphate was broadcast and incorporated into the soil at final land preparation.

Table 1 Fertilizer application rate (kg ha^{-1}) for rice and maize

Crop	Urea	Muriate of potash	Triple super phosphate	Zinc sulphate	Gypsum
Rice	175	110	80	10	100
Maize	185	277	277	17	185

In BP and ST, fertilizers were broadcast before tillage operation. Urea was top dressed in three equal installments. In maize cultivation, one third urea and full dose of other fertilizers were applied during last plowing. In case of ZT, BP and ST, fertilizer was applied carefully in rows by hand after seeding at one centimeter distance from seed to avoid seed and fertilizer contact. One third of urea was applied at the 8-10 leaf stage and the rest at the 20-22 leaf stage. Weed infestation was severe in all the plots during first rice and maize crop. Hand weeding was done twice in rice and maize crops. Roundup® (a.i. 73.3% glyphosate and 2.9% diquat) was applied @ 3.75 L ha^{-1} from the second rice and maize crop one day before land preparation. Roundup® reduced the severity of weed infestation in all tillage trials, but it did not reduce the number of weeding operations in rice and maize crops. In the second and third rice crop, pre-emergence weedicide Rifit® (a.i. 50% pretilachlore) was applied @ 1 L ha^{-1} at four days after transplanting. The insecticide Sabion® (a.i. 10% diazinion) was applied @ 16 kg ha^{-1} at the vegetative stage to control stem borer (*Scirpophaga incertulas*) in rice cultivation. In rice cultivation, irrigation was applied when needed, in measured quantities. In maize cultivation, the first, second and third irrigation was applied at the 3-5, 8-10 and 20-22 leaf stages, respectively. The fourth irrigation was applied 15-20 days after the third irrigation.

The inputs in the form of labor, diesel, seed, chemical fertilizer, plant protection products (insecticides/pesticides/herbicides) used in different stages of crop production and outputs obtained in terms of yield were taken into consideration by appropriate use of energy conversion factors (Table 2). The energy use was calculated for agronomic operations namely, (i) land preparation, (ii) puddling, (iii) seedling raising and transplanting, (iv) sowing/planting, (v) interculture/weeding, (vi) irrigation, (vii) crop management, (viii) harvesting and threshing. Energy input was also classified on the basis of source, whether it was direct or indirect.

Table 2 Energy values used in energy calculation

Particulars	Unit	Energy equivalent (MJunit^{-1})	Reference
A. Inputs			
Human labor	h	0.20	Bala and Hussain,1992
Machinery	h	62.7	Erdal *et al.*, 2007
Diesel fuel	L	56.31	Erdal *et al.*, 2007
Chemical fertilizers	kg		
(a) Nitrogen (N)		66.14	Esengun *et al.*, 2007
(b) Phosphate (P_2O_5)		12.44	Esengun *et al.*, 2007
(c) Potassium (K_2O)		11.15	Esengun*et al.*, 2007
(d) Zinc (Zn)		8.40	Argiro et al., 2006
Cowdung	kg	1.00	Bala and Hussain,1992
a. Chemicals (granular)	kg	120	Canakci *et al.*, 2005
b. Chemical (liquid)	ml	0.10	Gopalan *et al.*, 1978; Binning *et al.*, 1983
Water for irrigation	m^3	1.02	Acaroglu and Aksoy, 2005
Seed (maize)	kg	15.10	Binning *et al.*, 1983
Seed (paddy)	kg	14.57	Bala and Hussain,1992
B. Outputs			
Grain paddy	kg	14.57	Bala and Hussain,1992
Grain maize	kg	15.10	Binning *et al.*, 1983
Straw	kg	12.50	Ozkan *et al.*, 2004

The direct energy input is the energy consumption of physical energy resources for physical work in field operations. Energy input such as human labor and fuel consumption have been considered as direct energy input. Indirect energy is the energy used to produce equipment and other goods and services that are used in the farm. Physical energy input in terms of energy from the mechanical power source, chemical and biological inputs were considered as indirect energy input. Chemical fertilizer and pesticide were considered as chemical energy input while seed is considered as biological energy input. Energy productivity was another way of determining the efficiency of energy use. Energy productivity was calculated from the quotient of grain yield to energy input. Energy output-input ratio (energy use efficiency) was calculated from the quotient of energy value of outputs and energy value of the sum of all direct and indirect inputs.

