Rice Mechanization in Bangladesh

An entrepreneurial opportunity

AKM Saiful Islam

BANGLADESH RICE RESEARCH INSTITUTE

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Preface

Mechanical intervention in crop cultivation is spreading in a faster way due to acute labor shortage especially in peak transplanting, weeding and harvesting period. Researchers, extension agents, farmers, public and private sectors, donors and non-government organizations are actively involved in the adoption process of mechanized cultivation. Machinery purchase price, unavailability of spare parts, small land holdings, plot size and shape, inaccessibility of farm machinery to the crop field are the major issues, which affect the successful implementation of farm mechanization in the country. Our rural economy is mostly based on rice cultivation as it is the staple food to Bangladeshi people. Therefore, an attempt has been made to identify the constraints and entrepreneurial opportunity in mechanized rice cultivation and the result have been presented in the book. The book is divided into eight chapters, which describe the mechanization status, farm machinery rental system, mat type seedling raising, mechanical rice transplanting, business consideration, business model, land size and shape as well as transplanter operation and mechanical rice harvesting. The book describes a lot of facts on the mechanical rice transplanting where transplanters are still new machine to the most of the rice farmers in this country. Business opportunity and constraints on the farm machinery rental system are well investigated and the results have been presented in concise form. Seasonal use and payback period of selected farm machinery are the limiting factors in the adoption of farm mechanization. Entrepreneurs should consider those before going to start service business. The book points out the importance of land improvement works as operational efficiency of farm machinery dependent on the plot size and shape. It will be useful to the readers to be updated and understand the entrepreneurial opportunity in mechanized rice cultivation and will serve as a reference to the policymakers, researchers, academics and extension agents in the national and international arena. The readers are encouraged to provide opinion for further improvement of the book.

Foreword

Mechanical intervention in crop production is urgently needed to boost up crop production in Bangladesh. This country should switch from subsistence to commercial agriculture to make the production profitable in sustainable way. Dr AKM Saiful Islam has written this book based on the survey and research findings on rice mechanization in Bangladesh. The book is well organized and very informative describing the present status of farm mechanization, farm machinery rental system, mat type seedlings raising, business opportunity of mechanical rice seedlings transplanting service, effect of plot size and shape on the performance of transplanter and mechanical rice harvesting in Bangladesh. It summarizes the research findings on rice mechanization especially focusing on the mechanical rice seedling transplanting and harvesting services in Bangladesh. The author also explored the actual field performance of mechanical rice transplanter in the present land tenure system. Dr Islam has described the existing rental system of farm machinery in different parts of the country, necessity of farm machinery in crop production sector and business opportunity. He also identified the business constraints and opportunities of farm machinery rental system in Bangladesh. I hope this would be a reference work for the scientists, academics and policy makers as well. The essence of this book is that it is a summary presentation of rice mechanization in Bangladesh and beyond. Dr Islam is working on mechanization for a long time without losing enthusiasm, certainly he has the potential to do more in order to transform our farming community in the long run.

(Dr Md Shahjahan Kabir)
Director General
Bangladesh Rice Research Institute
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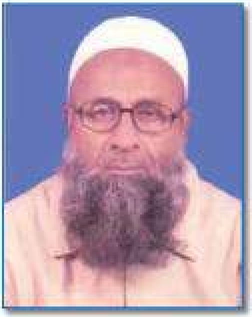
Foreword



Dr AKM Saiful Islam has written the book `Rice Mechanization in Bangladesh', which is a good step that gives us essential information about the topic. The author conducted research and country–wide survey on prevailing situation of rice mechanization, analysed the essential data and nicely presented them to reach a meaningful conclusion. As a result, we have found a one-stop source of information that can deliver the required data regarding the use pattern of machinery in different areas of the country, their needs and benefits, manufacturing conditions including problems and prospects. Comparing and contrasting the past with the present, near with the distant, developing with the developed world, the author has shown his power of interpreting the issues in a brilliant, scholastic and insightful manner. The author also mentioned the case studies on the impact of mechanization to make the research more authentic. Operational efficiency of farm machinery in the present land size and shape are elaborately discussed in the text. He emphasized the importance of land improvement work to get better operational efficiency of the farm machinery. In a nutshell, we can conclude that this is a very good publishing attempt. The author is working on mechanization for a long time and I appreciate his relentless effort. Wishing him every success in his carrier.

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About the author

Dr AKM Saiful Islam 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, United Kingdom in 1997.

Dr Islam started his career as a Scientific Officer in Farm Machinery and Postharvest Technology Division of Bangladesh Rice Research Institute in 1998. The author obtained PhD in Agricultural Engineering from the Department of Farm Power and Machinery, Bangladesh Agricultural University, Mymensingh in 2012. He got professional training from India, China and Japan. Dr Islam has 46 scientific papers published in the national and international journals. The author was the member of the technical committee of mechanization road map 2021, 2031 and 2041. The author published several leaflets, booklets, reports and training manuals on the farm mechanization and postharvest technology. The author also wrote book on conservation agriculture in rice farming systems and mechanized rice transplanting in Bangladesh. Dr Islam is involved in the development of seedlings raising for mechanical rice transplanter, prilled urea fertilizer applicator, rice-wheat reaper, rice-wheat thresher, panicle thresher, mini combine harvester, winnower, air-blow engelberg rice mills and long grain rice processing. At present, he is working as a Principal Scientific Officer in the same division.

Acronyms and Abbreviations

ACI	Advanced Chemical Industries Limited
ACIAR	Australian Center for Agricultural Research
Aman	Paddy/Rice cultivated in rainy season (July to November)
AMS	Agricultural Machinery Services
ARMP	Agricultural Research Management Programme
Aus	Paddy/Rice cultivated in summer season (May to August)
BADC	Bangladesh Agricultural Development Corporation
BAMMA	Bangladesh Agricultural Machinery Manufacturer Association
BARC	Bangladesh Agricultural Research Council
BARI	Bangladesh Agricultural Research Institute
BBS	Bangladesh Bureau of Statistics
Bigha	One bigha equals 33 decimal land
BMDA	Barendra Multipurpose Development Authority
BMTF	Bangladesh Machine Tools Factory
Boro	Paddy/Rice cultivated in winter season (January to May)
BRRI	Bangladesh Rice Research Institute
BSM	Bangladesh Shilpa Malik Samity
CDT	Close drum thresher
CIMMYT	International Maize and Wheat Improvement Center
DAE	Department of Agricultural Extension
DAS	Days after seeding
DTW	Deep tubewell
FAMMPZ	Forum of Agro Machinery and Manufacturing and Processing Zone
FAO	Food and Agricultural Organization
FC	Fixed cost
FGDs	Focus group discussions
FMPHT	Farm Machinery and Postharvest Technology Division
FOAB	Foundry Owners' Association of Bangladesh
FPMU	Food Planning and Monitoring Unit
GBK	Golden Barn Kingdom Pvt. Ltd
GDP	Gross domestic product
GoB	Government of Bangladesh
HT	Hand transplanting
iDE	International Development Enterprise
IRRI	International Rice Research Institute
JICA	Japan International Co-operation Agency
KOICA	Korea International Co-operation Agency
L/W	Length-width ratio
LLP	Low lift pump

LSP	Local service provider
MAWTS	Mirpur Agricultural Workshop and Training School
MoA	Ministry of Agriculture
MT	Mechanical transplanting
NGOs	Non-government organization
ODT	Open drum thresher
PTOS	Power tiller operated seeder
R&M	Repair and maintenance
REFPI	Research and Extension in Farm Power Issues
SAARC	South Asian Association for Regional Cooperation
SID	Statistics and Informatics Division
SOJAG	Somaj-O-Jati Gathan, An NGO
STW	Shallow tubewell
SWOT	Strength, weakness, opportunity and threat
Tk	Taka
USDA	United States Department of Agriculture
USG	Urea super granule
VMP	Versatile multi-crop planter

Content

CHAPTER I

MECHANIZATION STATUS

Introduction

Bangladesh is a fast forwarding lower middle income country in South Asia with a population of 159.1 Million (World Bank, 2015). It is a land of agriculture where rice (*Oryza sativa* L.) is the major crop cultivated in 80% (11.27 mha) of the total cropped area (Kabir *et al.*, 2016a). Rice is grown in three distinct seasons- namely *boro, aus* and *aman*. The country produced 34.5 million metric ton of cleaned rice in 10.61 million hectares of land (BRRI, 2014). The yearly per-capita rice consumption is decreasing from 180 kg in 1977 (Ahmad and Hasan, 1983) to 148 kg in 2015. The population will reach 215.4 million in 2050 and the demand of cleaned rice would be 44.6 million ton (Kabir *et al.*, 2016b). High degree of land fragmentation i.e. 3.2 plots per farm with average plot size of 0.16 ha were observed in Bangladesh. The non-farm household number is increasing at 7% per year (Mandal, 2014). The land area is decreasing at the rate of 80,000 hectare annually due to construction of road, house and industry (BRRI, 2009). The farmers have to grow more food within the limited land resources to meet the growing demand. The country aims at increasing productivity in order to achieve food for raising demand and establish social security of this growing population (USDA, 2015). The contribution of agriculture lost its dominancy to service and industry in GDP (Gross domestic production). Still 47.5% of the population is directly engaged in agriculture and around 70% depends on agriculture for livelihood. The economy of Bangladesh shifted from agriculture to service in 1984 and industry in 2004 (Fig. 1).

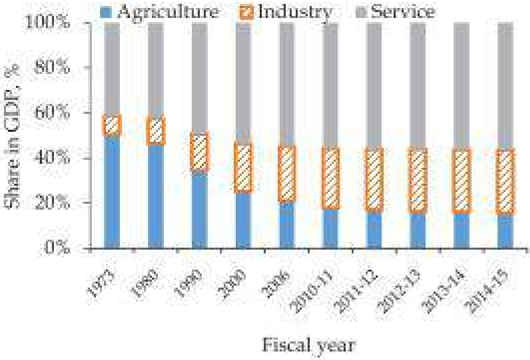


Fig. 1 Trend of sectorial contribution in GDP

Source: BBS, 2016

The contribution of agriculture in national GDP stands at 15.51% in fiscal year 2014 and the contribution of industry and service stands at 28.15 and 56.35%, respectively. The country's labor force stood at 56.7 million on 2010 from whom 9.2% are already diverted to other professions by 2014 (BBS and SID, 2015). Bangladesh is extraordinarily gifted with the highest portion of arable land than any other country in the world (Table 1). To keep progressive trend in GDP, the country has to ensure maximum use of its arable land and other potential resources (i.e. manpower).

Table 1 Agricultural contribution in national economy and employment

Status	GDP at market prices, Trillion $	Arable land (% of land area)	Employment in agriculture (% of total employment)
High income	52,850	9.40	4.00
Middle income	24,750	12.40	25.00
Bangladesh	8,245*	70.00	47.50
Lower middle income	5,781	19.30	44.00
Low income	399	9.60	50.00

Source: World Bank 2014, 2016*

Farm mechanization in Bangladesh is a complex challenge to overcome because of various inherent constraints like fragmented land holding, poor financial ability of farmers, lack of technology diffusion in rural areas and lack of good quality machinery. Agricultural holding in Bangladesh is small and fragmented due to social structure and large number of owners. Despite insufficient supply of machines in the field, Bangladesh's cereal production rate is higher than any other middle income country (Fig. 2). The machine gap that would be required to obtain such large cereal production is being covered by manual labor over decades.

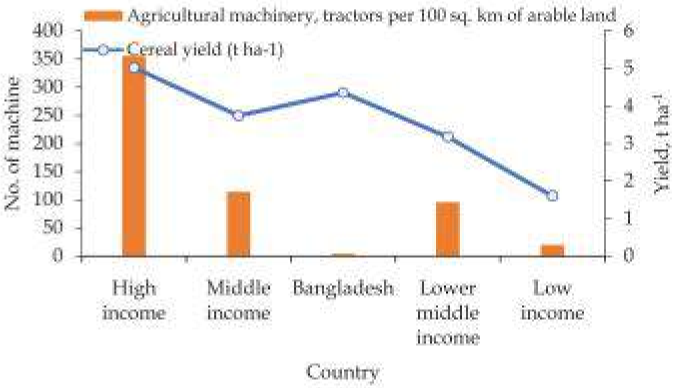


Fig. 2 Cereal productions and machinery use (World Bank, 2016)

There is a substantial contribution of mechanization in agricultural operations that made it possible to release agricultural laborers to get into other high income professions (i.e. business or service). Mechanization can help to increase the cropping intensity by reducing the turnaround time and faster operation of agricultural activities. To keep economical consistency over the shifting of manpower from agriculture to service and industry, it requires filling up the labor gap in agricultural operations by mechanical interventions (Islam *et al.*, 2016a).

Labor situation

Rice production area is decreasing day by day due to urbanization, industrialization and high population pressure. The agricultural labor force followed decreasing trend (48.3 % in 2002-03 and 45.1 % in 2013) whereas it is increasing in non-agricultural sector (51.7% in 2002-03 and 54.9% in 2013) due to shifting low productivity to high productivity sector (BBS, 2015). Rice cultivation was threatened by frequent northwester storm just at the time of harvesting. Farmers often lost paddy at the last stage of crop growth due to natural calamity and labor shortage. Transplanting of seedlings into heavy puddled soils is the common practice of rice cultivation in Bangladesh. Soil puddling is a capital and energy-intensive process and requires a large volume of water. It was reported that a delay in transplanting by one and two months reduced the yield by 25 and 70%, respectively (Rao and Pradhan, 1973). Further, due to rapid industrialization and migration to urban areas, the availability of labor became very scarce and with hike in the wages of labor, manual transplanting found costly leading to reduce profits to the farmers. Weeding, harvesting and threshing are also the labor intensive operations involving human drudgery. Due to the non-availability of laborers, farmers are compelled to practice delayed harvesting which results in yield loss; sometimes incurred total loss of field crops due to natural disaster. It also hampers the land preparation and sowing operations for the next crop.

Farm power availability

Power availability in agricultural operation indicated the intensity of mechanization. Farm power availability was calculated based on the energy input per unit area of cultivable land. Figure 3 shows the farm power availability in agriculture over the period of 1960 to 2013. The power availability was very low before 1984. From 1960 to 1984, the rate of increment of farm power was observed 1.2%. The farming sector got momentum to use machinery after liberalization of import policy on power tiller in 1988. After 1995, government emphasized the importance of mechanization and taken different initiatives such as provided fund in research and extension on farm machinery, policy formulation, tax exemption on some important itemsand encouraged local manufacturing of farm machinery. Hence, power availability in farming sector sharply increased at 8% rate due to intervention of government policy in mechanized cultivation. The progression on the farm power availability in farming sector continued due to provide government assistance to procure selected farm machinery at farmer's level, exemption of import tax on some items; disbursement of fund on the machinery research, extension and capacity building.

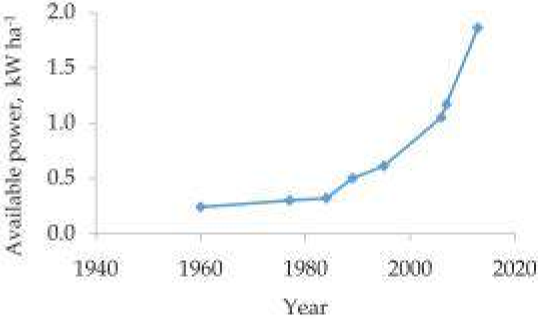


Fig. 3 Farm power availability in agriculture sector (Islam, 2010 and CSAM, 2015)

Why farm mechanization

Labor force is becoming increasingly costly and scarce during peak period of farm operations. Transplanting, weeding, harvesting and threshing operations are considered as four major labor intensive operations in rice cultivation. Table 2 presents the operation wise labor requirement in manual and mechanized rice cultivation. Mechanized cultivation substantially reduces the labor force than manual operation.

Table 2 Labor requirement in manual and mechanized rice cultivation

Technology	Labor requirement		Remarks
	Manual man-hr ha^{-1}	Machine man-hr ha^{-1}	
Transplanter	123-150	9-11	Islam *et al.*, (2016)
Prilled urea applicator	4	4	Islam *et al.*, (2015)
USG applicator	4	4	Islam *et al.*, (2015)
Weeder	86	22	Islam *et al.*, (2017)
Reaper	80-84	9-10	Alam *et al.*, (2014)
Open drum thresher	50-52	20-22	Islam (2006)
Close drum thresher	50-52	14-18	Islam (2006)
Winnower (man-hr t^{-1})	21	5	Ahiduzzaman *et al.*, (2000)

Mechanization is the need of the hour to offset the problems of labor intensive works. It is essential to introduce mechanical devices in all stages of crop production to ensure timeliness and faster operation, reduce crop losses and increase cropping intensity. Mechanical intervention in crop production is the only way to reduce the burden of labor force, helps timeliness of operation and improves the productivity. Mechanization embraces the use of tools, implements and machines for agricultural land development, crop production, harvesting, and on-farm processing. The manufacture, distribution, repair, maintenance, management and utilization of agricultural tools, implements and machines are covered under this discipline regarding how to supply mechanization inputs to the farmer in an efficient and effective manner (www.unupcam.org). The main reason of mechanization is to increase the productivity of labor force and cropping intensity. It is advantageous when it can minimize a high peak labor demand that occurs over a relatively short period of time every year.

Land preparation and threshing are fully mechanized whereas transplanting, fertilizer application, weed management, harvesting and winnowing are depended on traditional methods, which required huge time and labor. Traditional method is incapable whereas adoption of mechanization is a way to meet such conditions with a burden of large investment (i.e. machine purchase cost). Emphasis should be given to mechanize these operations in order to reduce the labor requirement in rice cultivation. To increase crop security, faster transplanting and harvesting operation are ways that could only be established by mechanical intervention. Mechanization combats the acute labor shortage during peak planting and harvesting period. It also improves working condition and the performance of jobs that would otherwise be difficult or impossible by hand method. Mechanization transforms the labor intensive works to power intensive works and reduces the human drudgery. It has been proven that mechanization maximizes the production, reduces the cost of cultivation and post harvest loss and made agriculture profitable. Aurangzeb et al., (2007) stated that mechanization boost up the overall productivity and production with the lowest cost of production. Mechanization relieves the farmers to earn off-farm incomes which facilitates to improve the rural livelihood. It also create an opportunity in rural employment generation.

Impacts of agricultural mechanization

Before 1990s, economists and policy makers thought that mechanization would displaced the labor and ultimately cause unemployment in the rural areas, which would disrupt the social system. Earlier literature suggested that mechanization was not possible in the small and fragmented land (Ahmed, 1965; Alim, 1974).

The situation has been changing rapidly as the country faces acute shortage of agricultural labor force especially in peak transplanting and harvesting time and farmers are compelled to adopt mechanization. Now, it is proven that mechanization creates an employment opportunity in rural areas through diversifying the business especially development of skilled manpower and growth of spare parts shops in the village level. More labors are engaged to manufacture different types of farm machine. Repair and maintenance workshops are developed in the rural areas to support the repairing works of those machines. It helps poverty reduction and facilitates better livelihood of the rural poor people. Everybody realizes the urgency of mechanical intervention in crop production to minimize the labor demand and increase the crop productivity. Farm machinery contributes to increase cropping intensity by reducing turnaround time between two crops. It reduces the burden of labor shortage during peak periods, increase the labor productivity and encourages the off-peak employment of labor in rural non-farm activities especially post-harvest activities i.e. drying, bagging, cleaning are basically done by the female farmers. Mechanical intervention reduces the operational time and drudgery in post-harvest operation. Female farmers get the opportunity to utilize their extra time in other family affairs. The quality products obtained from machine use increase the income of the producers. Local service providers invest money to procure farm machinery and operate rental service system. Mechanization also helps in strengthening the capacity of local manufacturers to produce agro-tools.

Benefits of mechanized cultivation

Mechanization offers direct and indirect benefit. The direct benefits are to reduce the labor requirement in different stages of crop production, improve the land and labor productivity, reduce drudgery, fast operation, ensure the timeliness of operation, reduce the interval times between two crops, increase cropping intensity, increase the safety and comfort of the operator, create congenial working environment and create job opportunity. The indirect benefits are to increase the livelihood of the rural people, reduce the burden of female worker, ensure the growth of service sector and repairing workshop. It increases income for agricultural workers and improves social equality and overall living standards.

How mechanization increases yield

Yearly two million peoples are added in the country and expected to reach 215.4 million population in 2050. The demand of cereals by the year 2050 has been projected to reach 44.6 million tons and rice yield needs to be increased from 3.17 to 4.82 t ha^{-1} (Kabir *et al.*, 2016). Grain yield per unit area should be increased in decreasing land resources to maintain the national food requirement. There are possible ways to increase the grain yield/output i.e. development of suitable high yielding variety, efficient resource management, mechanized cultivation and improved milling system. Mechanized cultivation is the key way to increase the production in sustainable manner. Table 3 shows the yield benefits of mechanized cultivation.

Table 3 Yield benefit in mechanized cultivation

Operation	Technology	Yield/output	Source
Transplanting	Transplanter	9-14% yield increase	Islam *et al.*, (2016b)
Weeding	Weeder	Upward	Islam *et al.*, (2017)
Urea fertilizer application	Prilled urea applicator	Upward	Islam *et al.*, (2015)
	USG applicator	Upward	Islam *et al.*, (2015)
Harvesting	Reaper	0.26% loss over traditional	Alam *et al.*, (2014)
Threshing	Mechanical thresher	2-3% output increase	Islam (2006)
Rice milling	Air blow engelberg huller	1% head rice increase	Islam *et al.*, (2014)
	Convert to rubber roll huller	2-3% head rice increase	Islam (2004)

Crop production constraints

The country's cultivable land is decreasing due to expansion of non-agricultural activities such as construction of housing, factory, office building etc. There is a limited scope to expand agriculture horizontally. Researchers, extension agents, policy makers and farmers are trying to expand agriculture vertically to grow more food grains.Transplanting and harvesting on time secures the crop production. Mechanical intervention performs the timely operation in all the activities. Agriculture is becoming less attractive and rural youths are not interested to work in this sector rather they prefer to work in service sectors. Therefore, farmers face acute labor shortage and wage rate goes high. Consequently, cost of production increases due to high wage rate of labor and other inputs. Flush flood, natural calamity, salinity, tidal surge, excessive rain, drought and cold also affect the crop production.

Constraints of mechanization

The major constraints in adoption of mechanical cultivation is the lack of appropriate farm machine suitable in our land condition, purchasing power of small holder farmers, fragmented land, farm road, institutional leadership, financial subsidies, specialized institute for mechanization, professional personnel, experienced engineers and technicians. Farmers are not aware about the benefit of mechanized cultivation due to inadequacy of extension activity involving farm machinery or mechanization. Good quality fuel and oil are not available in the local markets. Scarcity of quality spare parts, replaceable tools, accessories and inadequate after-sales services restricted the adoption of mechanical devices. Skilled mechanics and operators are needed for efficient operation, proper maintenance and repair of machinery. After abolishing of standardization committee, some manufacturers are fabricating the sub-standard farm machine as there is no law to maintain the quality product. Local manufacturers are not getting proper designand drawing, standard material, fabrication guidelines, skilled manpower, technical assistance and credit facility. There is a variation in tariff system i.e. low tariff on imported machines and high tariff on materials for local fabrication (especially carbon steel).

Mechanization scenario

The change in agricultural sector such as migration of rural labor to urban areas, price hike of wage rate during peak period, attractive wage rate in off-farm activity, industrialization, government policies, distribution of farm machines through development assistance accelerated the farm mechanization in the country. Farm mechanization substitute the human labor or animal power and improve the farm management. The increase in off-farm employment of farmers contribute to enhance farm mechanization. The use of farm machinery not only depends on economic and policy matters but also social and psychological factors to the acceptance of modern machinery in the farming operation. Labor shortage and high labor wage rate compelled the farmers to accept farm mechanization.

Government intervention plays an important role in promoting farm mechanization. Quality machinery and after sale service are necessary insuccessful implementation of farm mechanization program. Mechanization is still in development stages compared to Korea and Japan. Small and fragmented land restricts the farmers to use larger size of farm machinery. Present land tenure system does not permit the easy movement of farm machinery. The important aspect of farm mechanization is to enlargement of land size. Small size of plot decrease the field capacity of the farm machines.

Table 4 presents the present scenario of farm machinery available in Bangladesh. Mechanical intervention in crop production is gradually increasing from 1980s after massive introduction of two-wheel tractor and small engine due to liberalization of import tax and banning of standardization committee on farm machinery. Still power tiller is more popular than tractor due to low purchase price and advantage in carrying, moving, hauling. Government assistance accelerates to power tiller farming. Now-a-days, land preparation is fully depended on either power tiller or tractor on custom hire basis. At present, 80% land is prepared by power tiller and 18% by tractor. Small diesel engine is not only used in crop production, it is also used in other commercial purposes like electricity generation, grain cleaning, boat, mobile huller, sugarcane crusher, irrigation pump, rural transport etc. Rice transplanting is done manually. Mechanized transplanting is being started recently using 4-row walking type transplanter through public and private sector intervention. Seedling raising is crucial part of mechanical transplanter. Farmers do not know how to raise seedlings suitable for mechanical rice transplanter.

The seeder machine is used in some parts of the country to sow jute, lentil, mungbean and rarely paddy seeds. Fertilizer application is mostly done by hand and applicators are rarely used to place urea super granule and prilled urea in subsurface. Weeding operation is mostly done by hand and some parts of the country, farmers use weeder to control weed. Weedicide use is getting popularity due to minimize the weeding cost. Knapsack sprayers are extensively used in crop production purpose. Farmers irrigate the land using deep tubewell or shallow tubewell or low lift pump. Traditional devices are used in very few areas to supply water especially in vegetable cultivation.

Harvesting operation is mostly done by sickle. Research institutes, department of agricultural extension, private sector and non-government organization are trying to promote local and imported reaper (self propelled or power tiller mounted) in the country. Due to limitation, this technology is not getting popular throughout the country. Farmers already understood the importance of threshing by mechanical thresher but there is a gap of mechanical intervention in transplanting and harvesting operation. Farmers need rice transplanter and combine harvester although those machines are not economically viable to the entrepreneur due to higher purchase price and limited annual use. The adoption rate of rice transplanter, seeder, granular urea applicator, prilled urea applicator, reaper, combine harvester and dryer is low due to several constraints. Combine harvester is complicated and sophisticated machine and performs four operations i.e. cutting, threshing, cleaning and bagging in one pass travel. GoB took initiative to introduce reconditioned combine harvester under farm mechanization project during 2009. Entrepreneurs purchased the reconditioned combine harvester with one tenth price of new combine harvester, replaced the damaged parts and refreshed it locally to make the combine harvester in operational condition. Uttaran Engineering Workshop, Kalitola, Dinajpur purchased the reconditioned combine harvester, dismantled in their workshop and identified the parts to know the working principle of different parts with a view to fabricate harvester using locally available materials. In the meantime, operators and mechanics were developed and gained confidence to operate, repair and maintenance of the combine harvester. Later, the government banned the import of recondition combine harvester because of introducing machine in worst condition. BRRI, BARI and local manufacturer developed threshers having different capacities, which are extensively used in the country to thresh rice, wheat and other crops. BRRI also engaged in the development of mini combine harvester suitable to our present land tenure system.

Crop drying is considered as major problem of the farmers to protect grain from spoilage especially in rainy season. Farmers were unable to pay drying cost as it increased the production cost. They are heavily depended on the sun rays to dry the crops inorder to minimize the drying cost. The drying efficiency of Ludhiana State University (LSU) dryer was very much higher as it was re-circulating type and extensively used in the auto rice mills. In industry level 30% paddy is processed by using engelberg huller and 70% with rubber roll huller. In village level, rice is milled in engelberg huller. Rice milling in mobile huller is the cheapest way to process the paddy at village level. It is extensively operated in the village level on custom hire basis and farmers get the service in the door step. Small quantity of paddy can be milled in mobile huller. Two to three passes are needed in engelberg huller to get the cleaned rice. Moreover, husk and bran cannot be separated in the engelberg huller. Bulk amount of paddy is needed to process in commercial mill equipped with either rubber roll or engelberg huller.

Table 4 Present status of farm machinery in Bangladesh

Machine	Quantity, no.	Source
Diesel engine	25,00,000	MoA, 2016
Power tiller	7,00,000	Ahmed, 2014
Tractor	60,000	Ahmed, 2014; Kabir, 2014
Seeder	5,000	Wohab, 2012
Rice transplanter	300	Islam, 2016
Weeder	2,50,000	Ahmed, 2014
Prilled urea applicator	800	MoA, 2016
Granular urea applicator	18,000	MoA, 2016
Sprayer	13,00,000	Ahmed, 2014
Reaper	500	Ahmed, 2014
Combine harvester	130	Ahmed, 2014; Kabir, 2014
Jute ribboner	40,000	MoA, 2016
Open drum thresher	1,50,000	MoA, 2016
Closed drum thresher	2,20,000	MoA, 2016
Maize sheller	42,000	Ahmed, 2014
Sugarcane crushing machine	50,000	MoA, 2016
Winnower	3,000	Ahmed, 2014
Dryer	500	MoA, 2016
Rice mill	15,000	MoA, 2016
Improved parboiling tank	70	MoA, 2016
Power driven pump	1,67,175	MoA, 2016
Deep tube well	35,566	MoA, 2016
Shallow tube well	15,48,711	MoA, 2016

Market price of the farm machinery

Alam (2014) stated that annual total agri-machinery market size of about Tk 74.63 billion of which local production market share was about Tk 40.44 billion. Market size regulates the price of the product. Table 6 presents the purchasing price of farm machinery of different makes and models available in the local market. Product sell not only depends on the market price but also the annual use the machinery. Market price is not only one indicator to increase the sales volume of the farm machinery, however, recovery patterns, after sale service, availability of spare parts regulate the sales volume. Entrepreneurs purchase the machine based on the operational efficiency, after sale service, initial down payments, payment on installment basis, number of installment and grace period. During selection process of farm machinery, entrepreneurs are influenced by their neighbor who had already purchased the machine.

The market of power tiller, tractor, irrigation pump, sprayer and thresher has been developed and their potential is well recognized by the entrepreneur due to the scope of rental service. However, the market potential of transplanter, reaper and combine harvester has not yet been developed due to limited annual use and less scope in providing rental service. Market price of paddy is the main determinant to regulate the rural economy. Paddy price appeared as another limiting factor to purchase the farm machinery. Therefore, paddy exchange rate is used to compare the market price of farm machinery. Islam *et al*. (2016) compared the paddy exchange rate to purchase farm machines and mentioned that farmers have to sell 18 tons of paddy to procure a transplanter in Bangladesh, whereas, in Republic of South Korea farmers need to sell only 2.5 t of paddy to procure the same model of transplanter. Paddy exchange rate is higher in tractor compared to other farm machinery that does not restrain the entrepreneur to purchase the tractor due to versatile use. In off-season, tractors are used to carry goods, which enhance the rural economy. Farmers are getting good return by providing custom hire service in land preparation and other operations especially carrying goods. Although paddy exchange rate of BRRI weeder is very nominal, the farmers do not want to use it to control weeds in rice field due to expanding herbicide market rapidly. The limiting factor of weeder operation is to transplant seedlings in line, water level during weeder operation, soil type and weeding regime. Paddy exchange rate of larger size of head feed combine harvester is higher than other farm machines. The limited annual use, small fragmented land, inaccessibility of farm machinery to the plot, rural road condition, lower elevation of plots from the road, loading/unloading facility, unavailability of spare parts and extended payback period restrained the entrepreneur to buy combine harvester. Farmers showed keen interest to use combine harvester in harvesting rice and wheat as it performs four operations simultaneously i.e. harvesting, threshing, cleaning and bagging. However, entrepreneurs are unable to get profit by providing rental service to the farmers due to higher purchase price and seasonal use of the combine harvester. The paddy exchange rate of reaper is lower than other harvesting equipment. Farmers were hesitant to use reaper in harvesting crops due to problems of gathering crops after harvesting and carrying crops from field to homestead for threshing that needs extra labor. The reaper has also the limitation to harvest lodged crops and unable to operate in muddy field. Reaper performed well in harvesting wheat due to land became dry during harvesting time. Therefore, market potential of reaper is limited and the entrepreneurs are not enthusiastic to buy reaper due to same reasons as mentioned in case of combine harvester. There is a market potential of mini combine harvester due to cheap price and performs the same operation like larger size of combine harvester.

Table 5 Market price of farm machinery with paddy exchange rate

Machinery	Power	Import/ local	Price, Tk unit^{-1}	Paddy exchange rate, t unit^{-1}
Power tiller	12 hp	Imported	1,20,000	5.00
	16 hp	Imported	1,50,000	6.25
Tractor	55 hp	Imported	13,60,000	61.80
	60 hp	Imported	14,60,000	60.83
Transplanter	4-row	Imported	4,00,000	16.67
	6-row	Imported	16,00,000	66.67
Seeder	12-16 hp	Imported	60,00z0	2.50
Sprayer	16 L	Local	2,200	0.09
USG applicator		Local	5,000	0.21
Prilled urea applicator		Local	5,000	0.21
Weeder		Local	800	0.03
Power weeder		Local	60,000	2.50
Irrigation pump	LLP	Local	15,000	0.63
	STW	Local	1,00,000	4.15
	DTW	Imported	52,000	2.17
Reaper	6.5 hp	Imported	1,70,000	7.08
Thresher	16 hp	Local	1,05,000	4.38
Combine harvester	62 hp	Imported	26,00,000	108.33
	12 hp	Imported	6,00,000	25.00

Source: Field survey 2017, paddy price: Tk 24,000 per ton

Import scenario of farm machinery

At the initial stage of mechanization, power tillers were imported from Japan and tractors were imported from Russia (Belarus model) and England (Messy Ferguson model). Now-a-days, most of the tractors are imported mainly from India. After liberation war, Kubota and Yanmar model power tillers were imported from Japan. Performance of those models were satisfactory however, price was beyond the purchasing power of our farmers. After devastating flood in 1988, government relaxed the import tax on power tiller and low cost power tillers were imported from China. Now, almost 100% power tillers are being imported from China. Two models of power tiller namely Dongfeng and Sifang are widely used in the country. Very few rice transplanters including walking and ride on types are operated in the country and all the transplanters are imported from Korea and China. CIMMYT introduced power tiller operated Chinese seeder (2BG-6A) in 1995. The use of seeder machine is increasing day by day, Most of the seeder machines are imported from China and very few are manufactured locally. Irrigation pumps and sprayers (either power or knapsack sprayer) were imported from Korea, China, Brazil, and India. Now, irrigation pumps and sprayers are manufactured locally. At present, reapers are imported from China, South Korea, Vietnam and India. Very few rice-wheat reapers were manufactured locally and sold to the farmers. The quality of reaper was not up to the mark. The local manufacturer was unable to manufacture good quality cutting blade which was the crucial part of the reaper due to lack of heat treatment facility. The demand of rice-wheat thresher and maize sheller are met up by the local manufacturer. Combine harvester of different makes and model are imported from India, South Korea and China.

Farm machinery manufacturing industry

Until the beginning of this century, The Rahman Engineering Workshop, Kushtia; Alim Industries Limited, Sylhet; Comilla Cooperative Karkhana, Comilla; MAWTS, Dhaka; Mahboob Engineering, Jamalpur and Uttaran Engineering Workshop, Dinajpur played pioneering rule in manufacturing different kinds of farm machinery especially hydrotiller, weeder and thresher. There were also small manufacturers available in the country to fabricate threshers and irrigation pumps and sold directly to the farmers. Good quality spare-parts especially liner, piston, valve guide, bush, pumps and impellers are produced in Bogra district and exported to Bhutan, India and Nepal. Farouq *et al*. (2007) mentioned that more than 40,000 small and medium-sized local metal working workshops have grown up to manufacture farm machinery all over the country. In recent years, the GoB has given due importance on the expansion of farm mechanization activities. The country realizes that adoption of mechanized cultivation is the only way to feed the population. The agri-machinery sub-sector has got momentum on the production and marketing of different kinds of machinery and spare-parts. Now, the scenario has been changed and new entrepreneurs come forward to fabricate different types of farm machinery using locally available materials.

The growth of local farm machinery manufacturing industry is expanding day by day. Alam *et al.* (2014) stated that the growth of farm machinery manufacturing and associated industries were about 70 foundries, 800 agro-machinery manufacturing workshop, 1,500 spare parts manufacturing industries and workshops and about 20,000 repair and maintenance workshops are engaged in agro-machinery subsector of the country. Knapsack sprayers, irrigation pump, seeder, thresher, corn sheller, rice milling equipment and spare parts of power tiller and engine are manufactured locally in different parts of the country and satisfy the local demand. Manufacturers started to manufacture combine harvester in their workshop.

Among the farm machinery manufacturers Alim Industries Limited, Sylhet modernizing the workshop facility with the co-operation China venture. Janata Engineering Works, Chuadanga expand the machinery business and modernize the workshop. Large manufacturers are establishing the research and development section, setting up marketing and testing facility, creating good environment for worker, installing modern capital machinery to start line production with maintaining quality of the product. Bangladesh Machine Tools Factory (BMTF) is the only one government owned farm machinery manufacturing industry which is run by the Bangladesh Army and producing, supplying and marketing of different kinds of farm machinery.

Sarker *et al.* (2001) and Islam *et al.* (2001) studied the production problems of the farm machinery manufacturing industries. Most of the farm machinery manufacturers considered machinery business as seasonal due to seasonal demand. Very few manufacturers got technical assistance from the research institutes. In general, small manufacturers do not use jigs and fixtures and produce different standard machines. On top of that, manufacturers do not use quality materials and follow the exact specifications consequently produce low quality machine. Manufacturers do not have heat treatment and foundry facility. Very few manufacturers have research and development section to modify the farm machinery according to the demand of the farmers. Manufacturers do not have the instrument to test the machine in off-load and load condition. Before marketing, machinery should pass the endurance test. The major concern of the manufacturing industry is the safety issues i.e. wearing helmet, gloves, goggles, shoe while working in the workshop. Reverse engineering started in Dholaikhal and Nawabpur area in old Dhaka town. Later those factories were shifted to Bogra and Jessore areas. Bogra is the largest manufacturer of farm machinery and spare-parts in Bangladesh.

Manufacturer face problems on capital, setting up infrastructure, skilled labor, complexity in bank loan, low quality of raw material and technical know-how of the worker. Alam *et al*. (2014) also conducted an in-depth study on the opportunities and constraints on the agri-machinery subsector. The authors identified that similar problems were existed as mentioned in Sarker *et al*. (2001) and Islam *et al*. (2001) after 12 years. In the competitive market, many manufacturers produced sub-standard machinery and sold to the farmers at the lowest price, which created a negative impact among the farmers.

Manufacturer association

The organizations linked with the farm machinery manufacturing formed different associations such as Foundry Owners' Association of Bangladesh (FOAB), Bangladesh Shilpa Malik Samity (BSM), Bangladesh Agricultural Machinery Manufacturer Association (BAMMA),Forum of Agro Machinery and Manufacturing and Processing Zone (FAMMPZ) to make a deal with decision makers to remove the barrier on the growth of this sub-sector. They sit together, discuss with each other, identify the current barrier and logistics needed to run the machinery business smoothly. According to the demand of the manufacturer association, Government has exempted tax on fourteen items.

Repairing workshop

Due to expansion of mechanized cultivation, repairing workshops are set up in the root level. Engine repairing and maintenance facilities are available in the village level. Spareparts of farm machinery are also available in the local shop. A good number of mechanics are developed and provided service to the machinery owner on the repair and maintenance.

Trading of farm machinery

Chittagong Builder Limited is the main importer of small engines. ACI motor Ltd, and The Metal (Pvt) Ltd, Corona Limited, Karnafuli Group started their business to market tractor and power tiller. They expand their business and marketing diesel engine, transplanter, sprayer, reaper, thresher and combine harvester through their sales agent.

Marketing network

The marketing channel of the imported farm machinery is the importer, wholesaler/dealer, sales employee and retailer. The traders have the good marketing network throughout the country and providing after sale service. They have set up show rooms in different districts where farmer/entrepreneur can watch the machine and purchase directly from the show rooms. Small manufacturers sold the product directly to the farmers in different parts of the country through their own manpower as well as dealership network. Most of the manufacturers have the limited access to collect information on the market size. Information on market size in each product helps the entrepreneur to make decision on production volume and establishment of sales network. Small manufacturers are unable to gather market information from different parts of the country due to resource constraints and sell the product in local areas only.

Warehouse facility

Alim Industries Limited, Sylhet constructed big warehouse facility to stockpile thresher, hydrotiller as well as other farm machines in off season and sent to the dealer before starting the season. Other manufacturers have limited ware house facility to stockpile their product. They started to manufacture farm machinery nearer to the beginning of season.

Education and training

Bangladesh Agricultural University, Mymensingh; Hajee Danesh Science and Technology University, Dinajpur and Sylhet Agricultural University, Sylhet are engaged in producing graduate studentson agricultural engineering. Agricultural engineers are playing vital role in promoting mechanized cultivation in the country. Technical School and College also offers Secondary School Certificate and Higher Secondary Certificate on Farm/agro machinery trade. Public and private sector institutions especially BRRI, BARI, DAE, ACI Motors

Limited, The Metal (pvt) Limited, Corona Industries Limited, and MAWTS provided hand-on training on the operation, repair and maintenance of farm machinery. Some of the trainees are professionally involved in the operation and repair of farm machinery.

Research on farm machinery

Farm mechanization depends on the development of appropriate machinery suitable to our present land and socio-economic condition of the farmers. Bangladesh Rice Research Institute, Bangladesh Agricultural Research Institute, Bangladesh Sugar-crop Research Institute and Bangladesh Agricultural University are actively involved in the design, development, field testing, farm level evaluation, validation, dissemination, feedback collection and modification of the farm machinery and technology. Farm Machinery and Postharvest Technology Division, BRRI has the prime responsibility to design, develop, test and validate the rice based machinery and technology. It has developed a number of farm machinery and technology and disseminated to the farmers' field. Among them, seedlings raising technique for mechanical rice transplanter, BRRI weeder, BRRI USG applicator, BRRI prilled urea applicator, BRRI rice-wheat reaper, BRRI open drum thresher, BRRI rice-wheat thresher, BRRI winnower and BRRI chopper are mentionable. These machines and technologies are widely used in the country.

BRRI is conducting research on the development and fabrication of farm machinery using locally available material under public private partnership approach. In the mean time, BRRI worked on the manual rice transplanter and power weeder with Alam Engineering Workshop, Dhaka; chopper and combine harvester with Janata Engineering Workshop, Chuadanga and panicle thresher with Farida Engineering Workshop, Bogra. Local manufacturer modify the farm machinery according to the demand of the farmers. Research institutes offer technical assistance to the manufacturer by providing design, drawing, technical expertise, suggestion and field testing.

Extension of farm machinery

Demonstration is the strongest tool for creating awareness of the farmers. Department of Agricultural Extension (DAE) is the only one government owned extension agency providing advisory supports to the farmers on all types of technology related to the agriculture. Agricultural engineers of DAE are conducting large scale demonstration program on different farm machinery and technology with the assistance of respective district and upazila agricultural extension office.

In 1998, BRRI for the first time of its history, got the small project named 'Adaptive research and impact study agricultural machinery in some district of Bangladesh (ARISAM)' to disseminate the BRRI developed farm machinery and technology in different villages of Thakurgaon and Dinajpur districts.This project was accomplished with the financial assistance from Agricultural Research Management Program (ARMP), Bangladesh Agricultural Research Council (BARC) from January 1998 to December 2000. BRRI rice –wheat reaper, BRRI rice-wheat thresher, BRRI open drum thresher and BRRI power winnower were demonstrated in the porject locations. Three local entrepreneurs namely: *Krishikausal Prokalpa*, Baliadangi, Thakurgaon; *Krishikal Prokalpa*, Ranisankail, Thakurgaon and *Pallikausal Prokalpa*, Katoali, Thakurgaon were developed to provide rental service of the farm machinery. Local farm machinery manufacturers were enlisted to fabricate and market BRRI machine to the farmers.