Computation of energy inputs, outputs, productivity and ratio

The energy input, output, output-input ratio as well as the energy productivity in rice and maize cultivation were calculated based on the following formula as described in Chamsing *et al.*, (2006).

Energy input (Ei)

$$\text{Energy input (Ei), GJ ha}^{-1} = \text{Ef} + \text{Es} \qquad (1)$$

Where,

Ef = energy input in farm operations, GJ ha^{-1}
Es = energy sequestered of machinery, GJ ha^{-1}

Energy input in farm operations (Ef)

$$\text{Energy input in farm operation (GJ ha}^{-1}) = \text{Phy} + \text{Chem} + \text{Bio} \qquad (2)$$

Where,

Phy = Physical energy input in farm operation, GJ ha^{-1}
Chem = Chemical energy input in farm operation, GJ ha^{-1}
Bio = Biological energy input in farm operation, GJ ha^{-1}

Energy sequestered in mechanical power sources, (Es)

Energy sequestered in machinery was calculated as following formula.

$$\text{Energy sequestered, GJ ha}^{-1} = \text{M} \times \text{h} \qquad (3)$$

Where,

M = Energy sequestered in manufacturing for machinery, GJ h^{-1}
h = Machine working hour, h ha^{-1}

Energy output (Eo)

Energy output was considered of main product and by-product.

$$\text{Energy output, GJ ha}^{-1} = (\text{Yield} \times \text{Eeqm}) + (\text{By-product} \times \text{Eeqb}) \quad (4)$$

Where,

Eeqm = Energy equivalent value of main product

Eeqb = Energy equivalent value of by-product

Energy productivity (Ep)

$$\text{Energy productivity, kg GJ}^{-1} = \frac{\text{Crop yield, kg ha}^{-1}}{\text{Energy inputs to crop production, GJ ha}^{-1}} \quad (5)$$

Energy output-input ratio (Energy use efficiency)

$$\text{Energy output - input ratio} = \frac{\text{Energy output, GJ ha}^{-1}}{\text{Energy inputs to crop production, GJ ha}^{-1}} \quad (6)$$

Results

Operation-wise energy distribution

Rice cultivation

Operational energy was computed for the seedling raising, tillage, transplanting, weeding, fertilizing, spraying, harvesting and winnowing (Table 3).

Table 3 Operation-wise energy input under different tillage options in rice cultivation