After successful completion of ARISAM project, GoB provided fund to BRRI on the project named 'Popularizing Agricultural Machinery Project (PAMP)' for the research and extension of rice based machinery and technology. The project was executed in 21 districts namely Dhaka, Mymensingh, Tangail, Sherpur, Comilla, Noakhali, Chittagong, B. Baria, Sylhet, Gopalganj, Jessore, Kushtia, Satkhira, Barisal, Bogra, Rajshahi, Naogaon, Pabna, Thakurgaon, Rangpur and Dinajpur in 2002-06. During the project period, farmers purchased more than 5000 BRRI machines at their own cost and operated those machines on custom hire service. Custom hire service of BRRI machines generated rural employment. A total of 5,300 farmers, manufacturers, farm machinery operators were trained on the operation and maintenance of BRRI machines. In PAMP project, one unit of BRRI rice-wheat thresher was given to SAAO through DAE, Rajshahi. He was advised to split the income into three portions i.e. one third for paying operator charge, another one third for repair and maintenance cost and the rest for supervisor charge. This model appeared as accepted model for threshing rice and other crops. Higher threshing capacity with cleaning mechanism attracted the farmers to accept this technology. Moreover, entrepreneur can earn additional profit from threshing wheat, mungbean, blackgram, lentil and chickpea. By seeing the profitability, entrepreneurs purchased 70 units of thresher and provided service to the farmers on rental basis.

The Department of Farm Power and Machinery (DFPM) of Bangladesh Agricultural University, Mymensingh implemented the project named 'Research and Extension in Farm Power Issues (REFPI)' in 2000-2003 under the financial and technical assistance of The Department for International Development (DFID) of United Kingdom to improve the livelihoods of the rural poor through effective and efficient use of farm power and machinery by small farms and rural systems in Bangladesh. REFPI implemented their activity through providing competitive research fund to GO-NGOs. Those projects created tremendous impact on the spreading of mechanized cultivation in Bangladesh.

GoB also funded BRRI to execute the project named 'Farm Machinery and Technology Development (FMTD)' to disseminate BRRI farm machinery to the farmers through extensive field demonstration and training. During the project period, 5,375 BRRI developed machinery were sold to the farmers at 60% subsidized price. Altogether, 4,220 numbers of farmers/operators were trained on the operation and maintenance of farm machinery during the project period. Fifteen new agricultural machinery were developed and six machinery were modernized during the project period, which were contributed to minimize production cost as well as postharvest loss.

DAE started to execute mechanization activity with agricultural engineers in 1997. The disseminaton activity on mechanization was discontinued after the ending of project in 2004 due to absence of institutional set up of Agricultural Engineering Wing in DAE. At present, the personnel having degree on agricultural engineering are engaged in the dissemination work onfarm mechanization in upazila level through the mainstream DAE network. Department of Agricultural Extension (DAE) executed GoB funded project named 'Enhancement of Crop Production through Farm Mechanization Project Phase-I' during 2009-12 to disseminate the farm machinery throughout the country under subsidy program. Farmers got 25% government assistance to procure different types of farm machinery.

Currently, DAE is also executing the GoB funded five-year project named 'Enhancement of Crop Production through Farm Mechanization Project Phase-II' for 2013-2018 in all over the country and widen the subsidy program. Under this project, amount of assistance is increased and farmers get 50% government assistance to procure different kinds of farm machinery especially transplanter, seeder, thresher, reaper and mini combine harvester. The government also provided transplanter and reaper in *haor* areas under full assistance. DAE is also setting up 100 custom hire service centers to provide service on farm machinery and technology to the farmers.

The expansion of mechanization is the outcome of the combined efforts of different stakeholders involved in the process of mechanization i.e. ministry, research institute, extension agent, development partner, manufacturer, trader, dealer and farmer. Development partners like CIMMYT, IRRI, ACIAR, iDE, KOICA, JICA and NGOs are also involved in the spreading of farm machinery and technology through providing training and logistic support to the end users. Researchers and development partners are actively involved in the development of business model on farm machinery and encourage rental service through formation of local service provider. Ministry of Agriculture, research institute, development partner and manufacturers organize seminar, workshop, motivational tour and field day to disseminate the research findings on the issues, constraints and opportunities of mechanized cultivation.

Extension material

In 1994, DAE published 'Farm Machinery Resource Handbook' by the Canadian Assisted Crop Diversification Project. This book was enriched with pictorial descriptions of seven categories of farm machinery i.e. (i) tillage (ii) inter-culture, seeding and planting machines, (iii) plant protection (iv) irrigation (v) harvesting and threshing (vi) agro-processing (vii) transport (Mandal, 2017). BRRI prepared leaflet, brochure and posters on different types of farm mahcinery and technology and those distributed to the stakeholders. BRRI also prepared operational manuals on farm machinery and technology. The operational manuals included mat type seedlings raising, transplanter, USG applicator, prilled urea applicator, weeder, rice-wheat reaper, open drum thresher, rice-wheat thresher (TH7), rice wheat thresher (TH8), winnower, dryer, stove andlong grain rice processing technology. The manuals provide pictorial description on the operation, repair and maintenance of farm machinery and technology and trouble shooting. The addresses of the farm machinery manufacturers and dealers were incorporated in the manual. Documentary on the operation, repair and maintenance of the rice based farm machinery and technology was prepared to broadcast in mass media, agricultural fair and training session. SAARC Agriculture Center, Dhaka also published "Directory of Successful Farm Machinery in SAARC Countries" with pictorial illustration of farm machinery in Bangladesh, India, Pakistan, Nepal and Sri Lanka.

Internet service/mobile apps

BRRI prepared 16 fact sheets on the machinery and technology and uploaded in Bangladesh Rice Knowledge Bank (www.brkb.brri.gov.bd). BRRI also providing service through mobile apps on the rice based technology especially on farm mechanization. The government has given top priority on the information and communication system throughout the country and setup community based information networks at union level. Farmers have the good access on the internet at village level where they can get information on machinery availability, type of machinery use, cost of machinery operation and after-sale service etc.

Mechanization road map

The country's agricultural system should be changed from subsistenceto commercial agriculture to make the production sustainable. Mechanical intervention in crop production is the key element to make the crop production business viable. The Government of Bangladesh realized the importance of mechanized cultivation and formulated mechanization road map 2021, 2031 and 2041 in 2016. The road map committee identified the challenges, which hindered the mechanization activities in Bangladesh. The challenges mentioned in the road map were the reduction of farm labor at an increasing rate, reduction of agricultural land, climate change, land fragmentation, manufacturing inferior quality farm machinery, suitability of farm machine in local condition, lack of farm road, high price of the farm machinery, low purchasing power of the farmer and depletion of ground water. Mechanization road map also encouraged the development partners to be involved actively in achieving the mechanization goal. The road map proposed the implementation strategy to reach the target of mechanized cultivation.

Strategy to implement mechanization road map

- Research and development of appropriate farm machinery and technology with the active participation of public and private organization
- Develop entrepreneurship on manufacturing farm machinery and technology
- Popularize appropriate farm machinery and technology throughout the country

- Standardize and certify locally developed and imported farm machinery through set up of testing laboratory
- Restructuring institutional manpower and recruiting root level manpower having agricultural engineering degree in thedepartment of agricultural extension
- Capacity building of different stakeholders by providing training on the operation, repair, maintenance, manufacturing and dissemination of farm machinery technology
- Modernize infrastructural facility and manpower development in the research station
- Develop entrepreneurship and set up custom hire service center to provide machinery service to the farmers on rental system
- Provide development assistance or incentive on the selective machinery for faster adoption of farm machinery and technology especially in vulnerable and disadvantaged areas.
- Provide soft loan facility to set up farm machinery manufacturing industries and to procure farm machinery by farmer and entrepreneur
- Formulate policy to implement the farm mechanization activity
- Prepare safety regulation on the use and operation of farm machinery

Table 6 shows the mechanization road map that also targeted the machinery use in different farming activities. The concerned authority should take the relevant steps to achieve the goal. It is impossible to achieve the mechanization goal by government intervention alone. It would be a holistic approach through inclusion of different stakeholders especially public, private, development partners, extension agents, traders, manufacturers, local elites, taxation department, media partners etc.The next step of mechanization road map is to prepare action plan and execute the plan accordingly. The government is trying to develop congenial atmosphere to spread the mechanization activity in faster way.

Table 6 Target of farm machinery use in crop production

Activity	Target of machinery use			
	Present status, %	Short term (2021), %	Medium term (2031), %	Long term (2041), %
Transplanting	<1	20	40	80
Seeding	3	25	50	80
Harvesting	2	30	60	80
Efficient irrigation and water management	33	40	50	70
Fertilizer application	1	10	30	80
Weeding	2	5	15	30
Potato seeding and harvesting	0.1	10	30	80
Power spraying	0	5	10	30
Maize harvesting	0	5	10	60
Jute harvesting and processing	0	10	30	80
Sugar crop planter and harvester	0	10	30	60
Processing perishable product	0	10	30	80
Crop storage	10	20	40	80
Utilization of renewable energy	1	10	30	50
Precision agriculture	0	5	20	50
Fruit harvesting	0	10	30	80
Conservation agriculture	0.1	5	20	40

Source: MoA 2016

Policy issues

Sustainability of mechanization need holistic approach through intervention of public and private organization. Every stakeholder should come forward to make plan on mechanization. In some places, our policy may not match with other countries due to difference in socio-economic conditions of the farmers and land tenure system. Course curriculum and research facility should be modernized in graduate and post graduate level. Syllabus should be modified in the farm machinery trade under Technical School and College. Courses on farm machinery to be included in the youth training center. Agricultural Training Institutes (ATI) under DAE should have a definite curriculum on farm mechanization and post harvest technology; and they are to be provided with a set of potential farm machinery developed by research institute for the training purposes. Research institutes must have the sufficient manpower with infrastructural facility to conduct research on the machinery and technology suitable to our country condition. Insufficient manpower having knowledge on farm machinery and technology existed in the department of agricultural extension. Opportunity should be created in DAE to employ agricultural engineer with operator and mechanic at upazila level. Adequate development assistance is needed to the farmers for purchasing farm machines. Long-term credit facilities at low interest can be provided to the individual farmers, manufacturers and local service providers to accelerate supply and demand of farm machines.

Fund of local annual development program (ADP) may be utilized to procure farm machinery and distributed to the poor farmers. It is imperative to promote local manufacturer to meet the domestic demand and export potential of farm machinery. Manufacturers manufacture the sub-standard product and offer lower price to compete in the market. Proper monitoring is needed to maintain the quality of the farm machinery produced in different engineering workshops in the country. Sufficient facilities should be provided on the development of local service provider to offer farm machinery service at cheapest rate. Machinery testing center should be developed in each zone to test the farm machinery, quality control, training and demonstration. Standardization committee should be revitalized for controlling quality of the local or imported machine and certification should be given to the quality product for getting import facility.

It has been experienced that farm machinery can not be operated efficiently due to present land size, shape and lack of farm road. Government intervention is needed to improve the land size and shape for better field performance and create farm road for accessibility of farm machines. Postharvest activities are mostly done by rural women and they are to be motivated and trained on the use of farm machinery especially weeder, thresher, winnower, drier, improved stove etc. Extensive training on the operation and maintenance of farm machinery should be provided to the government, non-government and private level extension workers, operators, farmers etc. Government assistance on the procurement of farm machinery should be continued for faster up-scaling the service of modern machinery. Bogra and Jessore districts are treated as the central hub of manufacturing farm machinery and spare-parts with limited foundry and heat treatment facility. Those zones fulfill the country's demand on farm machinery and spare-parts. Some of the locally manufactured spare-parts have got the export potential and exporting to Bhutan, Nepal and India. Agrimachinery production zone (APZ) may be set up in Bogra and Jessore districts where all facilities will be available (Alam 2014b).

Farm mechanization model

Mechanization model on different farm machinery is needed to be developed by its own way. Such a model do need to follow Korean or Japanese model that based on greater manufacturing capacity of iron processing industry and abundant petroleum resources. They have accomplished complete agricultural mechanization in relatively short period of time, because of good manufacturing infrastructures. Korea started agricultural mechanization by adopting irrigation pump first, then thresher, reaper and binder, finally rice transplanter and combine harvester.

The agricultural mechanization period in Korea was actually the period of steel processing manufacturing industry built-up in which big steel factories had begun to produce steel products such as steel plates and various steel rods, etc. Daedong Ltd. was the pioneer of manufacturing machines in 1960's to 1970's. In recent years, steel manufacturing industries are growing faster in Bangladesh to manufacture different graded steel and rod. These industries could be a base to supply different graded material to the local machinery manufacturing industries to manufacture farm machinery that can suit our country condition.

The propagation of rice transplanter and combine harvester can not be achieved by importing all the machine from abroad and it may take decades to build manufacturing infrastructure in Bangladesh for domestic production of farm machinery. Agricultural mechanization planning should be prepared by considering many parameters including level of industries status, localization schemes of various parts in different machines, demand of farmers, socio-economic effects of mechanization, petroleum resources and climate change impacts. Developed countries' agricultural mechanization models can be one alternative and they are all depended on petroleum fuels. Now, time is changing to alternative energy using era. Bangladesh needs different model utilizing alternative energy for agricultural mechanization programs.

CHAPTER II

FARM MACHINERY RENTAL SYSTEM

Introduction

Economy of Bangladesh depends heavily upon agriculture. Human labor is declining in farming sector due to shifting labor in non-farm activity. Farm power availability reduces the drudgery and minimizes the input cost. Mechanical intervention in crop production is very much important to minimize labor shortage. The farmers are very poor and land holding size is very small. Small land holding farmers are often unable to purchase the machinery and deprived of the benefit of farm power use. Rental system or custom hire service of the farm machinery is the best way to promote farm mechanization in the country.

Custom hiring is a popular method of gaining short-term control of farm machinery. Custom services may be available from a neighbor, a local dealer, or a business specializing in custom farming that performs all types of field operations. Custom hiring is particularly advantageous for expensive machine and used only seasonally. Modern machinery is still not available to the farmers due to lack of capital and familiarity. Custom hire service will provide the farmers to use the machinery and thus input cost will be reduced. Complete mechanization in rice production by custom hiring based on using modern agricultural machinery is the ultimate goal of the business. The high price and scarcity of labor in agricultural sector increased the crop production cost. Tractor or power tiller, transplanter, reaper and thresher save the production cost and benefit service provider and farmer. Hire service enterprise offers many opportunities for the small holder farmers in rural areas to diversify and increase income sources. Small scale farmers can make their cultivation practice more efficient by using hire service.

Evolution of farm machinery entrepreneurship

Government initiated mechanical intervention in crop production under the scheme of Mechanized Cultivation and Power Pump Irrigation (MCPPI) in 1950-51 by Agricultural Directorate and distributed 2,238 power pumps, 2000 tractors and 13,828 sprayers in 1960-65. International charitable organizations also distributed 138 tractors and 569 power tillers to the cyclone affected areas in 1970 (Alam, 2014). Entrepreneurship as an essential part of farm mechanization was started to develop in 1970 after the introduction of irrigation pump, power tiller and tractor. With the help of government institution, entrepreneurs of mechanized irrigation stood up and still acting throughout the country. Later on, 2-wheel tractor (2WT) locally known as power tiller was brought under entrepreneurial investment. The 2WTs are offered for tillage service to the neighboring farmers and in off-season used in transport by attaching trolley. The 4-wheel tractor (4WT) was introduced in 1950 but gained entrepreneurial attention in 1996-2006 (Roy and Singh, 2008). At present, there are 60,000 tractors being used in tillage and transport. Marginal farmers are getting tillage services via custom-hire model. Use of rice transplanter in Bangladesh started back in 2010. It began with eight rice transplanter (both walking and ride on type) procured by BRRI and 25 walking type rice transplanters procured by DAE. At present, around 300 transplanter machines are available in the country (Islam, 2016).

The International Maize and Wheat Improvement Centre (CIMMYT) introduced Chinese seeder in 1995, which is commonly known as power tiller operated seeder (PTOS). This seeder machine accomplished four operations i.e. tilling, seeding, covering and leveling in a single pass operation. Public and private organizations are actively involved to improve and disseminate the seeder machines to the end users and promote rental service of seeder machine through local service provider. After 2000, service business on thresher was widely spread all over the country. In some places, a group of laborer purchased the thresher machine and made contract with the farmers to harvest crops by sickle and thresh by thresher.

Livelihood change

Bangladesh involves a major portion of her manpower in agricultural operations in rural areas. Mechanical intervention in agricultural operations releases these laborers to upgrade their profession as well as lifestyle. The high demand exists in off-farm operation i.e. garments workers, shopkeepers, auto rickshaw drivers, three-wheeler drivers, rural telecommunication and mobile banking agents in urban areas. Mechanization not only displaces the rural labor force but also creates an opportunity of new professions like operator, mechanic, machinery manufacturer, workshop worker and retailer of spare parts.

Custom hire service

Rolle (2014) reported that custom hiring of agricultural machinery reduces drudgery, expand or intensify production, reduce post-harvest and marketing costs and increase smallholder incomes. The author also marked good business plan, skilled labor and support services to sustain the enterprise as success factors for quality and competitive service delivery to meet market demand.

Justice and Biggs (2010) analyzed the rural transport hire service in Nepal. He mentioned that more than 40% of the tractors were equipped with locally-fabricated transport trailers. Those trailers were used for carrying harvested crops and earned extra income by transporting agricultural and non–agricultural goods in rural and remote areas.

Rental system in different countries

In southern and central Iraq, farm machinery hire services were commonly provided by the private sector solely by farmers on a neighbor to neighbor basis and 51% farmers used their own equipment and 49% received custom hire service for land preparation and harvesting (Bishay, 2003). In Kenya, public sector, NGOs and private sector provided hire services in the two districts of Laikipia and Nakuru. Agricultural Machinery Services (AMS) under the Ministry of Agriculture (MoA) offered mechanization services with about 20 branches countrywide, including one in each of the two districts. Smallholder farmers got little opportunity from AMS due to limited capacity, understaffing and the ability of AMS to offer timely services to their clientele.

Private entrepreneurs provided the hire service in land preparation, planting, weeding and harvesting. Insufficient support services, high poverty levels and little awareness are the main constraints to promote hire service in the rural areas (FAO, 2006). In the 1990s, wheat was threshed in the community threshing floor in the Nepalese terrain plains region. Local large-scale landowner provided the rental service with heavy spike-toothed thresher. The thresher machine was operated with 7 hp diesel engine. The thresher machines were extensively used in the country and 50% of them were manufactured locally. The number of thresher machines increased from 19,000 in 1991 to over 90,000 in 2010. The increasing use of threshers demanded the higher capacity of mobile thresher (Justice and Biggs, 2010). Small-scale enterprises were actively engaged in providing harvesting and threshing services for rice and wheat with hired combine harvesters to the small and medium size landholders (typically with 0.81ha) in the Gujranwala district of Punjab province in Pakistan. One service provider, Mr Abdul Waheed owns a small mechanical workshop in Rassool Nagar and also run a small-scale enterprise known as Waheed Zarri Alaat (Waheed Agri Equipments). Heowned five Indian-made combine harvesters, which he hired out to local farmers for harvesting rice and wheat. He provides his own combine drivers to ensure that the machines are correctly adjusted and operated and charges US$18 to US$24 per acre for rice; and US$14 to US$18 for wheat harvesting. The rental charge varied according to crop density, weed populations, expected yields, ground conditions and transport distance from Rassool Nagar. During the last Kharif season (October –November, 2010) about 500 acres of rice crop were harvested and earned reasonable amount by this business (Sims *et al*., 2011).

Organization for joint use of farm machinery

In Bangladesh, mechanized transplanting is now in rudimentary stage and very few organizations have taken initiatives to expand transplanting business by piloting different business model. Syngenta offered service charge of Tk 15,000 per ha for mechanical transplanting of rice seedlings with an assurance to provide seed, seedlings, mechanical transplanting and advisory support for successful crop production. BRRI provided machinery as well as technical support to them for trouble free operation of the transplanter. The company could not get benefit as it incurred huge cost in tray preparation, tray carrying to the nursery, nursery management, seedlings carrying to the farmer's field, high wage for skilled operator and labor, transplanter rental charge, cost of fuel, repair and maintenance and the company stopped the mechanical transplanting business in 2015. Golden Barn Kingdom Pvt. Ltd (GBK) offered service charge of Tk 12,350 per hectare for mechanical rice seedlings transplanting. High rate of cost escalation was observed in nursery management and seedlings transportation from nursery to the farmers' field. The company incurred huge monetary loss in commercial transplanting (Islam, 2016). ACI Motors Limited started commercial use of mechanical transplanter in Rangpur district during *boro* 2016. The company transplanted the farmers' managed seedlings using their transplanter and took rental charge of Tk 3,700 per hectare. The company continued the transplanting business in 2017 season.

ACI Motors Limited and The Metal (Pvt) Limited offered rental service of combine harvester for harvesting rice and wheat. The Answer Energy Bangladesh Limited purchased two tractors and four combine harvesters in 2012 and provided rental service of farm machinery to the farmersin Naogaon, Bogra, Joypurhat, Dinajpur, Thakurgaon and Kishorganj districts. They offered rental charge for tillage by tractor of Tk 280-300 per *bigha* (two passes) to complete dry tillage only. Farmers themselves inundate the field, level and make ready for transplanting. The rental charge of combine harvester varied with type of crop and season. They offered rental charge of combine harvester for harvesting wheat Tk 1,500 and *boro* rice Tk 1,400 and *aman* rice Tk 1,000 per *bigha* Transportation cost of large size combine harvester seemed to them higher and incurred huge monetary loss to conduct this service. Local service provider named Mr Anwar, Birampur, Dinajpur also provided rental service of harvesting equipment to harvest wheat and paddy in different parts of the country. He formed a promising and dedicated service team to operate, repair and maintain harvesting equipment. In 2014, alocal NGO named SOJAG, Dhamrai, Dhakain association with BRRI provided commercial service of head feed combine harvester for harvesting rice in the farmers' field under public private partnership program. BRRI trained up two local operators to operate, repair and maintenance of the combine harvester. After seeing the performance of the combine harvester and business opportunity, SOJAG purchased larger size of head feed combine harvester and operated commercially in their locality to harvest paddy.