Operation	CT (GJ ha⁻¹)	SPWT (GJ ha⁻¹)	BP (GJ ha⁻¹)	ST (GJ ha⁻¹)
		Rice2009		
Seedling raising	0.45 (2)	0.45 (2)	0.45 (2)	0.60 (3)
Land preparation	6.60 (25)	6.16 (23)	2.53 (12)	1.13 (6)
Transplanting and weeding	0.08 (0)	0.08 (0)	0.18 (1)	0.18 (1)
Fertilizer application	9.93 (37)	9.93 (38)	9.93 (49)	9.93 (52)
Plant protection	3.93 (15)	3.93 (15)	3.93 (19)	3.93 (21)
Irrigation	5.71 (21)	5.70 (22)	3.20 (16)	3.28 (17)
Harvesting and winnowing	0.05 (0)	0.05 (0)	0.04 (0)	0.04 (0)
Total	26.75a (100)	26.29a (100)	20.27b (100)	19.09c (100)
		Rice 2010		
Seedling raising	0.45 (2)	0.45 (2)	0.45 (2)	0.60 (3)
Land preparation	7.01 (28)	3.21 (15)	2.37 (12)	1.74 (8)
Transplanting and weeding	0.12 (0)	0.16 (1)	0.16 (1)	0.16 (1)
Fertilizer application	9.95 (40)	9.95 (46)	9.95 (49)	9.95 (48)
Plant protection	3.93 (16)	3.93 (18)	3.93 (19)	3.93 (19)
Irrigation	3.54 (14)	4.13 (19)	3.57 (17)	4.38 (21)
Harvesting and winnowing	0.03 (0)	0.03 (0)	0.03 (0)	0.03 (0)
Total	25.03a (100)	21.86b (100)	20.46c (100)	20.79c (100)
		Rice 2011		
Seedling raising	0.45 (2)	0.45 (2)	0.45 (2)	0.60 (3)
Land preparation	6.74 (27)	3.25 (15)	2.81 (14)	2.13 (10)
Transplanting and weeding	0.08 (0)	0.11 (1)	0.12 (1)	0.11 (1)
Fertilizer application	9.94 (40)	9.94 (47)	9.94 (48)	9.94 (46)
Plant protection	4.38 (18)	4.38 (21)	4.38 (21)	4.38 (21)
Irrigation	3.07 (12)	3.11 (15)	2.97 (14)	4.38 (20)
Harvesting and winnowing	0.05 (0)	0.05 (0)	0.05 (0)	0.05 (0)
Total	24.71a (100)	21.30c (100)	20.72d (100)	21.60b (100)

Figures in the parenthesis indicate the percentage. In Aman 09, $LSD_{0.05}$ = 0.73, CV (%) = 1.57, in Aman 10, $LSD_{0.05}$ =0.49, CV (%) = 1.12 and in Aman 11 $LSD_{0.05}$ = 0.33, CV (%) = 0.30

In puddled CT, energy associated with different operations are: fertilizer 37-40%, tillage 25-28%, irrigation 12-21% and plant protection 15-18% of total energy consumption. Fertilizer ranked first and tillage ranked second as input energy in CT.

In unpuddled BP, energy associated with different operations accounted as fertilizer 48-49%, tillage 12-14%, irrigation 15-19% and plant protection 19-21% of total energy consumption. Fertilizer ranked first and tillage ranked fourth as input energy in BP. Similar pattern was observed in puddled SPWT and unpuddled ST. Three years average data on rice cultivation showed that energy input was the highest in CT followed by SPWT, BP and ST. Energy input was the lowest in ST compared to BP due to the lowest land preparation energy whereas, irrigation energy was the highest in ST. SPWT, BP and ST saved 15%, 20%, and 20% energy input, respectively compared to CT. The introduction of unpuddled BP and ST and puddled SPWT in wet season rice cultivation allows a major reduction in the number of mechanical operations.

Maize cultivation

In maize cultivation, energy was computed for all the operations (Table 4). In CT, energy associated with different operations accounted tillage 17-19%, fertilizer 75-76%, irrigation 1-3% and plant protection 3% of total energy consumption. Fertilizer ranked first and tillage ranked second in CT. Similar trend was observed in other tillage operations. Minimum tillage systems accounted fertilizer 82-93%, tillage 4-11%, plant protection 3-4%, irrigation 3% of total energy consumption. Tillage practices showed significant effect on energy input in maize cultivation. Averaging three years data in maize cultivation showed that energy input was the highest in CT followed by BP, ST and ZT. The minimum tillage ZT, ST and BP saved 15%, 12% and 9% of energy input compared to CT in maize cultivation. Combining the impact of tillage treatment, energy input in CT, SPWT in rice followed by ZT in maize, BP and ST was, 49, 42, 42 and 41 GJ ha^{-1}, respectively in rice-maize cropping systems.