Necessities of farm machinery rental system

Farmers faced acute labor shortage during transplanting and harvesting time. Labor migrated from on-farm to off-farm job due to attractiveness of job and created vacuum in rural labor forces. Labor price also exceeds the normal charge during peak transplanting and harvesting period. Moreover, agricultural activity is not attractive to the rural youth. Therefore, acute labor shortage compelled the farmers to delay in transplanting and harvesting ultimately incurring yield penalty. Modernization in agricultural activity is urgently needed to attract the rural youth. Before the introduction of tillage equipment, animal hire service prevailed in the rural areas for tillage operation. Neighboring farmers provided cattle to the farmers on rental basis. Agricultural goods were carried by animal cart, human head and shoulder.

At present, transportation system has been changed to trolley powered by either power tiller or tractor due to change in road condition. In *haor* (inundated by flash flood) and low lying areas, farmers used boat to carry the harvested crops. Most of the peasants are very poor and limited access to purchase the farm machinery.

Rental system will provide them access to use the machinery in their farming activities and facilitate the rapid expansion of mechanized cultivation. Hire services enabling the farmers to get more time to carry out additional farm and non-farm works. The objective of the hire service is to foster farm mechanization by making easy access of farm machinery to the small and medium holder farmers. Hire service is an appropriate way to keep the operating cost of farm machine at minimum level. It will also create a business venture for the rural unemployed youths. It has been seen in the development of countries emerging from the Soviet era in Europe and Asia that the quality of road infrastructure has a marked influence on the demand for investment in agricultural machinery (World Bank, 2009). Rural infrastructure created an opportunity to get access to the crop fields, markets and increased the role of farm machinery in the transport of products and inputs. With the advancement of information and communication system, farmers got the updated information on crop production technology and market price of the agricultural products through mobile phone and internet system.

Mode of operation

Farmers in Bangladesh are heavily depended on hire, custom or leasing services for land preparation, planting, intercultural operations, harvesting, threshing, shelling and transportation (Table 1). Some farm machines and technologies are used in research trial. Seedlings preparation, transplanting, weeding, harvesting and winnowing are done by hiring laborer. Entrepreneurs provided rental service in land preparation and threshing. The local service providers are mostly smallholder farmers within the village communities. On the other hand, the service providers are those farmers who have identified a potential for hiring services in their region and invested in equipment for own use and hire services (FAO, 2012). Usually, the service provider came from poor family and took as seasonal business on farm machinery service except power tiller and tractor business.

Table 1 Mode of operation of farm machinery in rice cultivation

Activity	Method/ Machine	Mode of operation/ rental system	Source
Seedlings preparation	Seedlings on seedbed	Hiring laborer	Mamun *et al.* 2013
	Seedlings on tray	Research trial	Islam *et al.* 2016a
Tillage	Tractor	Custom hire	FAO, 2012
	Power tiller	Custom hire	Kabir, 2016
Leveling	Manual ladder	Ownership	Miah and Haque, 2015
	PT-equipped ladder	Custom hire	Miah and Haque, 2015
Transplanting	Hand transplanting	Hiring laborer	Islam *et al.* 2016a
	Transplanter	Research trial/ Custom hire	Islam *et al.* 2016a Islam *et al.* 2015
Weeding	Hand weeding	Hiring laborer	Islam *et al.* 2017a
	Weeding by power weeder	Research trial	Islam *et al.* 2017a
Harvesting	Sickle	Hiring laborer	Islam *et al.* 2016a
	Reaper	Research trial	Islam *et al.* 2016a
Threshing	Open drum thresher	Customhire	Islam *et al.* 2016a
	Close drum thresher	Custom hire	Yasmin, 2013
Winnowing	Winnowing by *kula*	Hiring laborer	Ripa, 2009
	Motor winnower	Research trial	Islam *et al.* 2016a

Existing rental charge of farm machinery

The service market of farm machinery is accelerating day by day. Islam and Kabir (2017) evaluated the rental charge of farm machinery through field survey in different parts of the country to get acquainted with the existing situation of farm machinery rental service. A multistage sampling was applied in this study. The field survey was conducted in 54 villages in 54 upazilas in 52 districts under eight administrative divisions of Bangladesh. About 10-15 key informant farmers was selected purposively for focus group discussion (FGD) to delineated with the existing situation of farm machinery rental service. One FGD was conducted in each village to collect data on rental charge of farm machinery, labor cost of major intercultural operations of rice cultivation and farmers opinions about using farm machinery and availability of labor for farming during January-March 2017 (Table 2). The data were summarized in crop production stage wise and discussed in administrative division wise.

Table 2a Survey areas under Barisal division

District	Upazila	Union	Village
Barguna	Amtali	Chawra	Chalitabunia
Barisal	Sadar	Charamoddi	Charamoddi
Jhalokathi	Sadar	Kirtipasha	Orposha
Patuakhali	Galachipa	Amkhola	Basbonia
Pirojpur	Nazirpur	Nazirpur	Mativanga

Table 2b Survey areas under Chittagong division

District	Upazila	Union/municipal	Village
Brahmanbaria	Sadar	Pourashavha	Hatihata
Chandpur	Sadar	9 no. ward	Anathpur
Chittagong	Mirersorai	2 Engoli	Paschim Engoli
Comilla	Chauddagram	Alkora	Uttar Latimi
Feni	Daganbhuiyan	2 no. Rajapur	Paschim Joy narayanpur
Lakshmipur	Sadar	9 Chandraganj	Shekhpur
Noakhali	Sadar	Pourashavha	Maijdi

Table 2c Survey areas under Dhaka division

District	Upazila	Union	Village
Dhaka	Dohar	Bilashpur	Dohar uttarpara
Faridpur	Bhanga	Sadar	Hasemdia
Gazipur	Sadar	Shimultali	Faokal
Gopalganj	Kasiani	Rajpat	Paschim para
Gopalganj	Muksedpur	Tengrakhola	Provakordi
Kishoreganj	Sadar	Latifabad	Mokshedpur
Madaripur	Rajoir	Bajitpur	Bajitpur
Rajbari	Kalo khali	Sadar	Goalia
Tangail	Ghatail	3 no. Jamuria	Gungram
Tangail	Dhanbari	Dhanbari	Jhopna

Table 2d Survey areas under Khulna division

District	Upazila	Union	Village
Bagerhat	Fakirhat	Fakirhat	Pagla uttar para
Chuadanga	Sadar	Katulpur	Boalia
Jessore	Kotoali	Noapara	Akal pachbaria
Jhenaidah	Sailkupa	Sailkupa	Khalkula
Khulna	Dumuria	Baratia	Kulbaria
Kushtia	Khoksha	Goppara	Satpakhia
Magura	Sadar	Hajrapur	Esha khada
Meherpur	Gangni	Matmura	Akabpur
Satkhira	Tala	Zialanta	Charibhanga

Table 2e Survey areas under Mymensingh division

District	Upazila	Union	Village
Mymensingh	Sadar	Sirta	Char Sirta
Sherpur	Nakla	Nakla	Nakla Bazardi
Jamalpur	Sorishabari	Aauna	Ponchashi
Netrakona	Sadar	Collisha	Sakua

Table 2f Survey areas under Rangpur division

District	Upazila	Union	Village
Rangpur	Sadar	15 no. ward	Ghaghotpara
Lalmonirhat	Sadar	Panchagram	Haridev
Dinajpur	Sadar	Sadar	Paschim Khudihar para
Thakurgaon	Sadar	16 no. Nargun	Kismat Daulatpur
Panchgarh	Sadar	10 no. Gorinabari	10 no. Gorinabari
Gaibandha	Gobindaganj	Kamardaha	Digholkandi
Kurigram	Sadar	Mogolbasha	Uttar Naowabas

Table 2g Survey areas under Rajshahi division

District	Upazila	Union	Village
Bogra	Sadar	Fapore	Kanar
Chapainawabganj	Shibganj	Shibganj	Shekhtola
Joypurhat	Sadar	Bambvu	Hismi Bazar
Naogaon	Sadar	2 no. Halain	Toruk
Natore	Sadar	11 Kaforia	Khandarpar
Pabna	Bera	Aminpur	Fokirkandi
Rajshahi	Paba	8 Horian	Mohonpur
Sirajganj	Ullapara	Hatikumrul	Choria chockpara

Table 2h Survey areas under Sylhet division

District	Upazila	Union	Village
Habiganj	Sadar	8 no. Habiganj	Khalpar
Moulavibazar	Sadar	1 no. Amorkona	Daudpur
Sunamganj	Sadar	6 no. Lakshmanjir	Bahadurpur
Sylhet	Sadar	Khadimpara	Kollya

Land preparation

In Barisal division, tillage was done by either tractor or power tiller in the survey areas of all districts except Barguna and Jhalokathi districts (Table 3a). Tractor owner offered higher rental charge than power tiller. The number of passes varied from two to three depending on the soil type and moisture content during land preparation. Service provider offered same rental charge to prepare land for rice, lentil and wheat cultivation. In Patuakhali district, rental charge for land preparation either by tractor or power was higher than the other districts in Barisal division.

Table 3a Rental charge of power tiller and tractor in tilling the land in Barisal division

District	Crop	Power tiller		Tractor	
		No. of pass	Charge, Tk *bigha*$^{-1}$	No. of pass	Charge, Tk *bigha*$^{-1}$
Barguna	Rice, lentil	3	800	-	-
Barisal	Rice, lentil	2	800	2	900
Jhalokathi	Rice	2	700	-	-
Patuakhali	Rice	3	1,000	3	1,200
Pirojpur	Rice, jute	2	800	2	800

Source: Field survey 2017

Note: *indicates leveling is complementary with tillage

Power tiller was widely used in land preparation in the survey areas of Chittagong division (Table 3b). Tillage by tractor was also observed in the survey areas of Comilla, Noakhali and Lakshmipur districts. Only two passes were required for rice land preparation. Irrespective of power tiller and tractor, the rental charge varied from Tk 650-850 per *bigha*, which was depended on the location and soil condition.

Land preparation was mostly done by power tiller in the survey areas of Dhaka division (Table 3c). Land preparation by tractor was not observed in the survey areas all districts except in Tangail district. Service provider offered higher rental charge for land preparation due to excessive demand of power tiller in the peak season (*boro* season). Only two passes were needed to prepare the land for rice, jute and wheat cultivation and service provider offered the rental charge of Tk 600-700 per *bigha*. The rental charge of power tiller variedin *boro* and *aman* season. Land leveling charge was not included in the land preparation. It was mainly depended on the relationship between the owner of the machine and farmers. Sometimes, farmers offered light refreshment to the operator to do the extra work like land leveling. Besides, farmers had to pay extra charge for leveling. The machinery owner offered rental charge of Tk 165 per *bigha* for leveling the land. In Gazipur, Tangail and Dhaka districts, rental charge for land preparation was higher due to inclusion of land leveling with tillage. Machinery owner offered similar rental charge to prepare the land for cultivation of rice, wheat, jute and lentil.

Table 3b Rental charge of power tiller and tractor in tilling the land in Chittagong division

District	Power tiller		Tractor	
	No. of pass	Charge, Tk *bigha*$^{-1}$	No. of pass	Charge, Tk *bigha*$^{-1}$
Comilla	2	650	2	700
Brahmanbaria	2	800	-	-
Feni	2	850	-	-
Chandpur	2	850	-	-
Chittagong	2	800	-	-
Noakhali	2	850	2	850
Lakshmipur	2	750	2	750

Source: Field survey 2017

Note: *indicates leveling is complementary with tillage

Table 3c Rental charge of power tiller and tractor in tilling the land in Dhaka division

District	Crop	Power tiller		Tractor	
		No. of pass	Charge, Tk *bigha*$^{-1}$	No. of pass	Charge, Tk *bigha*$^{-1}$
Dhaka	*Rice	3	800	-	-
Faridpur	Rice, wheat, jute	2	700	-	-
Gazipur	*Rice	3	1200	-	-
Gopalganj	Rice, jute, lentil	2	600	-	-
Kishoreganj	Rice (*boro*)	3	650	-	-
	Rice (*aman*)	2	500		
Madaripur	Rice, jute, wheat	2	600	-	-
Rajbari	Rice, jute, wheat	2	700	-	-
Tangail	*Rice	3	900	2	650

Source: Field survey 2017

Note: *indicates leveling is complementary with tillage

Tillage by tractor was not observed in the survey areas of Jhenaidah, Khulna, Kushtia, Magura and Meherpur districts (Table 3d). Power tiller was extensively used in land preparation in Khulna division. The number of passes varied from two to three and rental charge in land preparation was depended on the type of crops to be grown due to difference in number of passes. The rental charge of tillage by power tiller was Tk 700-950 per *bigha* for rice land preparation and Tk 600 per *bigha* for wheat and jute land preparation. In Jhenaidah district, rental charge for jute and wheat land preparation was lower than that of rice cultivation. In Bagerhat district, land leveling was included with tillage operation and offered rental charge of Tk 950 per *bigha*. Land leveling was done by draft animal in Kushtia and Khulna districts. In Satkhira, Khulna and Bagerhat districts, rice was cultivated in the *gher* (artificial pond for fish culture) area surrounded by artificial canal where fish were cultured. Farmers faced difficulty to move farm machinery over the canal. In some places of Satkhira district, cost of land preparation by draft animal was Tk 1,200 (three passes with leveling).

Table 3d Rental charge of power tiller and tractor in tilling the land in Khulna division

District	Crop	Power tiller		Tractor	
		No. of pass	Charge, Tk *bigha*$^{-1}$	No. of pass	Charge, Tk *bigha*$^{-1}$
Bagerhat	*Rice	3	950	3	950
Chuadanga	Rice, jute	3	850	3	1,000
Jessore	Rice, jute	2	700	2	800
Jhenaidah	Rice	3	900	-	-
	Wheat	2	600	-	-
	Jute	2	600	-	-
Khulna	Rice	3	850	-	-
Kushtia	Rice	3	900	-	-
Magura	Rice	2	700	-	-
Meherpur	Rice	3	750	-	-
Satkhira	Rice	2	650	-	-

Source: Field survey 2017

Note: *indicates leveling is complementary with tillage

Tillage was preferably done by the tractor in the survey areas of Mymensingh division (Table 3e). Limited number of tractors were found in the survey areas. Land preparation cost was depended on the number of passes to be required for particular land. Three to four passes were required to prepare the land and number of passes depended on the soil type and moisture content of land. The rental charge of tillage by tractor was varied from Tk 600-900 *bigha*$^{-1}$ and land leveling was included in the tillage operation. Land leveling was done by ladder and offered service charge of Tk 345 per *bigha*. In some places, land preparation cost was fixed for all types of land in both the seasons. The cost of land leveling depended on the relationship between the machine owner and farmer. In the survey area of Jamalpur district, land preparation was done by either power tiller or tractor. Land preparation costs varied from tractor to power tiller due to variation on the number of tillage passes. Tillage by power tiller needed three passes whereas tractor needed two passes to prepare the land in *boro* season. However, tractors were not available to support all the farmers during peak period. In *aman* season, rental charge of power tiller was low compared to *boro* season because of only two passeswere needed in land preparation. Irrespective of tillage by power tiller or tractor, land leveling charge was included in the rental charges of land preparation.

Table 3e Rental charge of power tiller and tractor in tilling the land in Mymensingh division

District	Crop	Power tiller		Tractor	
		No. of pass	Charge, Tk *bigha*$^{-1}$	No. of pass	Charge, Tk *bigha*$^{-1}$
*Jamalpur	Rice (*boro*)	3	800	3	800
	Rice (*aman*)	2	600	2	600
*Mymensingh	Rice	-	-	3	900
Netrakona	Rice	-	-	3	900
Sherpur	Rice	-	-	3	800

Source: Field survey 2017

Note: *indicates leveling is complementary with tillage, One *bigha* equals 33 decimal

Tractor and power tiller were extensively used in land preparation in the survey areas of Rajshahi division (Table 3f). Number of tillage passes varied from two to four and rental charge depended on the number of passes. The rental charge in rice land preparation varied from Tk 1,000-1,200 and Tk 700-1,200 per *bigha* for tractor and power tiller, respectively. The wide range of variation was observed in the rental charge of tillage which might be due to variation in soil condition. The rental charge of tractor for tillage operation was higher than that of power tiller due to deep tillage. Land leveling was treated as separate work. Service providers were not responsible to level the land. Land leveling was done by the respective farmers in their own management.

Table 3f Rental charge of power tiller and tractor in tilling the land in Rajshahi division

District	Crop	Power tiller		Tractor	
		No. of pass	Charge, Tk *bigha*$^{-1}$	No. of pass	Charge, Tk *bigha*$^{-1}$
Bogra	Rice,potato	4	900	3	1,000
Chapainawabganj	Rice	2	700	-	-
Joypurhat	Rice	2	1,000	2	1,200
Naogaon	Rice, wheat	2	700	-	-
Natore	Rice, wheat	2	800	-	-
Pabna	Rice	2	1,000	2	1,000
Rajshahi	Rice	4	1,200	-	-
Sirajganj	Rice	2	1,200	2	1,200

Source: Field survey 2017

Note: *indicates leveling is complementary with tillage

Land was prepared by either power tiller or tractor in the northern districts of Bangladesh (Table 3g). Draft animal power was rare in Rangpur district. Draft animal power was used in some fields where it was difficult to access power tiller. In Thakurgaon district, tractor was more preferable to the farmers than powertiller in land preparation as land size was larger whereas in Dinajpur district, land preparation was dominated by power tiller. Farmers demanded power tiller rather tractor for tillage in small and fragmented land. During potato cultivation, a large number of tractors from different parts of the country entered into the Rangpur district to get good profit from rental service. Tractor service business became successful in potato dominating region due to demand of high speed rotary tiller. Rental charge for power tiller and tractor in land preparation depended on the number of passes, availability of machine in peak period and locations. Rental charge of tractor was higher than the power tiller due to deep plowing and good pulverization. Service providers were responsible only to till the land in the survey areas of Dinajpur, Thakurgaon, Lalmonirhat and Kurigram districts. Land leveling and laddering was done by the farmers using the traditional methods. In case of plowing by draft animal, land leveling was included in the rental charge.

Table 3g Rental charge of power tiller and tractor in tilling the land in Rangpur division

District	Crop	Power tiller		Tractor	
		No. of pass	Charge, Tk *bigha*$^{-1}$	No. of pass	Charge, Tk *bigha*$^{-1}$
Rangpur	*Rice	3	800	3	1,000
	*Wheat	3	670	3	1,000
	*Potato	4	900	4	1,350
Gaibandha	*Rice	4	1,050	3	1,100
	*Potato	4	1,000	3	1,100
Thakurgaon	Rice		-	3	900
Dinajpur	Rice	4	850	-	-
	Wheat	-	600	-	-
Lalmonirhat	Rice	3	11,000	3	1,000
	Wheat	4	700	2	700
	Jute	4	700	2	700
Kurigram	Rice	4	1,200	4	1,000
	Wheat	4	800	2	800
	Jute	4	800	2	800
	*Maize	4	1,100	2	1100
Panchgarh	*Rice	4	1,100	-	-

Source: Field survey 2017

Note: *indicates leveling is complementary with tillage

Tillage by tractor was not observed in the survey areas of Sylhet division (Table 1.5h). Only two passes were needed to prepare the land for rice cultivation. The rental charge for tillage by power tiller was varied from Tk 600-650 per *bigha*.

Table 3h Rental charge of power tiller and tractor in tilling the land in Sylhet division

District	Power tiller		Tractor	
	No. of pass	Charge, Tk *bigha*$^{-1}$	No. of pass	Charge, Tk *bigha*$^{-1}$
Habiganj	2	650	-	-
Moulavibazar	2	650	-	-
Sunamganj	2	600	-	-
Sylhet	2	650	-	-

Source: Field survey 2017

Animal hire service was rarely available in the rural areas for tillage operation. Land preparation was done by either power tiller or tractor. The power tiller was widely used in tillage operation in the survey areas of all the eight administrative divisions. Rental charge varied location to location, area coverage, soil type, number of passes, type of tillage (dry or puddling), type of crops to be grown. Farmers preferred power tiller rather than tractor for tillage operation in small land due to ease of turning. Potato cultivation required fine tilth of soil and farmers preferred tractor instead of power tiller for good pulverization of soil. Entrepreneurs got more profit from potato land preparation. Most of the places, land leveling was not included in the tillage operation. Service providers were not responsible to level the land after tillage.

Business constraint

- Frequent breakdown happens in tractor and power tiller during tillage operation
- Operators do not have the professional training on the operation, repair and maintenance of the tractor and power tiller
- Mechanics are not readily available nearer to the field
- In case of breakdown, mechanics offer higher service charge
- Spare-parts are not readily available nearer to the field
- Operators do not care the proper maintenance of the power tiller and tractor
- Land preparation depended on the supply of irrigation water and also on the wish of the pump owner
- Small and fragmented land consumes more fuel and time
- Service providers do not get good quality fuel and oil in the local market
- Plot to plot movement time is higher due to dispersion of plots
- Service providers face difficulty to collectthe rental charge from the farmers
- Dishonest operators do not report the actual area coverage to the entrepreneur
- Some farmers hide the actual land area to reduce the rental charge.