Table 4 Operation-wise energy input under different tillage options in maize cultivation

Operation	CT (GJ ha^{-1})	ZT (GJ ha^{-1})	BP (GJ ha^{-1})	ST (GJ ha^{-1})
		Maize 2010		
Land preparation	4.17 (18)	0.01 (0)	2.30 (11)	1.69 (8)
Seeding	0.27 (1)	0.25 (1)	0.23 (1)	0.23 (1)
Weeding	0.13 (1)	0.32 (2)	0.17 (1)	0.24 (1)
Fertilizer application	17.77 (77)	17.77 (93)	17.77 (84)	17.77 (83)
Plant protection	0 (0)	0 (0)	0 (0)	0 (0)
Irrigation	0.66 (3)	0.65 (3)	0.65 (3)	0.61 (3)
Harvesting and shelling	0.07 (0)	0.06 (0)	0.07 (0)	0.06 (0)
Total	23.06a (100)	19.07d (100)	21.19b (100)	20.61c (100)
		Maize 2011		
Land preparation	3.94 (17)	0.91 (4)	1.87 (9)	0.87 (4)
Seeding	0.26 (1)	0.24 (1)	0.23 (1)	0.24 (1)
Weeding	0.03 (0)	0.04 (0)	0.03 (0)	0.02 (0)
Fertilizer application	17.79 (76)	17.79 (87)	17.79 (83)	17.79 (88)
Plant protection	0.77 (3)	0.77 (4)	0.77 (4)	0.77 (4)
Irrigation	0.64 (3)	0.58 (3)	0.66 (3)	0.53 (3)
Harvesting and shelling	0.10 (0)	0.10 (0)	0.10 (0)	0.10 (0)
Total	23.52a (100)	20.42c (100)	21.45b (100)	20.32d (100)
		Maize 2012		
Land preparation	4.39 (19)	1.05 (5)	2.33 (11)	1.51 (7)
Seeding	0.28 (1)	0.26 (1)	0.24 (1)	0.26 (1)
Weeding	0.07 (0)	0.05 (0)	0.03 (0)	0.06 (0)
Fertilizer application	17.78 (75)	17.79 (88)	17.79 (82)	17.79 (86)
Plant protection	0.77 (3)	0.77 (4)	0.77 (4)	0.77 (4)
Irrigation	0.34 (1)	0.30 (2)	0.35 (2)	0.28 (1)
Harvesting and shelling	0.08 (0)	0.08 (0)	0.08 (0)	0.08 (0)
Total	23.71a (100)	20.30d (100)	21.58b (100)	20.75c (100)

Figures in the parenthesis indicate the percentage. In maize 10, $LSD_{0.05}$ = 0.51, CV (%) = 1.23, in maize 11, $LSD_{0.05}$ =0.12, CV (%) = 0.29 and in maize 12, $LSD_{0.05}$ = 0.15, CV (%) = 0.27

Source-wise energy distribution

Rice cultivation

Table 5 presents the source-wise energy distribution in rice cultivation under different tillage practices. Direct energy included fuel and human labor. Direct energy consumption accounted for only a small proportion of the total energy consumption ranging from around 9-12% in CT, 6-7% in SPWT, 8-9% in BP and 4-7% in ST. Direct energy was the highest in CT and the lowest in SPWT due to difference in fuel use. Fuel is the main contributor of direct energy with 8-11% in CT, 5-6% in SPWT, 7-8% in BP and 3-6% in ST. Indirect energy consumption included seed, machinery use, fertilizing, plant protection and irrigation. Indirect energy shared 88-91% in CT, 93-94% in SPWT, 91-92% in BP and 93-96% in ST¬.

Table 5 Energy consumption based on energy sources under different tillage options in rice cultivation

Source	CT (GJ ha⁻¹)	SPWT (GJ ha⁻¹)	BP (GJ ha⁻¹)	ST (GJ ha⁻¹)
		Rice 2009		
Direct energy				
Fuel	2.20 (8)	2.24 (8)	1.51 (8)	0.54 (3)
Human	0.16 (1)	0.17 (1)	0.25 (1)	0.25 (1)
Subtotal	2.35 (9)	2.41 (9)	1.76 (9)	0.78 (4)
Indirect energy				
Seed	0.44 (2)	0.44 (2)	0.44 (2)	0.58 (3)
Machinery	4.39 (16)	3.89 (15)	1.01 (5)	0.60 (3)
Fertilizing	9.93 (37)	9.93 (38)	9.93 (49)	9.93 (52)
Plant protection	3.93 (15)	3.93 (15)	3.93 (19)	3.93 (21)
Irrigation	5.71 (21)	5.71 (22)	3.21 (16)	3.28 (17)
Subtotal	24.40 (91)	23.88 (91)	18.51 (91)	18.31 (96)
Total	26.75 (100)	26.30 (100)	20.27 (100)	19.10 (100)
		Rice 2010		
Direct energy				
Fuel	2.06 (8)	0.99 (5)	1.33 (7)	1.08 (5)
Human	0.21 (1)	0.24 (1)	0.23 (1)	0.24 (1)
Subtotal	2.26 (9)	1.22 (6)	1.56 (8)	1.31 (6)
Indirect energy				
Seed	0.44 (2)	0.44 (2)	0.44 (2)	0.58 (3)
Machinery	4.93 (20)	2.22 (10)	1.04 (5)	0.66 (3)
Fertilizing	9.93 (40)	9.93 (45)	9.93 (49)	9.93 (48)
Plant protection	3.93 (16)	3.93 (18)	3.93 (19)	3.93 (19)
Irrigation	3.54 (14)	4.13 (19)	3.57 (17)	4.38 (21)
Subtotal	22.76 (91)	20.64 (94)	18.90 (92)	19.48 (94)
Total	25.03 (100)	21.86 (100)	20.46 (100)	20.79 (100)
		Rice 2011		
Direct energy				
Fuel	2.81 (11)	1.27 (6)	1.53 (7)	1.38 (6)
Human	0.17 (1)	0.20 (1)	0.20 (1)	0.20 (1)
Subtotal	2.98 (12)	1.47 (7)	1.73 (8)	1.58 (7)
Indirect energy				
Seed	0.44 (2)	0.44 (2)	0.44 (2)	0.58 (3)
Machinery	3.92 (16)	1.96 (9)	1.28 (6)	0.76 (3)
Fertilizing	9.93 (40)	9.93 (47)	9.93 (48)	9.93 (46)
Plant protection	4.38 (18)	4.38 (21)	4.38 (21)	4.38 (21)
Irrigation	3.07 (12)	3.11 (15)	2.97 (14)	4.38 (20)
Subtotal	21.73 (88)	19.82 (93)	18.99 (92)	20.02 (93)
Total	24.71 (100)	21.30 (100)	20.72 (100)	21.60 (100)

Indirect energy contributed maximum energy compared to direct energy in rice production. The largest source of indirect energy consumption was from fertilizer 9.93 GJ ha-1 (37 to 52 % of the total energy consumption). Seed energy was the highest in ST compared to other tillage operation. Machinery energy was the highest in CT followed by SPWT, BP and ST.

Maize cultivation

Table 6 presents source-wise energy distribution under different tillage practices in maize cultivation.

Table 6 Energy consumption based on energy sources under different tillage options in maize cultivation