Business opportunity

- Power tiller and tractor have the opportunity to use in multipurpose. In off season, entrepreneur can earn extra income from operating trolley, human huller and mobile huller
- Power tiller and tractor can be operated in 365 days a year (day and night operation)
- Comparatively low investment is needed to purchase the power tiller than tractor due to cheap price
- Power tiller demand is high in small and fragmented land.


Photo 1a Tillage by bullock


Photo 1b Tillage by power tiller


Photo 1c Tillage by tractor


Photo 1d Laddering by bullock


Photo 1e Land leveling by placing weight on the ladder

Transplanting

In Barisal division, transplanting of rice seedlings was done on contract basis and payment was made in cash (Table 4a). Laborers uprooted the seedlings from seedbed and transplanted in the main field manually. Three to five laborers were recorded to involve in the transplanting of one bigha land. The labor wage rate varied from Tk 300-500 per man-day. Labor wage rate was the highest in Patuakhali district than the other districts in Barisal division. Farmers depended on the migrated labor in transplanting *aman* rice. Labor price was higher in *aman* than *boro* season. Most of the lands were kept fallow in *boro* season. Plots were inundated by tidal surge.

Table 4a Labor cost of manual rice transplantingin Barisal division

District	Labor, man-day *bigha*$^{-1}$	Wages, Tk man-day^{-1}	Labor cost, Tk *bigha*$^{-1}$
Barguna	3	500	1,500
Barisal	5	400	2,000
Jhalokathi	4	500	2,000
Patuakhali	5	500	2,500
Pirojpur	5	300	1,500

Source: Field survey 2017

Farmers faced acute labor crisis during transplanting in the survey areas of Chittagong division (Table 4b). The most common reasons of labor crisis were to migration in abroad, shifting to garments and industries. Laborer offered higher wage rate due to labor crisis in peak transplanting time. Labor wage rate varied from Tk 450-500 per *bigha*. Farmers depended on the migrated labor to transplant rice seedlings. In peak time, labor came from the northern district to mitigate the labor crisis. In the survey areas of Chittagong and Comilla districts, lands were kept fallow in *boro* season. In Chandpur and Feni districts, lands were kept fallow in *aman* season due to inundation by flood.

Table 4b Labor cost of manual rice transplantingin Chittagong division

District	Labor, man-day *bigha*$^{-1}$	Wages, Tk man-day^{-1}	Labor cost, Tk *bigha*$^{-1}$
Comilla	5	480	2,400
Brahmanbaria	4	500	2,000
Feni	5	450	2,250
Chandpur	5	450	2,250
Chittagong	4	500	2,000
Noakhali	4	500	2,000
Lakshmipur	4	450	1,800

Source: Field survey 2017

Table 4c showed that four to five laborers were required to transplant seedlings manually in the survey areas of Dhaka division. Farmers depended on the migrated labor to transplant rice seedlings. Labor wage rate varied from one place to another. The laborer transplant rice seedlings on contract basis in the survey areas of Kishoreganj and Tangail districts. Farmers maintained line to line spacing after every eight and six rows by using rope in the survey areas of Kishoreganj and Tangail districts. Farmers expressed that laborers were not available during transplanting period. During *aman* season, farmers usually transplanted twenty-five to 30-day-old seedlings. However, 40-45-day-old seedlings were transplanted in low land. It was mainly depended on the availability of water in their field. Transplanting cost in *aman* season was low compared to *boro* season. During *aman* season, line to line spacing was almost double and seedlings density was low. As a result, less labor was required, which minimized the transplanting cost. In the survey area of Gopalganj, Madaripur, Faridpur and Rajbari districts, farmers broadcast rice seed on the upland jute field or after removal of flood water from the jute field.

Table 4c Labor cost of manual rice transplanting in Dhaka division

District	Season	Labor, man-day *bigha*$^{-1}$	Wage, Tk man-day^{-1}	Labor cost, Tk *bigha*$^{-1}$
Dhaka	*Boro*	5	400	2,000
Faridpur	*Boro*	5	400	2,000
Gazipur	*Boro*	5	400	2,000
Gopalganj	*Boro*	5	400	2,000
Kishoreganj	*Boro*	Contract	-	2,000
	Aman	Contract	-	1,500
Madaripur	*Boro*	4	450	1,800
Rajbari	*Boro*	4	450	1,600
Tangail	*Boro*	Contract	-	2,000
	Aman	Contract	-	1,500

Source: Field survey 2017

In the survey areas of Khulna division, transplanting cost varied from Tk 1,250 to 2,000 per *bigha* due to variation of wage rate (Table 4d). Labor wage rate varied from Tk 250-400 per man-day. Farmers depended on the migrated labor to transplant rice seedlings in the survey area of Jessore, Meherpur and Chuadanga districts. However, local labor transplanted rice seedlings in Kushtia and Magura districts.

Table 4d: Labor cost of manual rice tr.ansplantingin Khulna division

District	Labor, man-day *bigha*$^{-1}$	Wages, Tk man-day^{-1}	Labor cost, Tk *bigha*$^{-1}$
Bagerhat	4	500	2,000
Chuadanga	4	350	1,400
Jessore	4	350	1,400
Jhenaidah	5	400	2,000
Khulna	4	400	1,600
Kushtia	5	300	1,500
Magura	4	400	1,600
Meherpur	5	250	1,250
Satkhira	4	350	1,200

Source: Field survey 2017

In Mymensingh division, rice seedlings were transplanted manually on contract basis by a laborer group consisted of 20-25 members and payment was made on cash. The leader of the laborer group managed the total laborers required in transplanting operation. Farmers were fully depended on the laborer group. Without this group, there were no daily laborers available to perform the transplanting activity in the survey areas of Mymensingh division. The group leader fixed the wage rate for transplanting with the consultation of other group members and proposed the demand to the farm owners. By tradition, farmers were bound to transplant seedlings by those group laborers. Without this tradition, the land owner had nothing to do. Transplanting cost depended on the availability of labor in the market and wage rate. Labor crisis created an unusual situation and because of that it was hard to manage transplanting. Sometimes, farmers hired laborers by providing three meals with other extra facilities. Laborers could not maintain any proper line to line spacing. Transplanting cost was the lowest in *aman* season as compared to *boro* season (Table 4e). Farmers faced acute labor crisis in the peak time of transplanting due to shortage of laborers. Farmers in Netrakona district maintained the proper line to line spacing during transplantig to operate weeder.

Table 4e Contractual labor cost of manual rice transplanting in Mymensingh division

District	Season	Labor cost, Tk $bigha^{-1}$
Jamalpur	*Boro*	2,000
Mymensingh	*Boro*	2,000
	Aman	1,600
Netrakona	*Boro*	2,000
	Aman	1,500
Sherpur	*Boro*	2,000
	Aman	1,500

Source: Field survey 2017

In the survey areas of Rajshahi division, labor charge for transplanting was high and labor crisis was acute due to migration off-farm laborer to other occupations especially in Joypurhat, Rajshahi and Sirajganj districts (Table 4f). It was observed that farm laborers were decreased due to increase in educational level. Young generations do not prefer to be involved in agricultural activity as it is drudgery based and less attractive to the rural youth. In the survey area of Rajshahi, Chapainawabganj, Pabna and Sirajganj districts, farmers depended on the migrated labor in transplanting rice seedlings. However, in Natore and Joypurhat districts, farmers depended on the migrated labor in *aman* season. In Naogaon district, farmers fully depended on the migrated labor to transplant rice in both the seasons. Labor wage rate varied in different places and seasons. Labor wage rate varied from Tk 250-400 per day. Labor wage rate was relatively cheap in Chapainawabganj district due to soil was soft after irrigation. Farmers in the Chapainawabganj and Rajshahi districts are gradually shifting their rice lands to mango cultivation due to more profit and less labor management.

Table 4f Labor cost of manual rice transplanting in Rajshahi division

District	Labor, man-day $bigha^{-1}$	Wages, Tk $man\text{-}day^{-1}$	Labor cost, Tk $bigha^{-1}$
Bogra	4	300	1,200
Chapainawabganj	5	250	1,250
Joypurhat	4	400	1,600
Naogaon	4	400	1,600
Natore	5	300	1,500
Pabna	4	300	1,200
Rajshahi	4	400	1,600
Sirajganj	4	400	1,600

Source: Field survey 2017

In the survey areas of Rangpur division, transplanting works were done either on contract or daily basis (Table 4g). Labor wage rate varied from one location to another. In Rangpur district, rice seedlings were transplanted in line. Both contractual and daily laborers were available in transplanting purpose. In Rangpur division, tribal communities were engaged in transplanting activity and the labor wage rate was cheap in case of women labor. Labor wage rate for male and female was Tk 300-400 and 200-250 per day, respectively. In *boro* season, labor wage rate raised to Tk 500 per day for male and Tk 300 per day for female worker. Labor wage rate for the female was always lower than the male worker for the same work. In case of contract system, labor charge for seedlings uprooting to transplanting varied from Tk 825-1,000 per *bigha* whereas the labor cost ondaily basis varied from Tk 1,200 to 1,280 per *bigha*. Labor cost depended on the nature of transplanting i.e. line or haphazard transplanting. Line transplanting required more labor than haphazard transplanting.

Table 4g Labor cost of manual rice transplantingin Rangpur division

District	Labor, man-day *bigha*$^{-1}$	Wages, Tk man-day^{-1}	Labor cost, Tk *bigha*$^{-1}$
Dinajpur	4	320	1,280
Gaibandha	-	Contract	900
Kurigram	4	300	1,200
Lalmonirhat	4	300	1,200
Panchgarh	4	300	1,200
Rangpur	-	Contract	825-900
Thakurgaon	-	Contract	1,000

Source: Field survey 2017

In the survey areas of Sylhet division, labor wage rate varied from Tk 350-400 per man-day. Labor wage rate was observed cheap in the survey area of Habiganj district during transplanting time. Soil compactness was less in this region and easy to transplant rice in the field. The cost of transplanting varied from Tk 1,400-1,600 per *bigha*. Labor crisis was observed acute in Sylhet district due to migration of manpower to other districts and labor wage rate increased to Tk 400 per man-day. In the survey area of Moulavibazar and Sylhet districts, farmers depended on the migrated labor to transplant seedlings in *aman* season. The cultivable land for rice was partially available in this region and labor charge was not expensive. Moreover, women labor was readily available at cheapest wage rate. In Sunamganj district, farmers depended on the migrated labor in both seasons. However, transplanting was done by local labor in the survey area of Habiganj district.

Table 4h Labor cost of manual rice transplanting in Sylhet division

District	Labor, man-day *bigha*$^{-1}$	Wage, Tk man-day^{-1}	Labor cost, Tk *bigha*$^{-1}$
Habiganj	4	400	1,600
Moulavibazar	4	350	1,400
Sunamganj	4	350	1,400
Sylhet	4	400	1,600

Source: Field survey 2017

In short, transplanting was one of the major activities in rice production. Transplanting was done by using hand and payment was made on contract or daily basis. Labor crisis occurred during peak time of transplanting. Labor wage went high and consequently increased the transplanting cost. Labor charge included uprooting of seedling, washing, carrying to the main field and transplanting. Older aged seedlings were transplanted in all the rice seasons. Labor charge in transplanting depended on the availability of labor and varied in location to location. Laborers were not habituated to transplant seedlings in line. In some places, farmers preferred to transplant rice seedlings in line to facilitate intercultural operation. Labor cost depended on the nature of transplanting i.e. line or haphazard transplanting. Line transplanting required more labor than haphazard transplanting.

Mechanical transplanting

Mechanical rice transplanting is gaining attraction to the Bangladeshi farmers. Almost 300 mechanical transplanters are available in the country (Islam *et al.*, 2016). Those transplanters are mostly used in demonstration purpose to create awareness among the farmers about the benefit of mechanized transplanting. Mechanical rice transplanting service was not yet been developed. Public and private organizations are trying to develop local entrepreneur to provide mechanical transplanting service to the farmers. Syngenta offered service charge of Tk 15,000 per hectare (including seedlings, gap filling, transplanting, herbicide and advisory). The Golden Barn Kingdom offered rental charge of Tk 12,350 per hectare (including seedlings, mechanical transplanting, advisory support) for the farmers and Tk 13,500 per hectare (seeds supplied by BADC, transplanting and advisory support) for BADC seed production. Both, Syngenta and GBK reported that cost was escalated in seedling sraising, nursery management and seedlings carrying from nursery to field. In Rangpur district, ACI Motors started the service business of transplanter where local farmers were being provided the transplanting service at a lower rate than traditional practice in 2016. ACI Motors Limited has taken strategy to make the mechanical rice seedlings transplanting service viable. Farmers were trained on seedling raising technique. The company used the rice seedlings management by the respective farmers and offered rental charge of Tk 3,700 per hectare for the operation cost of mechanical rice transplanter. Local entrepreneur was not yet been developed to provide rental service of mechanical rice transplanting.

Business constraint

- The mechanical rice transplanter has the opportunity to use only in rice season (maximum 45 days per year)
- The purchase price of the transplanter isvery high
- The payback period of the transplanter is extended due to seasonal use
- Entrepreneurs are unable to pay installment in off-season
- Skilled operator and mechanics are needed to operate, repair and maintenance of the transplanter
- Mechanical rice transplanter needs mat type seedlings
- Farmers are not habituated to use tender age seedlings
- Transplanter movement from one plot to another is difficult due to lack of farm road
- Excess water in the land hinders the movement of transplanter
- Transplanting schedule could not be maintained properly due to delay in land preparation
- Irregular shape of plot causes inability to operate transplanter
- Machine performance depends on the seedlings density, seedlings height, uniformity of seedlings and seedlings density adjustment
- Small and fragmented land requires extra fuel, time and labor in transplanting.

Business opportunity

- Seedlings raising service will be created in rural areas
- Field capacity of mechanical transplanting is very much higher than the manual transplanting
- Mechanical transplanting ensures the faster operation and minimize the labor shortage during peak transplanting time
- Farmers prefer line transplanting due to ease in intercultural operation Mechanical transplanter maintains the proper line transplanting

- Farmers can get higher grain yield due to use of infant seedlings.

a Seedling uprooting

b Manual transplanting

Photo 2 Traditional rice seedling transplanting

a Seedlings raised in tray

b Mechanical transplanting

Photo 3 Mechanical rice seedling transplanting

Seeding

Table 5 shows that seeder machinewas used for both seeding and tilling purposes in the survey areas of Bangladesh. Local service provider has already been developed in some parts of the country especially Jessore, Rajbari, Magura, Chuadanga, Rajshahi and Thakurgaon districts to provide rental service of the seeder machine. The seeder machine sowed paddy, wheat, maize, lentil, mungbean, blackgram, chickpea and jute seed. Farmers in Rajbari district usually purchased powertiller operated seeder (PTOS) machines for tilling purpose only as it produces fine tilth (Photo 4). The entrepreneur offered rental charge of seeder machine from Tk 15-20 per decimal. Farmers preferred to prepare land by using high speed rotary tiller for onion and garlic cultivation as it produced fine tilth, which was prerequisite to establish onion and garlic. In case of using high speed rotary tiller, machinery owner offered the same rental charge. Table 5 also shows that two passes were required to prepare the land. In the first step, operator tilled the land by using high speed rotary tiller, broadcast fertilizer manually then tilling and seeding was done by the seeder machine. Normally, two passes tillage were required in garlic and onion cultivation. Number of tillage passes depends on the soil type, severity of weed and soil moisture content. Farmers reported that less labor was required to sow onion seed in fine tilth soils. In some places, farmers broadcast seed and fertilizer in the open field then tilling was done by high speed rotary tiller. Farmers were asked about the performance of seeder machine and replied that uniform seed dispensing was not achieved and gap filling was required after seeding. Operators were not well educated on the seed calibration and operation of the seeder machine.

Farmers believed that deep tillage was required to establish crops. However, research findings revealed that seedlings emergence appeared good under minimum tillage (Islam, 2013). Seeding by seeder ensured the timeliness, faster in operation and reduced the labor requirement in seeding. The business opportunity of seeder machine in seeding and tilling operations was increasing in non-rice seeding. Different types of seed metering devices were available in the market to sow different sizes of seeds. Farmers and operator should be educated to calibrate, operate and repair the seeder machine for successful adoption of the technology. BARI also developed high speed rotary tiller, seeder and bed planter and used as commercial purpose in farmers' field (Photo 5). The service provider offered rental charge of Tk 500 per *bigha*. Another model of seeder machine named versatile multi-crop planter (VMP) was extensively propagated in different parts of the county with the financial assistance of ACIAR (Photo 6). VMP has the low field capacity compared to PTOS as the width of operation was half of the PTOS. On the other hand, VMP has an advantage of forming bed, strip and zero tillage. There was a market potential of seeding service by using seeder machine. Most of the seeder machines are basically used to seed non-rice crops.

Table 5 Rental charge of high speed rotatilling and seeder machine

District	Operation	No. of pass	Rental charge, Tk $bigha^{-1}$	Remarks
Rajbari	High speed rotatilling	1	525	Broadcast fertilizer and seeds of garlic, onion, wheat, mungbean, vegetable then tilling
	High speed rotatilling	2	900	Broadcast fertilizer and seeds of garlic, onion, wheat, mungbean, vegetable then tilling
Barisal	Tilling and seeding	1	825	Lentil and wheat seed
	Tilling and seeding	2	1400	First tilling only then seeding lentil and wheat seed and tilling
Jessore	Tilling and seeding	1	400-500	Wheat, lentil and jute seed
	High speed rotatilling	1		-
Kushtia	High speed rotatilling	1	600	-
	High speed rotatilling	1	1200	-
Rajshahi	Tilling and seeding	1	400-500	Maize, lentil, mungbean, jute and wheat seed
	High speed rotatilling	1		Vegetable seed
Jhenaidah	Seeding	1	500	Rice, wheat, maize, mustard and mungbean seed

Source: Field survey 2017

Photo 4 Power tiller operated seeder (PTOS) for seeding jute seed

Photo 5 BARI high speed rotary tiller

a Strip tillage b Bed planting

Photo 6 VMP for strip tillage and bed planting

Business constraint

- Seeder machine equipped with flute type seed meter needs proper calibration for different seed sizes. Plate type seed meter can minimize the time required to calibrate the seeder machine
- Operators should be educated to calibrate the seed machine for different seed sizes
- Operators should be aware to operate seeder machine having optimum moisture content of the soil
- The seeder machines are unable to move in the excessive wet soil
- Uniformity of seed dispensing could not be achieved due to vibration of the seeder machine
- Frequent turning events happened in small size of plots and seed loss occurred during turning
- Operators should avoid excessive dry land. The tillage tine is prone to breakage in excessive dry soil.

Business opportunity

- Four operations i.e. tillage, seeding, covering and leveling can be done by the same machine in single pass operation
- Strip, bed and zero tillage can be done by the same seeder machine
- Flute and inclined plate seeder can dispense different sizes of seed
- Hill dispensing can be ensured by using plate type seed metering device which ultimately minimize the seed rate.

Urea application

Urea fertilizer was broadcast manually in the rice field in three equal splits. Fertilizer application cost was ranged from Tk 80-100 per *bigha*. Fertilizer application cost was not considered by the farmers as they applied themselves by hand. Normally, farmer himself took a bowl with urea fertilizer, went to the field, broadcast the fertilizer and returned to home. Most of the farmers mixed the granular pesticide with fertilizer and broadcast to the field. BRRI and BARI urea super granule (USG) applicator and BRRI prilled urea applicator were developed for deep placement of urea fertilizer. These machines were extensively tested, validated and used in the farmers' field and saved 29-30% urea fertilizer without sacrificing grain yield. The applicators are used in limited scale due to inherent constraint such as line sowing of seedlings, soil should be soft to move the applicator and maintain 2-3 cm height of standing water during operation of the applicator. Rental system was not yet been developed on the operation applicator. Some farmers used the applicators by borrowing from the neighboring farmers or research institute. One farmer in Dohar, Dhaka used BRRI prilled urea applicator in his six hectare of rice field in *boro* 2017. He borrowed the machine from BRRI.

a Hand broadcasting of urea fertilizer

b Hand placement of USG

c BRRI prilled urea applicator

d BRRI USG applicator

Photo 7 Urea fertilizer application method

Weeding

Weeding cost was the highest in Barguna district than the other districts in Barisal division (Table 6a). Weed infestation was severe in Barguna district than other districts of the division and weed cost was escalated due to requirement of more labor. Two times of hand weeding were required in *boro* rice cultivation.

Table 6a Labor cost of manual weeding in *boro* rice cultivation in Barisal division

District	Labor cost, Tk $bigha^{-1}$		
	1st weeding	2nd weeding	Total
Barguna	1,500	1,000	2,500
Barisal	1,400	700	2,100
Jhalokathi	1,400	800	2,200
Patuakhali	1,400	600	2,000
Pirojpur	1,200	800	2,000

Source: Field survey 2017

Weeding was done manually in the survey areas of Chittagong division (Table 6b). Weeding cost depended on the severity of weed infestation and varied from Tk 1,000-1,500 per *bigha* for the 1st weeding. Second hand weeding was needed for complete removal of weeds. Weeding cost was observed less in second weeding compared to first weeding due to less weed infestation. Labor crisis was observed acute in weeding period in this division. In Lakshmipur district, third weeding was required in case of severity of weed infestation in rice field.

Table 6b Labor cost ofmanual weeding in rice cultivation in Chittagong division

District	Labor cost, Tk *bigha*$^{-1}$		
	1st weeding	2nd weeding	Total
Comilla	1,500	900	2,400
Brahmanbaria	1,000	700	1,700
Feni	1,200	500	1,700
Chandpur	1,500	800	2,300
Chittagong	1,300	900	2,200
Noakhali	1,250	850	2,100
Lakshmipur	1,400	1000	2,400

Source: Field survey 2017

Weeding was done by traditional method (by hand) in the survey areas of Dhaka division (Table 6c). The cost of weeding in rice cultivation was depended on the severity of weed infestation, weeding regime and weed control method. The weeding cost varied widely (Tk 1,500-2,400 per *bigha*) depending on the weed infestation. Farmers were reluctant to work in low land for controlling weeds. The farmers in the survey area of Rajbari district did not use weedicide in their rice field. Weeding cost by manual labor was observed the highest in Rajbari district. In Tangail district, farmers were largely depended on the use of weedicide to control weeds. In this region, more than 70% farmers applied weedicide to control weed in rice land. Weed infestation was not severe due to application of weedicide. In some cases, additional one hand weeding was required to control weeds in rice field. Some farmers opined that after application of weedicide, extra one hand weeding was not needed to control weed.

Table 6c Labor cost of manual weeding in rice cultivation in Dhaka division

District	Crop	Labor cost, Tk *bigha*$^{-1}$
Dhaka	Rice	2,400
Faridpur	Rice	1,800
Gopalganj	Rice	1,500-2,400
Kishoreganj	Rice (*Boro*)	1,600
	Rice (*Aman*)	1,000
Madaripur	Rice	1,600
Rajbari	Rice	2,000
Tangail	Rice (*Boro*)	500 (weedicide)

Source: Field survey 2017

Table 6d showed the cost of hand weeding in rice field in the survey areas of Khulna division. Weedicide was not applied in the rice field to control weeds. Weeding was done manually and two times hand weeding were required to remove weeds in the rice field. The cost of weeding varied from Tk 1,200-1,750 per *bigha* in the 1st weeding and Tk 500 to 1,050 per *bigha* in the 2nd weeding. Third hand weeding was not observed in the survey areas of Khulna division. Farmers reported that they did not use weeder machine in their rice field. Line sowing was rarely observed in the rice field. Farmers did not want to maintain the line transplanting as it required higher labor than haphazard transplanting.

Table 6d Labor cost of manual weeding in rice cultivation in Khulna division

District	Labor cost, Tk *bigha*$^{-1}$		
	1st weeding	2nd weeding	Total
Bagerhat	1,200	-	1,200
Chuadanga	1,750	1,050	2,800
Jessore	1,500	900	2,400
Jhenaidah	1,600	800	2,400
Khulna	1,200	-	1,200
Kushtia	1,500	600	2,100
Magura	1,200	600	1,800
Meherpur	1,000	500	1,500
Satkhira	1,100	900	2,000

Source: Field survey 2017

In Mymensingh division, weed infestation was not severe due to application of weedicide (Table 6e). Weeding was done manually by hand once at 50-55 days after transplanting. After that no weeding operation was required upto harvest. In Sherpur district, farmers used 30-45 cm long weeder machine to control weeds. The weeder was made of wood and blade. The price of each weeder was Tk 50 and manufactured locally. Farmers showed the satisfaction about the performance of weeder. Farmers expressed that one hand weeding was not required after weeding by weeder machine. This weeder was widely used in *aman* season. In the survey areas of Netrakona district, weeding operation was also done by weeder machine. It was similar to BRRI weeder and manufactured locally. The cost of each weeder was Tk 600-700. Majority of the farmers owned almost one weeder. Farmers borrowed additional weeders from the neighboring farmers when more than one weeeder was needed to control weed in rice fields. Farmers opined thatsoil was well pulverized during operation of weeder and weeds were uprooted successfully. After weeding, the uprooted weeds were cleaned by hand. As a result, weedswere not grown repeatedly. Frequency of weeding depended on the nature of weed infestation. In Jamalpur district, farmers were interested in applying weedicide to control weeds. They did not have idea about the adverse effects of weedicide application. Farmers applied weedicide to reduce the cost of weeding. Labor charge was very high in their areas. After application of weedicide, only one labor was enough to uproot weeds from one *bigha* land. Additional one hand weeding was not needed in *aman* season.

Table 6e Labor cost of manual weeding in rice cultivation in Mymensingh division

District	Crop (Season)	Number of weeding	Labor cost, Tk $bigha^{-1}$
Jamalpur	Rice (*boro*)	1	500
Mymensingh	Rice (*boro, aman*)	1	400
Netrakona	Rice (*boro*)	1	600
	Rice (*aman*)	1	300
Sherpur	Rice (*aman*)	1	800

Source: Field survey 2017

Table 6f showed the cost of hand weeding in *boro* rice cultivation in the survey areas of Rajshahi division. Normally, two hand weedings were required to control weed in rice cultivation. In some places, three hand weedings were rarely required to control the weed. Weeding cost was more in first than secondhand weeding. The weeding cost in rice cultivation varied from Tk 1,000-1,300 per *bigha* in 1sthand weeding depending on the severity of weed infestation and labor wage rate.

Table 6f Labor cost of manual weeding in *boro* rice cultivation in Rajshahi division

District	Labor cost (Tk *bigha*$^{-1}$)		
	First weeding	Second weeding	Total
Bogra	1,000	500	1,500
Chapainawabganj	1,100	600	1,700
Joypurhat	1,200	600	1,800
Naogaon	1,100	500	1,600
Natore	1,200	900	2,100
Pabna	1,200	600	1,800
Rajshahi	1,300	700	2,000
Sirajganj	1,200	800	2,000

Source: Field survey 2017

Weedicide was extensively used in Rangpur division due to reduction of weeding cost (Table 6g). Weeding cost was largely varied from Tk 800–1,750 per *bigha* due to severity of weed infestation and labor wage rate. In the studied area of Gaibandha district, weeding cost was observed Tk 800 per *bigha* due to use of weedicide. Labor wage rate varied from Tk 200-400 per man-day during weeding period. The cost of weedicide application was observed Tk 100-150 per *bigha* and application of weedicide in rice field reduced the intensity of labor. In Kurigram and Rangpur districts, two hand weedings were generally practiced and labor cost in Kurigram district was high due to labor shortage. Labor migration was the common scenario in Kurigram district.

Table 6g Labor cost of manual weeding in boro rice cultivation in Rangpur division

District	Number of weeding	Labor, man-days *bigha*$^{-1}$	Wages, Tk man-day^{-1}	Labor cost, Tk *bigha*$^{-1}$
Dinajpur	1	4	300	1,200
Gaibandha	1	4	250	1,000
Kurigram	2	6	250	1,500
Lalmonirhat	1	5	200	1,000
Panchgarh	1	3	400	1,200
Rangpur	2	7	200	1,400
Thakurgaon	1	4	300	1,200

Source: Field survey 2017

Weeding was done by manual labor in Sylhet division (Table 6g). Five to seven laborers were needed to control weeds in one *bigha* rice fields. Labor wage rate varied Tk 350-400 man-day^{-1}. Weeding cost was varied widely from Tk 1,750-2,800 per *bigha* due to severity of weed infestation and labor wage rate. Weedicide was not used in the survey areas of Sylhet division.

Table 6h Labor cost of manual weeding in rice cultivation in Sylhet division

District	Labor, man-day bigha^{-1}	Wages, Tk man-day^{-1}	Labor cost, Tk *bigha*$^{-1}$
Habiganj	7	400	2,800
Moulavibazar	7	350	2,450
Sunamganj	5	350	1,750
Sylhet	7	400	2,800

Source: Field survey 2017

Weeding was done by manual labor in most of the survey areas and labor requirement depended on the severity of weed infestation, weeding regime, frequency of weeding and application of weedicide. Therefore, weeding cost shared the largest portion on the cost of crop production. BRRI, BARI and local manufacturers developed different types of low land and upland weeder. The weed control efficiency and field efficiency of those models were very high compared to hand weeding. The prerequisite of the weeder operation was to transplant seedlings in line to facilitate the movement of weeder. Weeder of different makes and models were used in some areas in limited scale. As the price of the weeder was low, weeder never used as rental system. Farmers borrowed weeder from the neighboring farmers and return them after weeding.

Weedicide application was gaining farmer's attention due to low cost and less time required to apply in the field. Farmers changed the manual and mechanical weed control method to weedicide application. Therefore, farmers should be educated to apply weedicide at the right time and right dose to minimize the residual effect and environmental hazard. As the weedicide market was growing up rapidly, it was apparent that there was a little or no opportunity to use weeder in farming operation. On top of that environmental sustainability initiatives can make an opportunity to use weeder.

a First hand weeding

b Second hand weeding

c BRRI weeder

d BRRI power weeder

Photo 8 Weeding method

Knapsack sprayer

Knapsack sprayer was widely used to spray pesticide in the crop field and the application cost varied from Tk 100-110 per *bigha*. Farmers mixed the pesticide either powder or liquid form with fertilizer. In the survey area of Kishoreganj district, usually farmers did not have own sprayer. In emergency situation, farmers hired sprayer from fertilizer dealer shop and paid rental charge of sprayer machine of Tk 20 for 2 to 3 hours of operation. In Mymensingh division, most of the farmers have not owned knapsack sprayer machine and they did not need to buy sprayer. Knapsack sprayers were available at the fertilizer dealers' shop in the survey areas of Jamalpur, Mymensingh, Netrakona, Sherpur and Tangail districts,. In Jamalpur and Tangail districts, fertilizer dealer provided the sprayer to the farmers with free of cost who purchased fertilizer or pesticide from their shops. In Sherpur and Netrakona districts, farmers hired sprayer from fertilizer or pesticide dealer shop and paid machine rental charge of Tk 40-50 per day. Rangpur district was dominated by potato cultivation and spraying was done by the sprayer machine. Knapsack sprayer was widely used in this division and available in farmer's house. In some cases, fertilizer dealer supplied sprayer to their customers who purchased fertilizer or pesticide and received rental charge of sprayer machine of Tk 20-50 per day. Knapsack sprayer was widely used to spray pesticide for the protection of pest and disease. Most of the small holder farmers owned the sprayer due to cheap price. Sprayer never used as rental system in the locality. Farmers borrowed sprayer from the neighboring farmers and returned to the respective farmers after completion of spraying. Farmer used sprayer without taking safety measures. They should be educated to wear safety devices during spraying operation to protect themselves from hazardous incidences. Hand sprayer was widely used to spray horticultural crops. Power sprayer, power tiller and tractor mounted sprayer were not observed in the survey areas.

Business constraints

- Proper maintenance is needed in the pump and nozzle
- Water is not available nearer to crop field
- Operator does not follow the safety regulation
- Rate of application largely depends on the operator.

Business opportunity

- The purchase price of the knapsack sprayer is low
- Easy to operate the sprayer
- Low maintenance cost.

a Herbicide application

b Weedicide application

Photo 9 Spraying crops

Irrigation

Deep tube well (DTW) was more popular than STW and LLP in Rajshahi and Rangpur division. Water table was low in Rajshahi, Bogra and Naogaon districts. Deep boring was required to install DTW in those regions. BMDA was working to improve the irrigation water supply in Rajshahi and Rangpur divisions. In the studied areas of Joypurhat and Pabna districts, the pump owner charged 25% of paddy while harvesting. The cost of irrigation varied widely due to several factor i.e. type of crops grown, water holding capacity of soil, weather condition. Government irrigation scheme and subsidy on electricity were the major issues for the variation. BMDA irrigation project provided smartcard among the farmers where water charge was Tk 100 for one hour irrigation. In Rangpur district, the cost of irrigation in government subsidized electric motor system was Tk 30 per hour. In Sirajganj district, farmers paid Tk 1,000-1,500 per *bigha* as irrigation water charge to establish rice crops. Pump owner tried to avoid the supply of irrigation water in sandy soil as water holding capacity was very low.

Shallow tube well (STW) was the common source of irrigation in most of the survey areas of all divisions. The pump owner supplied water throughout the crop season on rental basis. The medium of exchange was paddy instead of cash. Water charge varied in location to location. Most of the places, the pump owner received 25% of the freshly harvested paddy. In some locations, pump owner preferred cash payments as water charge. In the survey areas of Jhenaidah district, pump owner himself harvested 25% of the crop by his own labor as water charge. In Jhenaidah district, farmers supplied diesel and pump owner received 25% of harvested crop as water charge. In the survey areas of Khulna and Magura districts, pump owner received 25% of the bundle of rice crops as water charge. In Netrakona district, the pump owner of STW offered irrigation water charge of Tk 1,650 per *bigha* in *boro* season. Farmers expressed that they did not need any irrigation water from STW in *aman* season as crops were grown on rainfed condition. Farmers divided the plot having larger in size by making artificial levees to hold water. In Sherpur and Jamalpur districts, STWs were available in the survey areas and machine owners supplied irrigation water to the paddy field on contract basis. The water charge of shallow tube well in *boro* season was too high compared to other survey areas. Deep set STW was observed in some areas of northern districts due to lowering down the water table.

In the survey areas of Barisal division, low lift and axial flow pumps were mostly used to draw surface water from canal and supplied to the crop field. Farmers in those regions waited for tide to supply irrigation water for land preparation. Farmers in Meherpur district paid Tk 2,000 per *bigha* to the owner of low lift pump (LLP) as water charge. In the survey areas of Sunamganj district, LLP was used to supply water to the rice field and paid water charge of Tk 1,000-1,500 per *bigha*. Irrigation water was supplied to the *boro* rice and farmers relied on the rainfall to cultivate *aman* rice.

Water charge varied with the irrigation system as well as type of crops grown i.e. number of irrigation water requirement by different crops. Farmers under the command area of DTW got the water with lowest charge. In STW area, water charge depends on the share of grain output. LLP was mostly used in areas where surface water was available especially in the southern districts to draw water from canal.

Business constraint

- High investment is required to install DTW
- Power interruption hamper the electricity operated irrigation system and unable to maintain the continuity of irrigation water supply to the crop field
- Pump owners face scarcity of quality diesel fuel in the local market
- Frequent breakdown occurs in diesel engine operated pump
- Private pump owner do not follow the regulation in the tube well set up
- Water conveyance loss is high in open and earthen channel due to inefficient water conveyance system
- Water charge may be on cash or share of the grain yield, sometimes pump owner face difficulty to collect payment from the farmer.
- Strong monitoring is needed to distribute water to the target field
- Recovery of water charge is often difficult if natural disaster damage crop
- Water table goes down in dry season, consequently reduce the water discharge and increase the energy cost.

Business opportunity

- Government provides subsidy on the electricity and fuel for operating irrigation pump
- Low investment is required to install STW and LLP

- Easy to repair and maintenance of STW and LLP. Spare parts are locally available
- Benefit cost ratio is high in STW and LLP
- During off-season, prime mover can be used in other income generating purpose
- Rain makes the irrigation project beneficial to the pump owner/service provider

a Deep tubewell

b Shallow tubewell

c Low lift pump

Photo 10 Irrigation pumps

Harvesting

In the survey areas of Barisal division, harvesting cost by using sickle was ranged from Tk 1,500-2,000 per *bigha* (Table 7a). The cost of harvesting rice was the highest in Patuakhali district due to shortage of labor. Labor wage rate was observed Tk 500 per man-day in peak period of harvesting. The cost of harvesting was also depended on the distance of crop field from the farmer's premises.

Table 7a Labor cost of manual harvesting of rice in Barisal division

District	Labor cost, Tk $bigha^{-1}$
Barguna	2,000
Barisal	1,600
Jhalokathi	1,500
Patuakhali	1,600
Pirojpur	1,900

Source: Field survey 2017

In Chittagong division, labor charge for harvesting rice was the highest in Chittagong, Comilla and Noakhali districts. Labor scarcity happened at the time of harvesting due to migration of farm labor to other off-farm jobs. Similar problem was also existed in Chittagong and Noakhali districts. In the survey areas of Comilla district, labor charge for harvesting rice was offered Tk 2,200 per *bigha* whereas only Tk1,500 per *bigha* was offered in Feni district.

Table 7b Labor cost of manual harvesting of rice in Chittagong division

District	Labor cost, Tk $bigha^{-1}$
Comilla	2,200
Brahmanbaria	2,000
Feni	1,500
Chandpur	1,700
Chittagong	2,200
Noakhali	2,200
Lakshmipur	1,650

Source: Field survey 2017

In Dhaka division, labor wage rate during peak period of harvesting ranged from Tk 400-500 per man-day in the survey area of Faridpur district (Table 7c). The labor wages depended on the mode of contract, water depth in rice land and weather condition. During *boro* season 2017, most of the lands in Madaripur districtwent under water in harvesting period and labor demanded 50% of the grain yield as their wages. Harvesting and carrying operations were done in combined way in Kishoreganj and Tangail districts. The cost of harvesting rice varied in *aman* and *boro* seasons. In case of *boro* season, labor cost was comparatively high due to harvesting rice inwater logged condition. Sometimes, laborers were not interested to harvest rice in the inundated field. In Tangail district, the cost of harvesting *boro* rice was high due to carrying bundle from field to threshing floor. In *aman* season, the harvested crops were laid down on the field for drying. As a result, no extra labor charge was required for carrying operation.

Table 7c Labor cost of manual harvesting of rice in Dhaka division

District	Crop	Labor charge, Tk *bigha*$^{-1}$
Dhaka		1,600
Faridpur		2,450
Gopalganj		1,900
Kishoreganj	*Boro* rice	4,000 (land submerged with water)
	Aman rice	2,500
Madaripur	Rice, wheat, jute	4 labor Tk 1,800
Rajbari		1,600
Tangail	*Boro* rice	2,000-2,500
	Aman rice	1,500

Source: Field survey 2017

The harvesting of rice using sickle was varied from Tk 1,400-2,100 per *bigha* due to variation of labor wage rate in the survey areas of Khulna division (Table 7d). Harvesting of rice was done on contract basis and payment was made on cash. Reaper machine was not observed in the survey areas of Khulna division.

Table 7d Labor cost of manual harvesting of rice in Khulna division

District	Labor charge, Tk *bigha*$^{-1}$
Bagerhat	1,200 (3 labor @ 400)
Chuadanga	2,100
Jessore	1,400
Jhenaidah	1,200 (4 labor @ 300)
Khulna	4,000 (8 labor @ 500, cut, carry and thresh by own pedal thresher)
Kushtia	1,200
Magura	1,600
Meherpur	1,500 (5 labor @ 300)
Satkhira	4,000 (8 labor @ 500, cut, carry and thresh by own pedal thresher)

Source: Field survey 2017

In Mymensingh division, harvesting was mainly done by using sickle and payment was made on cash. Basically, harvesting and carrying operations were done in combined way on contract basis. In this region, more than 80 percent of the laborers came from outside to work in the crop field. During crop season, laborers gathered in the labor market. Farmers hired laborer from the labor market and wage rate depended on the working time, providing two or three times meal or not etc. The length of labor market was observed 0.5-1.00 km long in peak period. Local laborers were not interested to involve in the agricultural activities due to extreme level of having leeches in the crop field in low land. Another reason was that they were not interested to work in the water logged condition. Besides, labor price was also depended on several factors. In case of inclement weather, the laborers offered higher wage rate. Labor price went high if labors were not available in the market, although weather condition was good, which effects the cost of paddy production.

In *aman* season, generally labor wage rate was Tk 400-500 per day in Netrakona district. In *boro* season, harvesting cost was comparatively high in low land due to unexpected flood occurred more or less every year. Sometimes, farmers offered Tk 700-800 per man-day with three time meals, eventhough they were not interested to work in low land. In Jamalpur district, harvesting and carrying operations were done in combined way on contractual basis with some conditions. For example, how they provide meal, how much rice was to be given to them etc. In Jamalpur district, most of the lands went into water due to low lying areas. Ultimately harvesting cost was too much high due to having water in the plot. Sometimes, in spite of offering high labor charge with other extra facilities, labors were not interested to harvest in low land. Farmers stated that fungus attacked in their hand if they harvested crop in inundated field. On the other hand, harvesting cost was comparatively low in *aman* season due to the availability of farm laborers.

Table 7e Labor cost of manual harvesting of rice in Mymensingh division

District	Crop	Rental charge, Tk *bigha*$^{-1}$
Jamalpur	*Boro* rice	3,000-4,000
Mymensingh	*Boro* rice	2,200-2,400
	Aman rice	1,000-1,200
Netrakona	*Boro* rice	2,200-2,400
	Aman rice	1,000-1,200
Sherpur	*Boro* rice	2,200-2,400
	Aman rice	1,600

Source: Field survey 2017

Table 7f shows that the labor cost of harvesting using sickle was varied from Tk 1,400-2,400 per *bigha* in the survey areas of Rajshahi division. The mode of payment was made on cash in all the districts except Naogaon district. In Naogaon district, labor group offered share of the harvested crop as a charge of harvesting cost.

Table 7f Labor cost of manual harvesting of rice in Rajshahi division

District	Labor charge, Tk $bigha^{-1}$
Bogra	2,200
Chapainawabganj	1,500
Joypurhat	2,000
Naogaon	8 kg paddy per 40 kg
Natore	1,800
Pabna	2,000
Rajshahi	1,400
Sirajganj	2,400

Source: Field survey 2017

Cropping intensity was high in Rangpur division and labor cost was relatively lower than other divisions. Labor scarcity existed in Gaibandha and Kurigram districts due to migration oflabor to the capital. Harvesting cost was observed Tk 2,000 per *bigha* in Kurigram whereas Tk 1,500 in Rangpur district. Harvesting cost was varied with season and weather condition. Labor crisis was observed as acute in harvesting *boro* rice and wage rate increased to Tk 100-200 per man-day from normal rate due to peak demand.

Table 7g Labor cost of manual harvesting of rice in Rangpur division

District	Crop	Labor charge, Tk $bigha^{-1}$
Dinajpur	Rice	2,100
Gaibandha	Rice	1,800-2,000
Kurigram	Rice	2,000
	Maize	1,800
Lalmonirhat	*Aman* rice	2,000
	Maize	3,000
Panchgarh	Rice	1,500-1,600
Rangpur	Rice	3,500
	Maize	1,240
Thakurgaon	Rice	1,800

Source: Field survey 2017

In Sylhet division, the labor charge for harvesting rice was varied from Tk 1,600-2,000 per *bigha* due to variation of labor wage rate (Table 7h). Farmers faced labor shortage in harvesting period. Only cash payment was prevailed in the Sylhet division.