Source	CT (GJ ha-1)	ZT (GJ ha-1)	BP (GJ ha-1)	ST (GJ ha-1)
		Maize 2010		
Direct energy				
Fuel	2.78 (12)	0.00 (0)	1.56 (7)	0.93 (4)
Human	0.26 (1)	0.43 (2)	0.25 (1)	0.33 (2)
Subtotal	3.04 (13)	0.43 (2)	1.82 (9)	1.26 (6)
Indirect energy				
Seed	0.22 (1)	0.22 (1)	0.22 (1)	0.22 (1)
Machinery	1.38 (6)	0.00 (0)	0.74 (3)	0.74 (3)
Fertilizing	17.77 (77)	17.77 (93)	17.77 (84)	17.77 (86)
Plant protection	0 (0)	0 (0)	0 (0)	0 (0)
Irrigation	0.66 (3)	0.65 (3)	0.65 (3)	0.61 (3)
Subtotal	20.03 (87)	18.64 (98)	19.38 (91)	19.34 (94)
Total	23.06 (100)	19.07 (100)	21.19 (100)	20.61 (100)
		Maize 2011		
Direct energy				
Fuel	2.00 (8)	0.34 (2)	1.15 (5)	0.42 (2)
Human	0.20 (1)	0.19 (1)	0.18 (1)	0.19 (1)
Subtotal	2.19 (9)	0.53 (3)	1.33 (6)	0.61 (3)
Indirect energy				
Seed	0.22 (1)	0.22 (1)	0.22 (1)	0.22 (1)
Machinery	1.94 (8)	0.55 (3)	0.71 (3)	0.43 (2)
Fertilizing	17.77 (76)	17.77 (87)	17.77 (83)	17.77 (87)
Plant protection	0.77 (3)	0.77 (4)	0.77 (4)	0.77 (4)
Irrigation	0.64 (3)	0.58 (3)	0.66 (3)	0.53 (3)
Subtotal	21.33 (91)	19.88 (97)	20.12 (94)	19.71 (97)
Total	23.52 (100)	20.42 (100)	21.45 (100)	20.32 (100)
		Maize 2012		
Direct energy				
Fuel	2.52 (11)	0.51 (3)	1.27 (6)	0.82 (4)
Human	0.23 (1)	0.23 (1)	0.17 (1)	0.24 (1)
Subtotal	2.75 (12)	0.74 (4)	1.44 (7)	1.07 (5)
Indirect energy				
Seed	0.22 (1)	0.22 (1)	0.22 (1)	0.22 (1)
Machinery	1.86 (8)	0.50 (2)	1.04 (5)	0.65 (3)
Fertilizing	17.77 (75)	17.77 (88)	17.77 (82)	17.77 (86)
Plant protection	0.77 (3)	0.77 (4)	0.77 (4)	0.77 (4)
Irrigation	0.34 (1)	0.30 (2)	0.35 (2)	0.28 (1)
Subtotal	20.96 (88)	19.56 (96)	20.14 (93)	19.68 (95)
Total	23.71 (100)	20.30 (100)	21.58 (100)	20.75 (100)

Direct energy consumption also accounted for only a small proportion of the total energy consumption, ranging from around 9-13% in CT, 2-4% in ZT, 6-9% in BP and 3-6% GJ ha^{-1} in ST. Fuel is the main contributor of direct energy with 8-12% in CT, 2-3% in ZT, 5-7% in BP and 2-4% in ST. Direct energy was the highest in CT and the lowest in ZT due to difference in fuel use. Indirect energy contributed maximum energy compared to direct energy in maize production. Indirect energy shared 87-91% in CT, 96-98% in ZT, 91-94% in BP and 94-97%in ST. The largest source of indirect energy consumption was from fertilizer 17.77 GJ ha^{-1} (75 to 90 % of the total energy consumption). Machinery energy was the highest in CT followed by BP, ST and ZT.

Energy output-input relationship

Rice cultivation

Table 7 shows the energy output-input relationship in rice cultivation. Energy gain was varied across the tillage treatment.

Table 7 Energy output-input relationship under different tillage options for rice cultivation

Tillage practice	Rice 2009			Rice 2010			Rice 2011		
	Energy output (GJ ha^{-1})	EP (kgGJ^{-1})	ER	Energy output (GJ ha^{-1})	EP (kg GJ^{-1})	ER	Energy output (GJ ha^{-1})	EP (kg GJ^{-1})	ER
CT	123	170	4.6	109	160	4.4	187	275	7.6
BP1/SPWT	125	170	4.8	119	200	5.5	184	308	8.6
BP	121	220	6.0	111	200	5.5	178	307	8.6
ST	122	230	6.5	114	190	5.5	180	304	8.4
CV (%)	8.88	5.8	8.7	1.12	6.34	6.91	1.50	1.32	1.77
$LSD_{0.05}$	NS	30	0.95	0.49	30	0.72	NS	8.52	0.30