Table 7h Labor cost of manual harvesting of rice in Sylhet division

District	Crop	Labor charge, Tk *bigha*$^{-1}$
Habiganj	Rice	1,600 (4 person @400)
Moulavibazar	*Aman* rice	1,750
Sunamganj	Rice	2,000 (4 person @300)
Sylhet	*Aman* rice	1,600

Source: Field survey 2017

Reaper

Reaper was available in Bogra, Naogaon and Madaripur district. Entrepreneur provided service to the farmers on rental system. Rental charge for harvesting rice and wheat was observed as Tk 500-600 per *bigha*. The machinery owner not only received rental charge as cash but there was an opportunity to pay rental charge as share of the grain yield or fixed amount of grain per unit area of harvest (Table 8). Md Somraj Sheikh, an agricultural machinery entrepreneur of Rajoir, Madaripur bought two reapers i.e. one was BRRI power tiller mounted and another was ACI vikino reaper in 2017 and harvested 7.50 hectare of wheat at the rate of Tk 4,000 per hectare. The entrepreneur earned profit of Tk 60,000 by harvesting wheat in one season. Different organizations are trying to develop entrepreneurship on harvesting equipment. In some places, entrepreneurship was developed on the harvesting by reaper.

Table 8 Rental charge of reaper for harvesting ricein selected districts

District	Crop	Rental charge, Tk *bigha*$^{-1}$
Bogra	*Boro* rice	600
	Aman rice	500
	Wheat	600 or 4 kg per 40 kg
Naogaon	*Boro* rice	500 or 20 kg *bigha*$^{-1}$
	Aman rice	500 or 25 kg *bigha*$^{-1}$
	Wheat	500 or 20 kg *bigha*$^{-1}$
Madaripur	Wheat	530

Source: Field survey 2017

Business constraint

- Chinese and Vietnamese brand reapers are available in farmers' field. In most of the cases major parts were failed during harvesting operation
- In*boro* season, natural calamity like storm and rain hamper the operation of reaper

- Extra labor was required to cut the paddy in the corner of the plot to facilitate the movement of the reaper
- Movement of reaper is restricted in excessive wet soil and inundated field
- Storm may lodge the crop and reaper machine is unable to cut the lodged crop
- Reaper machine may skid or slip in wet field consequently fuel consumption will be higher when operates in wet field
- Labor efficiency reduces when reaper operate in excessive sun light
- Small sizes of plot require more time and fuel due to more turning events
- After harvesting by reaper, farmer has to depend on other labor group to bind the harvested crop, carrying from field to threshing floor and threshing. Labor offered the same wage rate as complete operation i.e. harvesting to threshing operation
- Fragmented plots require more time to move reaper from one plot to another
- Reaper machine unable to enter into in the middle of plot surrounded by other crops.

Business opportunity

- Reaper ensures the faster operation of harvesting than that of manual harvesting
- Reaper is suitable to harvest crops in small and fragmented field
- Government provides assistance to procure reaper at subsidized rate
- Reaper machine reduces the labor requirement in harvesting
- It is not a complicated machine and operator can operate easily
- It requires low fuel in harvesting operation.

a Wheat harvesting by sickle

b Paddy harvesting by sickle

c Self-propelled reaper

d Powertiller mounted reaper

Photo 11 Crop harvesting method

In short, harvesting was done by using sickle. It was laborious and time consuming work among the crop production stage. Labor scarcity happened in the peak time of harvesting in all the survey areas of Bangladesh. Labor cost for harvesting rice varied widely due to variation of labor wage rate. Laborer offered higher wage rate in case of harvesting rice in inundated field. Labor wage was also depended on the distance from home yard to crop fields. It was observed that the mode of payment was made on cash or share of the harvested grain or fixed amount of grain per unit area of harvest. In some places, farmers had to provide three or two times meals to the laborers in addition to their wages. Farmers showed keen interest to harvest paddy or wheat by using reaper. It was not yet popularized due to some inherent constraints i.e. unablity to cut lodged crop, restricted movement to wet field, after harvesting farmers had to hire another group of labor to collect the harvested crop, carrying the harvested crop from field to threshing floor and threshing.

Thresher

In Barisal division, close drum thresher was widely used to thresh rice crops (Table 9a). The rental charge was based on the share of crop not in cash. The rental charge varied from 2-3 kg per 40 kg of threshed paddy. It depended on the demand of the thresher especially inclement weather and labor shortage.

Table 9a Rental charge of thresher for threshing rice in Barisal division

District	Rental charge, kg paddy per 40 kg	Type of thresher
Barguna	2	CDT
Barisal	3	CDT
Jhalokathi	2	CDT
Patuakhali	2	CDT
Pirojpur	2	CDT

Source: Field survey 2017, CDT = Close drum thresher

Farmers in the survey areas of Chittagong division threshed the rice crop byclose drum thresher. Rental charge was based on the share of the harvested grain and varied from 2.5-3 kg per 40 kg of threshed crop (Table 9b). Traditional method of threshing especially cattle treading and hand beating were not observed in the survey areas of Chittagong division.

Table 9b Rental charge of thresher for threshing rice in Chittagong division

District	Rental charge, kg paddy per 40 kg	Type of thresher
Comilla	3	CDT
Brahmanbaria	3	CDT
Feni	3	CDT
Chandpur	2	CDT
Chittagong	3	CDT
Noakhali	2.5	CDT
Lakshmipur	3	CDT

Source: Field survey 2017, CDT = Close drum thresher

In the survey areas of Dhaka division, threshing operation was done by hand beating and close drum thresher (Table 9c). The machine owner offered rental charge of 2- 3kg per 40 kg of threshed paddy. In the survey area of Kishoreganj district, the machine owner receivedone bundle from every 20 bundles of paddy i.e. 5% of threshed grain had to be given to the machine owner. This system was very popular in the survey areas. Traditional hand beating prevailed in the survey areas of Tangail district whereas threshing was fully mechanized in other districts. Traditional way of threshing required too many labors and it was very time consuming operation. Power tiller trading was observed in Rajbari district. In the survey area of Madaripur district, machine owner provided only opendrum thresher machine and offered rental charge of Tk 400 per day. The fuel, oil and labor charge was excluded in the rental charge. Farmers had to provide oil, fuel and operator charge to thresh paddy.

Table 9c Rental charge of thresher for threshing rice in Dhaka division

District	Rental charge, kg paddy per 40 kg	Rental charge, Tk *bigha*$^{-1}$	Type of thresher
Dhaka	3	-	CDT
Faridpur	2	-	CDT
Gopalganj	2	-	CDT
Kishoreganj	2	-	
Madaripur	-	Tk 400 per day (without fuel and oil cost)	ODT,CDT
Rajbari	3	-	CDT (85%)
		700	ODT (15%)
		500	PT treading
Tangail	-	800	Hand beating

Source: Field survey 2017, CDT = Close drum thresher, ODT = Open drum thresher

In Khulna division, open drum thresher was widely used in the survey areas of all districts except Magura and Chuadanga districts (Table 9d). Farmers preferred to thresh the rice crop in engine operated open drum thresher to keep long straw after threshing. Pedal threshers were widely used in the survey area of Bagerhat, Khulna, Kushtia and Magura districts. Different rates of rental charge were observed in the survey areas of Khulna division. Rental charge of thresher varied from 2-5 kg per 40 kg of threshed paddy. In Khulna district, Tk 4,000 per *bigha* was offered for harvesting, carrying and threshing by pedal thresher. In some places, farmers got the opendrum thresher from machine owner on rental system. The rental charge of opendrum thresher was offered Tk 250 per day. Farmers themselves managed the fuel, oil and operator charge.

Table 9d Rental charge of thresher for threshing rice in Khulna division

District	Rental charge, kg paddy per 40 kg	Rental charge, Tk *bigha*[-1]	Type of thresher
Bagerhat	-	1000 800 + rental charge of ODT Tk 250 per day	Own pedal thresher ODT
Chuadanga	3	-	CDT
Jessore	5	-	
Jhenaidah	5	-	ODT and CDT
Khulna	-	Tk 4,000 (cut, carry and thresh) Tk 250 per day	Own pedal thresher ODT
Kushtia	2	Hire charge of ODT Tk 250 per day 700	ODT Own pedal thresher
Magura	4		CDT-80%, 20% pedal thresher
Meherpur			
Satkhira		Tk 250 per day	Own pedal thresher

Source: Field survey 2017, CDT = Close drum thresher, ODT = Open drum thresher

Different types of threshing methods such as hand beating and mechanical means of threshing especially using pedal, opendrum and close drum thresher were being used in the survey areas of Mymensingh division. Thresher machine was not observed in the survey area of Jamalpur district. Farmers thresh paddy using traditional method of hand beating whereas in other districts, farmers used thresher machine. As a result, excessive labors were required in threshing operation, which ultimately increased the production cost. Laborers were hired on contract basis. Almost every farmer preferred to thresh paddy by using mechanical thresher. Farmers hired close drum thresher only for daily basis with rental charge of Tk 250 per day. Farmers did not want to keep the straw long after threshing. Therefore, they preferred to harvest crops by close drum thresher. In *boro* season, farmers used closedrum thresher (small) for threshing rice in Sherpur district. The threshing charge ranged from Tk 400-550 *bigha*[-1]. The threshing charge differed from *boro* to *aman* season. In *aman* season, farmer wanted to keep straw long after threshing. Close drum thresher was not used in *aman* season. Farmers used opendrum thresher having 1.6 m long. Three to five laborers were needed to thresh the rice crop. In Netrakona district, the scenario of threshing cost was unusual compared to other districts. There was no cash payment in threshing operation in this area. Mode of payment was the share of threshed crop. The owner of the thresher taken away 5% of the threshed paddy. Threshing operation costs in *aman* and *boro* were nearly the same in Netrakona district.

Table 9e Rental charge of thresher for threshing rice in Mymensingh division

District	Crop	Rental charge, kg paddy per 40 kg	Rental charge, Tk *bigha*$^{-1}$	Type of thresher
Jamalpur	*Boro* rice	-	700-800	Hand beating
Mymensingh	*Boro* rice	-	550	CDT
	Aman rice	-	550	ODT
		-	250 per day	CDT
Netrakona	*Boro* rice	2	-	CDT
	Aman rice	2	-	ODT
Sherpur	*Boro* rice	-	550	CDT
	Aman rice	-	550	ODT

Source: Field survey 2017, CDT = Close drum thresher, ODT = Open drum thresher

Rice crops were threshed by using open and close drum thresher in the survey areas of Rajshahi division (Table 9f). The mode of payment was based on either cash or share of the crop or fixed amount of crop per unit area of harvest. Most of the places, machinery owner offered rental charge of thresher machine on share of the threshed paddy. The rental charge varied from 2-5 kg per 40 kg of threshed paddy. In cash payment system, rental charge of the thresher machine varied from Tk 500-700 per *bigha*. The cost of fuel, oil, operator and labor was included in the rental charge. In some places, machinery owner offered rental charge of 20-30 kg per *bigha* for threshing rice and wheat. In Sirajganj district, opendrum thresher was used as rental basis to thresh rice crops and machinery owner offered rental charge on the share of the threshed paddy.

Table 9f Rental charge of thresher for threshing crops in Rajshahi division

District	Crop	Rental charge, kg paddy per 40 kg	Rental charge, Tk $bigha^{-1}$	Type of thresher
Bogra	*Boro* rice		700	ODT
	Aman rice		500	CDT
	Wheat	5	500	ODT
Chapainawabganj	Rice	5		ODT
Joypurhat	Rice	4		
Naogaon	*Boro* rice		500-700 or 20-30 kg $bigha^{-1}$	ODT
	Aman		500-500 or 20-25 kg $bigha^{-1}$	
	Wheat		500 or 20 kg $bigha^{-1}$	ODT
Natore	Rice	2		20% ODT, 80% Pedal thresher
Pabna	Rice	5		
Rajshahi	Rice	5		ODT
Sirajganj	Rice	5		20% ODT, 80% Pedal thresher

Source: Field survey 2017, CDT = Close drum thresher, ODT = Open drum thresher

In Rangpur division, rental charge was depended on the type of threshing method i.e. close drum thresher or open drum thresher or hand beating (Table 9g). Hand beating was often seen in Rangpur district and it was more costly than ODT and CDT on rental basis. Open drum thresher was more preferable than close drum thresher in this region. In Thakurgaon and Panchgarh district, bulk amount of close drum thresher came from Bogra district to use on rental basis at the time of wheat harvesting. Labor groups contracted with the owner of thresher machine and combined package was offered to the farmers in harvesting wheat.

Table 9g Rental charge of thresher for threshing rice in Rangpur division

District	Crop	Rental charge, kg paddy per 40 kg	Rental charge, Tk *bigha*$^{-1}$	Type of thresher
Dinajpur	*Aman*		275-300	CDT
Gaibandha	Rice		400-500	ODT
Kurigram	Rice		800	Pedal thresher
	Maize		1850	Maize sheller
Lalmonirhat	*Boro*		1000	ODT
Panchgarh	*Boro*	2	-	ODT
Rangpur	Rice		350-400	ODT
Thakurgaon	Rice		400	CDT

Source: Field survey 2017, CDT = Close drum thresher, ODT = Open drum thresher

Close drum thresher was widely used in the survey areas of Sylhet division (Table 9h). The rental charge of the thresher machine varied from 3-4 kg per 40 kg of paddy. The machine owner supplied fuel, oil, operator and labor to thresh and bagging paddy. Blower was attached in the thresher and cleaned grain can be obtained by using thresher. In *haor* area, farmers wanted grain rather than straw after threshing. Therefore, they preferred to thresh rice in close drum thresher.

Table 9h Rental charge of thresher for threshing rice in Sylhet division

District	Rental charge, kg paddy per 40 kg	Rental charge, Tk *bigha*$^{-1}$	Type of thresher
Habiganj	3	-	CDT
Moulavibazar	3	-	CDT
Sunamganj	4	-	CDT
Sylhet	-	700	CDT

Source: Field survey 2017

Business constraint

- Difficult to move thresher machine from one place to another due to lack of rural road
- Wheel is absent in most of the ODT and CDT. During movement of thresher machine from one place to another, engine needs to be dismantled from the machine to reduce the weight
- In case of breakdown, welding facility is absent in rural areas
- Blower fan is frequently broken down during operation
- Proper size of nuts and bolts are not available in the local market
- Capacity of CDT machine largely depends on the feed rate and length of straw
- The thresher machine has limited annual use. Thresher machine can be operated seasonally (45 days per year)
- Straw clogged in the CDT in case of feeding long straw.

Business opportunity

- Harvesting and threshing should be contracted by the same group
- Labor shortage compelled the farmer to thresh the crop by thresher
- Labor group can buy the machine
- Thresher machine reduces drudgery, ensures faster operation and increases labor productivity
- More grain can be obtained by using thresher as unthreshed grain is absent in the panicle
- Easy to repair and maintenance
- Various typesof thresher machines are available in the market
- Cleaned grain can be obtained if blower with sieve is attached to the thresher machine.

a Animal treading

b Hand beating

c PT treading

d Pedal thresher

e Opendrum thresher

f Close drum thresher

Photo 12 Threshing methods

Traditional method of threshing by using cattle is disappearing in the country quickly because of draft power shortage. Hand beating was also observed in limited scale in some areas although it takes long time to thresh. Farmers prefer to thresh paddy by using mechanical thresher. Different makes and model of threshers are widely used the farmers' field. There are two types of thresher namely ODT and CDT.

If farmers wanted to keep the straw remain unchanged after threshing, they prefer to thresh paddy by ODT. In some places, farmers use pedal thresher. Most of the farmers use diesel engine operated ODT having steel or wooden frame. Entrepreneur rent out the ODT only for daily basis. Farmers supplied fuel and labor for threshing paddy. This case specially happens in *aman* season. In *boro* season, farmers do not want to keep the straw long after threshing. Therefore, they prefer to thresh crops by CDT. The rental charge varied with the location. The CDT has another advantage of threshing other crops like wheat, lentil, chickpea, mustard, mungbean, blackgram etc. The entrepreneur earned money by renting the CDT for threshing non-rice crops. Therefore, the annual usage of thresher increased substantially than ODT consequently reduced the fixed cost per ton of processing. Labor group purchased thresher and operated it on rental basis. They carried thresher to the farmer's field and contracted to the farmer on combined operation of harvesting and threshing. The mode of payment of rental charge is either on cash or share of the threshed crop or fixed amount of grain per unit area of harvest.

Combine harvester

Harvesting crops by using combine harvester is attracting the farmers as it performs four operations namely harvesting, threshing, cleaning and bagging in single pass operation. The field capacity is very high compared to manual harvesting. Farmers do not have to be worried about the spoilage of crops in case of inclement weather. Private company offered rental charge of Tk 11,000 per hectare for harvesting crops by combine harvester. Farmers preferred head feed rather than whole feed combine harvester to retain straw after threshing. Straw can be cut into pieces in head feed combine harvester.

Photo 13 Head feed combine harvester (imported)

Business constraint

- Purchase price of the combine harvester is very high, which is beyond the capacity of the ordinary farmers
- The annual use of the combine harvester is limited to maximum 45 days per year. Payback period is extended due to limited annual use
- Combine harvester is a sophisticated machine. Professionally trained operator is needed to operate, repair and maintenance of the machine
- Larger size ofplots are needed to get the maximum efficiency of the combine harvester
- Smaller size and irregular shape of crop field are not suitable to operate the combine harvester
- Frequent movement of the machine from one plot to another damage the parts of the combine harvester
- Fuel consumption depends on the size of the engine. Larger size of engine is used to supply power in different parts of the combine harvester as it performs many operations
- The harvester machine is unable to move into middle of the crop field due to lack of farm road
- The machine requires more space to turn in the corner of the plot and turning events increase the loss time.
- Difficult to enter into the field due to low elevation from road to the crop field
- Crawler is prone to damage due to movement on the paved road.
- Professionally trained mechanics are needed to repair the combine harvester due to complexity in design. Such type of mechanics are not available in the village level
- Farmers hide the actual area coverage to reduce the rental charge of harvesting.

Business opportunity

- Harvesting, threshing, cleaning and bagging can be done in single pass operation
- Reduces the drudgery and burden of labor
- Ensures faster operation
- In can be operated in shallow depth of water and muddy field
- Straw can be cut into several pieces or intact after harvesting
- Combine harvester reduces the postharvest loss, which occurs in harvesting, carrying, threshing and bagging.

Winnowing

Winnowing was done by using traditional device *kula* in the survey areas of Bangladesh. Pedestrian fan was also used to clean the paddy. Farmers fastened the blade on the side of the diesel engine and cleaned the paddy, which was treated as most unsafe method of winnowing (Table 10). BRRI winnower has the capacity of 700 kg per hour. Two passes were needed to obtain the cleaning efficiency of 99%. The winnower was rarely used in the farmers' field to clean the paddy.

Table 10 Labor cost of winnowing rice in some selected districts

District	Labor cost, Tk	Amount, kg
Sirajganj	400 (Fan or *kula*)	160
Pabna	400 (Fan or *kula*)	160
Joypurhat	400 (Fan or *kula*)	160
Habiganj	400 (Fan or *kula*)	160
Sunamganj	350 (Fan or *kula*)	160
Meherpur	500 (2 labor) with fan or *kula*	240

Source: Field survey 2017

a Cleaning by *kula*

b Winnowing by fan

c BRRI winnower

Photo 14 Grain cleaning system

Carrying

Laborers carried the harvested crops from the rice field to homeyard either on head or shoulder. Carrying cost was included in the harvesting and threshing activities. In case of availability of road, crops were carried out by cart and power tiller trolley on rental system. In low lying areas, harvested crops were carried out on boat.

a Head carrying

b Shoulder carrying

d Cart

c Power tiller trolley

d Carrying in boat

Photo 15 Carrying system

Determination of rental charge

Table 11 shows the market price, yearly fixed cost and annul use of the farm machinery. Fixed cost of farm machinery is calculated based on the assumption as mentioned in Hunt (1995). Salvage value of the farm machine is taken into account as 10% of the purchase price. Interest on investment and repair as well as maintenance cost are regarded as 12 and 5%, respectively. Useful life of the machine and payback periodare considered as 6 and 3 years, respectively. Fixation of rental charge depends on the purchase price, annual use, life of the machine, labor wage, fuel and oil price, transportation cost, repair and maintenance cost, parts failure frequency, availability of spare parts and payback period. Among them, yearly fixed cost and annual use are the main determinant to calculate the rental charge of the farm machinery.

Annual use of farm machinery is varied largely and depended on the field activity. Annual use of power tiller and tractor is comparatively higher than any other farm machinery due to opportunity of versatile use. Therefore, machinery owner can get the return investment within few years from the service of power and tractor. However, fixed cost of the transplanter and combine harvester is higher and annual use is limited than the tillage equipment. The operation cost such as fuel, oil, labor, repair, maintenance and transportation depends on the market price, area coverage in each day, age of the machine, parts failure frequency and availability of spare parts. Table 11 contains the data that could be a base for the machinery owner or entrepreneur to calculate the rental charge of farm machinery.

Assistance on rental charge

At the initial stage of entrepreneurship development on farm machinery, government may provide assistance or incentive on the rental charge of selective machinery especially transplanter, seeder and harvester to get the service at reduced rate. It will encourage the local service provider to provide rental service on these three labor intensive works.