EP = Energy productivity, ER = Energy output:input ratio

Differences in energy input and similar yield resulted in a large variation of energy balance in wet land rice cultivation. Tillage treatment showed significant effect on energy productivity, which was the lowest in CT compared to other tillage treatment. Energy productivity was almost similar in SPWT, BP and ST. Energy productivity was 26%, 20% and 20% higher in SPWT, BP and ST, respectively compared to CT. Tillage treatment showed significant effect on energy output-input ratio. Which was found identical among SPWT, BP and ST. This ratio was the highest in third rice season due to increased yield in all the tillage operations. It was 14%, 21 % and 23% higher in SPWT, BP and ST, respectively compared to CT.

Maize cultivation

Table 8 shows the energy output-input relationship in maize cultivation.The energy output per unit area showed non-significant in maize cultivation except in third year. Tillage practices showed significant effect on energy productivity. Energy productivity was significant in the second and third maize crop whereas, insignificant in first maize crop. Energy productivity was the highest in ST followed by ZT, BP and CT. Energy productivity was 16%, 11% and 22% higher in ZT, BP and ST, respectively compared to CT. Tillage practices showed significant effect on energy output - input ratio. It was the lowest in CT compared to other tillage treatment.

Table 8 Energy output-input relationship under different tillage options for maize cultivation

Tillage practice	Maize 2010			Maize 2011			Maize 2012		
	Energy output (GJ ha^{-1})	EP (kg GJ^{-1})	ER	Energy output (GJ ha^{-1})	EP (kg GJ^{-1})	ER	Energy output (GJ ha^{-1})	EP (kg GJ^{-1})	ER
CT	242	336	10.5	215	307	9.2	349	476	14.7
ZT	250	367	13.1	243	375	11.9	348	554	17.2
BP	269	400	12.7	229	337	10.7	341	509	15.8
ST	235	350	11.4	241	386	11.9	402	626	19.4
CV (%)	6.90	7.76	7.20	5.63	1.20	5.82	0.87	0.93	0.93
$LSD_{0.05}$	NS	NS	1.84	NS	8.5	1.27	6.28	10.05	0.31

EP = Energy productivity, ER = Energy output:input ratio

In comparison to CT, energy output - input ratio was 23%, 14 % and 24% higher in ZT, BP and ST, respectively.

Rice-maize cropping systems

Yearly energy output of rice-maize cropping systems varied directly with grain yield and energy content of the grain (Table 9). Averaged across the cropping systems, there were no differences in energy output among the tillage treatments. However, the energy output for maize was two-fold higher than that of rice. In rice-maize cropping systems, energy output was the highest in SPWT followed by ZT and the lowest in CT. Energy output-input ratio was the highest in SPWT followed by ST and the lowest in CT. It was 25%, 19% and 26% higher in SPWT followed by ZT, BP and ST, respectively compared to CT.

Table 9 Energy output-input relationship under different tillage options in rice maize cropping system (average over three seasons)

Tillage practice	Rice			Maize			Cropping systems		
	Energy Input (GJ ha^{-1})	Energy output (GJ ha^{-1})	ER	Energy Input (GJ ha^{-1})	Energy output (GJ ha^{-1})	ER	Energy Input (GJ ha^{-1})	Energy output (GJ ha^{-1})	ER
CT	25	140	5.5	23	269	11.5	49	408	8.3
SPWT/ZT	22	152	7.1	20	280	14.1	42	432	10.4
BP	20	137	6.7	21	280	13.1	42	416	9.9
ST	20	139	6.8	21	293	14.2	41	431	10.5

ER = Energy output:input ratio

Discussion

In rice cultivation, energy input for fertilizing represented the major part of total input energy (39-52%), which was more than that of percentage energy utilized in fertilizing reported by Chaudhary *et al.* (2006) and Islam *et al.*, (2001). In maize cultivation, minimum tillage systems accounted energy for fertilizer 82-93%, tillage 4-11%, plant protection 3-4% and irrigation 3%. Clements *et al.*, (1995) reported that the percentage of energy input attributed to pesticides was 4–7% for maize, which was almost similar to this finding. In all tillage operations, fertilizing and land preparation contributed most of the energy input. Fertilizer-related energy input was more important than fuel consumption. Similar dose of fertilizer was applied in all the tillage trial. Only land preparation energy was the major determinant on energy input. Input energy requirements in seedling raising, seeding, transplanting, weeding, irrigation, harvesting, threshing and shelling were lower than that of energy input in fertilizing and land preparation due to the fact that these operations were labor intensive and low energy efficiency of labor compared to other operations. The total operational energy requirement for rice was higher because of more energy consumption in irrigation and plant protection compared to maize. Plant protection energy was lower in maize than rice due to less prone to disease. It was worth mentioning that rice was grown under irrigated condition and required 15-17 number of irrigations against only 3-4 for maize. On the other hand, fertilizer energy requirement was almost double in maize than rice cultivation. In source-wise energy analysis, fuel consumption for both rice and maize varied according to tillage treatment. Fuel consumption comprised the lowest percentage of total energy input in the ZT and the highest percentage of total energy input in the CT. Human input was low in CT compared to other tillage operations due to less labor involvement in crop cultivation. The other major forms of energy consumption were in irrigation, machinery used in conventionally tilled systems and plant protection. Minimum tillage decreased direct fuel use and reduced indirect machinery use in rice-maize cropping systems.

Energy input in minimum tillage was low due to the lowest fuel and labor requirement in land preparation. The minimum tillage ZT, ST and BP saved 15%, 12% and 9% of energy input compared to CT in maize cultivation. The energy input for land preparation decreased considerably with the reduction in the number and intensity of tillage operations compared with CT. In this study, the lowest percentage of energy input occurred in the minimum tillage and the highest in CT. These findings supported several investigations that the energy input for fuel consumption can be reduced with minimum tillage management (Franzluebbers and Francis, 1995; Borin *et al.*, 1997) and that the highest energy use occurred with CT (Bailey *et al.*, 2003). In system-based analysis, the minimum tillage (SPWT followed by ZT, BP and ST) saved 14-16% energy input compared to CT in rice-maize cropping systems. The use of minimum tillage practices provided significant energy savings compared to conventional tillage practices. Zentner *et al.,* (2004) reported that these savings were often offset by higher energy requirements for herbicides with conservation tillage management. Energy used for tillage and herbicides depends on the type of weed management system used (Swanton *et al.,* 1996). The energy output per unit area was fairly similar due to insignificant yield differences. The energy output for rice and maize exhibited a similar pattern to tillage. In contrast, Zentner *et al.,* (2004) also reported that energy output was generally lower with conventional tillage (sweep cultivator) than with minimum or no-till management. Energy output-input ratio was the highest in SPWT followed by ST (10.5) and the lowest in CT (8.3). Energy ratio of ZT and BP was 10.4 and 9.9, respectively. Energy output-input ratio was higher by 25%, 19% and 26% in SPWT followed by ZT, BP and ST, respectively compared to CT. Energy output-input ratio tended to increase when soil tillage operations were reduced. This is in agreement with Borin *et al.,* (1997). Many researchers reported that minimum tillage maximized the output-input ratio of crop production systems.

Conclusion

The minimum tillage (SPWT followed by ZT, BP and ST) saved 14-16% energy input compared to CT in rice-maize cropping systems. Energy productivity and energy output-input ratio in minimum tillage were 14-16% and 19-26% higher than conventional tillage in rice-maize cropping systems. Single pass wet tillage in puddled transplanting followed by zero tillage in maize cultivation, bed planting and strip tillage was more energy efficient in terms of energy costs and energy produced in rice-maize cropping systems.

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