Table 11 Purchase price, fixed cost and annual use of farm machinery

Activity	Machine	Purchase price, Tk	Capacity	Fixed cost, Tk yr^{-1}	Annual use, days yr^{-1}
Tillage	Power tiller	1,50,000	0.11 ha hr^{-1}	42,135	150*
	Tractor	13,00,000	0.18 ha hr^{-1}	3,65,174	200*
Transplanting	4-row walking transplanter	4,00,000	0.10 ha hr^{-1}	1,12,361	45**
	6-row ride on transplanter	16,00,000	0.13 ha hr^{-1}	4,49,445	45**
Seeding	Power tiller operated seeder	65,000	0.12 ha hr^{-1}	18,259	30
	BRRI seeder	65,000	0.12 ha hr^{-1}	18,259	40
	BARI seeder	65,000	0.12 ha hr^{-1}	18,259	40
	VMP	80,000	0.10 ha hr^{-1}	19,663	40
Fertilizer application	BRRI prilled urea applicator	5,000	0.03 ha hr^{-1}	1,405	40
	BRRI USG applicator	5,000	0.03 ha hr^{-1}	1,405	40
Weeding	BRRI weeder	800	0.03 ha hr^{-1}	225	50
	BRRI power weeder	60,000	0.07 ha hr^{-1}	16,854	50
Harvesting	Reaper	1,80,000	0.10 ha hr^{-1}	50,563	70
	Mini combine harvester	6,00,000	0.12 ha hr^{-1}	1,68,542	70
	Head feed combine harvester	26,00,000	0.16 ha hr^{-1}	7,30,348	70
Threshing	BRRI rice-wheat thresher (TH8)	80,000	800 kg hr^{-1}	22,472	70
	BRRI rice-wheat thresher (TH9)	1,05,000	1000 kg hr^{-1}	29,495	70
	Thresher (Steering system)	2,00,000	1200 kg hr^{-1}	56,181	70

Source: Field survey 2017, NB: *Tillage and other purpose, **Islam, 2016

Trend identification

Transplanting is a labor-intensive work and takes much time when performed manually. With the price hike of the daily commodities, labor expenses are beyond the reach of marginal farmers. By combining these problems, it is obvious that farmers need an alternate that could accomplish the task within time and reasonable expense. Rice transplanter started to be imported in Bangladesh from 2010 by different government, non-government organizations and companies (Fig. 1). At present, 400 transplanter machines are there in Bangladesh. This implicates an affirmative sign. The problems of manual transplanting are already noted by the policy makers and they approve the use of mechanical transplanting in harnessing advantages of timely transplanting saving labor and cost, preserving possibilities of good yield for the sake of food security in broader sense.

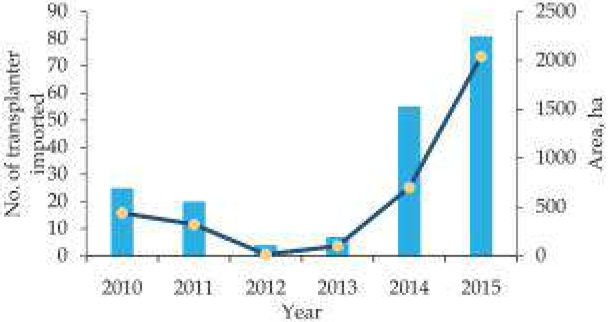


Fig. 1 Trading of transplanter (adopted from ACI motors, 2016)

Opportunity in custom hire service

The price and maintenance cost of rice transplanter and combine harvester is very high in contrast to the economy of Bangladeshi farmers and therefore ownership model for transplanter and combine harvester is not applicable. Besides, skill and proper knowledge is required to prepare mat type seedlings and operate transplanter and harvester efficiently, which is not available at the root level yet. Thus, it becomes obvious that customhire model is the only choice that could be taken at the current situation of Bangladesh. Moreover, the custom hire model offers scope for the young entrepreneurs to get into business and formulate scope for new profession.

Farm machinery rental system

Rental system is widely accepted form to provide service to the customer especially small holder farmers. Mechanized cultivation can be boost up through extensive use of farm machinery on rental system. Small holder farmers are unable to purchase the farm machinery due to capital constraint. Large farmers or company can invest money to purchase farm machinery and use in their own field. Small entrepreneur can come forward to invest money on purchasing farm machinery and providing rental service to the farmers if sufficient assistance is provided to them. Rental charge of the farm machinery should be lower than the cost of certain farming operation in existing traditional method. Except power tiller/tractor, most of the farm machinery are operated seasonally. Rental charge depends on the annual use of the farm machinery. Existing plot size and shape do not ensure the better performance of the farm machine. Inaccessibility of farm machinery to the plots also hampered the successful operation of the machine. Most of the times spent for plot to plot movement incur loss of time.

Some farm machinery have versatile use especially power tiller, tractor, irrigation pump and sprayer which ensure the extensive use of those machines. After tillage operation, power tiller and tractor can be used as hauling human, carrying goods, bricks, sand and other materials. Those machines can be operated in day and night. Therefore, profits come from other operations. Sprayer is not only used in spraying herbicide and pesticide, it can be used in spraying on the stored product, horticultural crops, small trees and flower garden. Irrigation pumps were used in draining water from stagnant areas. Initial price and depreciation as well as fixed cost of the transplanter and harvester are very high whereas, annual use is less than the tillage and irrigation equipment. Labor cost does not match the operating cost of the transplanter and harvester due to limited annual use. As the machine price is high, group ownership creates enabling environment to establish ownership rights of the farmers on farm machines. However, in Bangladesh condition, multiple owners create misunderstanding among them about theexecution of rental system and adversely affect the income distribution.

Obstacle

- Lack of capital to invest in purchasing the high value farm machinery
- Certain farm machinery especially transplanter, seeder and harvester has limited annual use. The entrepreneurs are not willing to invest on farm machinery service business on those machinery
- Farm machinery business is mostly seasonal. There is no opportunity to operate the machine continuously and machine has to keep idle for long time which needs extra maintenance cost without getting revenue in idle time
- Inaccessibility of farm machine to the respective farm due to lack of farm road
- Different types of crops especially similar crops having different duration are grown in the same region. Machinery accessibility in the middle of the plots is limited due to crops are matured in different times
- Skilled mechanics and operators are not available in the country
- Some spare parts are not available in the local market. Entrepreneur has to place offer to the respective company and took more time to get spare parts. In the mean time, season goes over
- After sale service is not readily available at door steps of the farmer
- Some farmers are reluctant to pay the rental charge in time.
- Entrepreneur will not get profit from mechanical transplanting and harvesting business due to high investment cost and less return.

Solution

- Government/private organization should provide sufficient assistance to procure high value farm machinery especially transplanter and harvester
- Custom hire service center should be set up under public private partnership approach where all farm machinery will be available to provide rental service at cheapest price
- Business model should be developed for each type machinery and technology
- Ensure the availability of spare parts nearer to the field of operation
- Entrepreneur should be trained on the business development and management to run the business smoothly
- Entrepreneur should have credit facility with low interest rate.

Strategy

- Create mass awareness through the large scale demonstration and focus group discussions (FGDs) on the use of farm machinery and technology
- Professional training should be given to the operator on the operation, repair and maintenance of the farm machine
- Training should be organized on entrepreneurship development to run the business efficiently. Public sector in association with private sector should take the responsibility to impart training
- Setup custom hire service center where one set of all types of farm machinery will be available for providing service to the end users
- Develop infrastructure for custom hire service center with the government assistance. One unit of farm machinery should be supplied to them on cost share basis
- Ensure the availability of frequently damaged spare parts
- Government may provide incentive on the procurement of some selective machinery to purchase the machine at reduced price
- Setup service center to repair and maintain the farm machine
- Formulate the marketing strategy on the promotion of rental service business
- Prepare business promotional material and distribute to the target stakeholder to scale up the rental service.

Expected outcome

- Small holder farmers will get the easy accessibility of different types of machinery by paying nominal rental charge
- Farm productivity will be increased substantially
- Mechanized cultivation directly and indirectly influences on the livelihood of rural people
- Mechanized cultivation relieved the farmers and they can utilize the extra time in other activities.

Long term benefit

- Custom hire service increases the mechanized cultivation
- Farmers will be dependent on the rental service of farm machinery in critical stage of crop production
- Entrepreneurship will be developed and encouraged to buy farm machinery.

CHAPTER III

MAT TYPE SEEDLING RAISING

Introduction

Mat type seedlings are needed for mechanical rice transplanter. The most common properties of mat type seedlings are proper root formation, bonding strength, seedlings height, uniformity of seedling and seedling age (Islam, 2016). Trays having high density seedlings can be obtained by combination of proper seed rate application and good nursery management. High density seedlings help in reducing tray requirement in transplanting. Soil amendment also affect the mat type seedlings. Seedlings are preferably grown on soil in a seedlings box having dimension of 58 × 28 × 3 cm. Several authors conducted the research on the raising of quality seedlings. Mamun *et al*. (2013) recommended that the media containing 25% cow dung or rice husk or poultry manure mixture with 75% soil could produce good quality seedlings. Kamruzzaman *et al*. (2014) mentioned that seedling raising in tray under polythene shed was found very effective and affordable technique during cold season of Bangladesh. Hossen and Rahman (2014) stated that clay loam soil showed better performance on rolling quality of the seedling mat and seedling strength over sandy loam soil. They also mentioned that *boro* season produced more seedling strength because of stunted growth due to cold spell that produced more dry matter per unit length over *aman* season. Goel *et al*. (2009) stated that twenty-day-old seedlings were most suitable for all the transplanters. Ahmed *et al*. (2008) recommended that the seedling height should not be more than 17 cm for effective crop establishment. Kitagawa *et al*. (2004) found that about 3-leaf-stage and 12 to 15cm height seedlings are good for machine transplanting.

Procedure of mat type seedlings raising

Seed germination

Seed rate depended on the germination rate. The seed germination and vigor should be more than 95% and 80%, respectively to avoid missing hill. Seed germination depended on the water availability and temperature. The germination percentage was calculated by following formula:

$$Germination\ (\%) = \frac{Number\ of\ seeds\ germinated}{Number\ of\ seeds\ on\ tray} \times 100$$

Seed selection

Seeds should be sun dried for one day and cleaned to remove impurities. Healthy seeds should be selected by specific gravity method. Dry seeds were immersed into water to remove unfilled grain and other impurities (Photo 1).

Photo 1 Seed treatment

Seed treatment

Autostin (a.i. Carbendazim) powder was mixed with water. Autostin powder was used to protect the seed from seed borne diseases.

Seed soaking

Soaking time depended on the ambient condition and water temperature. It was recommended to soak seed in 8-12 hours and not more than 24 hours (Photo 2). Excessive soaking time led to decompose the seed.

Photo 2 Dry and soaked see

Seed sprouting

Seeds were taken out from water and kept in gunny bags to create warm environment for sprouting. The seeds started sprouting after 48 hours (Photo 3). Sprouting time depended on the environmental temperature.

Photo 3 Sprouted seed

Seed rate

Seed rate is very much important to maintain proper seedling growth. The seed rate should be optimized for different sizes of rice variety to get optimum number of seedlings. Dry seed of 130g for bold grain, 140g for medium and slender grain and 120g for extra-long and slender variety were recommended to avoid missing hill during operation of mechanical rice transplanter (Hossen, 2012a). Higher seed rate influences on slender seedlings. Seedling growth appeared good in warm than cold environment.

There are two common methods of seedling raising suitable for rice transplanter

I. Tray system

II. Long mat system

Tray system

Preparation of rice seedlings on tray with dry soil

Fertile soil was collected from the field and sieving was done to remove any kinds of stones, gravels and roots from soil (Photo 4 and 5). Wooden piece was used to break the clods by beating. Sandy soil is less effective for mat formation and such type of soil should not be used for quality mat production. One layer of soil was spread onthe tray and level by using leveler (Photo 6). Sprouted seeds were broadcast uniformly (Photo 7). Finally, seeds should be covered by another thin layer of soil (Photo 8).

Photo 4 Collection of soil

Photo 5 Soil sieving

Photo 6 Soil filling and leveling

Photo 7 Spreading sprouted seed in tray

Photo 8 Seeds covered by another soil layer

Watering the tray

Watering was done by sprayer for proper setting of the soil (Photo 9). For the first 2-3 irrigation, water was sprayed on the tray in such a way that the flow of water would not damage the newly formed mats. Watering was done twice in a day until complete emergence of seedlings. Care must be taken so that the seedling mats are always wet. Trays were covered by polythene and white cloth to protect from poultry and cold injury. Fencing was done by net for protection from poultry and livestock (Photo 10).

Photo 9 Watering of the tray

Photo 10 Tray covered by polyethylene and fencing

Tray preparation time

Table 1 presents time required to prepare 200 trays. Five activities were done to prepare tray. The highest time (32%) would be required in soil sieving.

Table 1 Time requirement in preparation of 200 trays

Activity	Time, hr
Soil sieving	5.50
To fill one third of the tray with soil	3.20
To spread the seed in tray	3.20
To cover the tray with soil	2.30
Watering by sprayer	3.20
Total	**17.4**

Source: Islam, 2016

Preparation of rice seedlings on tray with mud

Mud was collected and spread on the tray upto 2 cm height (Photo 11). Mud was leveled by using hand or leveler (Photo 12). Sprouted seeds were distributed on mud in such a way that uniform placement of seeds were maintained (Photo 13). Trays were covered by polythene sheet to protect from rain and placed in the nursery field. This system was usually practiced in *aman* season when difficult to get dry soil due to heavy rain.

Photo 11 Spreading mud

Photo 12 Leveling mud

Photo 13 Spreading seed

Photo 14 Seedlings

Nursery fields

Relatively high land was chosen for nursery fields. Nursery fields must have the availability of sunlight, land, labor, irrigation and drainage system. The fields should be leveled and located at nearer to the main field to minimize the transportation distance of seedlings to the field. The fields should be away from trees to avoid shade andhomeyard to protect from damage caused by poultry and livestock.Seedlings were fenced by net to protect damage from poultry. Seedling trays were irrigated as and when needed. In cases of water shortage, trays were placed in the irrigation canal and rice field. Irrigation water was supplied by shallow tube well. Farmers used ponds, low lands, irrigated plots and drainage channels where 2 to 5 cm of standing water was available as shown in Photo 15. Seedling nurseries usually required 5–10% of the total farming area.

Photo 15 Seedlings management

Monitoring

The seedling nursery should be monitored everyday and ensuring the supply of irrigation water. Farmers were motivated to irrigate the trays time to time (Photo 16). Farmers, who used own seed were more careful about their trays than the other farmers.

Photo 16 Monitoring the seedlings nursery

Long mat system

Preparation of rice seedlings on polythene with dry soil

Polythene is an alternative of tray to raise mat types seedlings. One kilogram polythene (0.03 mm) provides 20 m^2 areas. It is essential to select the thickness of the polythene. Accounting the loss, 80% of the polythene can be effectively used to prepare seedlings mat.

Land selection

It is important to select the seedling station because quality of mat largely depends on the selection. The following criteria is essential to be maintained-

- Closer to irrigation source
- Avoid sandy soil
- Area should not be surrounded by trees (i.e open field and without having no shade)
- Nursery field should be nearer to the transplanting field to minimize carrying time and cost
- Fallow and marshy land should be avoided.

The following procedures should be maintained step by step

- Land selection for seedling raising
- Estimation of required polythene
- Tillage by spade or rotavator/tiller and one to two plankings to destroy the germinated weeds (Photo 17)
- Pulverize the soil by breaking clod
- Remove stone, gravel, straw and other hard material from the soil
- Soil may be mixed with farm yard manure to improve the soil fertility
- Level of land by using leveler
- Spread polythene sheet and make perforations of 1-2 mm diameter over it in different places to drain excess water (Photo 18)
- Place wooden frame at the border side of polythene sheet (Photo 19)
- It was observed that 16 man hr^{-1} laborer was required to prepare 300 mats with 1 m^3 soil.
- Spread soil on the polythene at 2.5 cm height
- Use leveler to maintain uniform height of the soil (Photo 20)
- Spread sprouted seed uniformly to achieve uniform seedlings density on the mat (Photo 21).
- Watering is done regularly (Photo 22)
- Cover the seed with soil (Photo 23)
- Stop watering before 24-48 hr of transplanting for easy to roll the mat. Soft or dry mat can break easily.

Photo 17 Tillage by spade

Photo 18 Spreading polythene

Photo 19 Placement of wooden frame

Photo 20 Leveling the soil

Photo 21 Distribution of sprouted seed

Photo 22 Watering the seedbed

Photo 23 Covering seedbed with polythene

Preparation of rice seedlings on polythene with mud

Preparation of long mat by mud was observed to be more cost effective than dry soil. It was the easiest way to prepare the long mat with mud. Perforated polythene sheet was placed on the plain field and spread mud on the polythene uniformly. It was very important to ensure the land leveling for uniform distribution of mud (Photo 24). Soil should be saturated enough with water that makes it easier to level on polythene. Leveler was used to level the top of the mat. Mat should not be long enough that hampered to maintain the leveling. The dimension of (9×1.5) m^2 mat required 9 kg seed and provided 68 number of tray.

Photo 24 Placement of mud and leveling

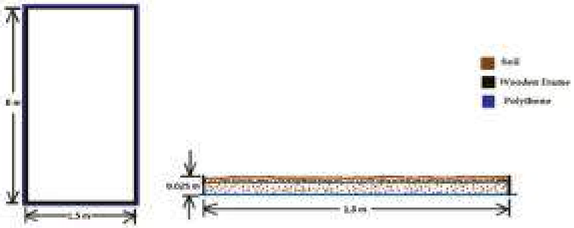


Fig. 1 Seedbed dimension

Seed distribution

The high yielding rice variety BRRI dhan58, BRRI dhan28 and BRRI dhan48 were used to raise mat type seedlings on polythene using mud (Photo 25). Uniformity of seedlings ensured the smooth operation of transplanting. Uniform seedlings reduced the cost of gap filling and uniformity greatly depends on the distribution of seed on the mat. Careful and uniform distribution is very much important task in mat preparation. Depending on the rice variety, 880 gm seed was required to distribute per square meter mat. Uniformity of seeding can be ensured by using seed sowermachine.

Photo 25 Distribution of seed on long mat

Seedling nursing

Daily monitoring of seedlings mat was very much effective to prepare a good mat (Photo 26). Watering was done by sprayer for first seven days of mat. Flood irrigation was applied after seven days. Another important task was to fencing the seedbed to protect it from any external harm.

Photo 26 Seedling nursing

Seedling age

- Seedlings are ready for transplanting in 12-15 days after seeding (DAS) in *aman* and *aus* season and 25-30 days in *boro* season
- In *boro* season, BRRI dhan28 and BRRI dhan29 required 25 and 30 days, respectively for proper mat formation due to cold
- Mats are ready to transplant when seedlings attained 2-3 leaves and 10-12 cm height.

Mat cutting

Water should be drained out one day before the cutting of seedlings mat. Frame having dimension of 58 x 28 cm area was made with mild steel. Mild steel frame should be placed on the mat provided that wooden hammer put little pressure (Photo 27). Sharp knife was used to cut the mat according to the specific dimension and rolled to make easy to carry. The uprooted nursery mats were ready for transporting to the field. It was estimated that one person could cut and uprooted seedlings for 2.47 ha in a day.

a Seedlings nursery

b Placing frame

c Mat cutting

d Mat rolling

Photo 27 Seedlings mat

Mat damage

Rice variety BRRI dhan58 was found better in mat formation than those of BRRI dhan28 and BRRI dhan48. It was observed that 17 % mats were damaged due to low population density, water shortage during cutting and placing steel frame (Table 2).

Table 2 Estimation of damaged tray

Mat no.	Variety	Mat dimension length, m	width, m	Area m²	Seed kg	No. of mat formed	Loss %	Seedlings no. m⁻²
1	BRRI dhan28	8.54	1.60	13.66	9	68	7.5	20604
2	BRRI dhan28	7.85	1.63	12.76	9	63	8.2	21534
3	BRRI dhan28	8.05	1.65	13.28	9	64	10.4	19675
4	BRRI dhan58	9.76	1.83	17.85	14	93	3.1	24323
5	BRRI dhan58	8.00	1.65	13.20	10	63	11.3	20914
6	BRRI dhan58	8.05	1.65	13.28	10	64	10.4	17196
7	BRRI dhan48	8.00	1.45	11.59	12	57	8.6	20140
8	BRRI dhan28	8.89	1.57	13.99	13	30	60.1	19210
9	BRRI dhan28	16.46	1.57	25.90	18	90	35.4	10690
10	BRRI dhan28	16.46	1.57	25.90	18	104	25.4	13943
11	BRRI dhan48	6.10	1.65	10.06	8	52	3.9	17971

Advantage of long mat type seedling raising

- No need for plastic trays
- Minimized the purchasing cost or hire charge of tray
- Locally available raw materials were used
- Appeared as cost and time effective system
- Farmers' acceptance was relatively high due to simplicity than the other methods.

Constraints in preparing long mat

- Difficult to separate foreign particles from mud. Careful separation of coarse particle is suggested to get quality mat
- Cracks may be formed in mat due to absence of moisture
- Birds may damage the plant by eating sprouted seeds (Photo 28)
- Irrigation water streams may destroy the newly formed mat
- Rodents and mites may destroy the mat. Standing water may have advantage in some situation

- Soil more than recommended height may raise problem in mat formation
- Plants adjacent to the edge of the frame may be damaged during cutting (Photo 29)
- Excessive dry and wet mat prone to damage
- Cattle may destroy the mat in absence of fencing (Photo 30).

Photo 28 Mat damage by rodents and excessive soil height

Photo 29 Plant damage during mat cutting by steel frame

Photo 30 Mats damaged by cattle

Precaution to overcome the constraints

- Ensure the seedlings station nearer to the transplanting fields and easy access of irrigation

- Mud should be free from coarse particle
- Seedling raising nursery should be perfectly leveled
- Excessive length and width of mat should be avoided
- Optimum soil height should be maintained
- Use fungicide in case of disease infestation
- Mat should be sufficiently wet during cutting
- Maintain uniform moisture on mat.

Mat formation in one-time tray

Seedlings were raised on one-time tray to observe the mat formation and quality seedlings (Photo 31). Mat formation was found good in one-time tray and mat can be rolled easily. The performance of the one-time tray was quite satisfactory to raise seedlings. It can be recommended to use one-time tray to raise seedlings suitable for mechanical rice transplanter. The cost of one-time tray was much lower than the plastic trays.

Photo 31 Mat formation in one-time trays

Comparison of seedlings raising cost

Table 3 shows the cost of raising mat type seedlings in three different methods. The seedling raising cost on plastic tray and long mat with dry soil was 46 and 11% higher than the traditional method of seedlings raising. Preparation of tray type seedlings is labor intensive work. Manual seeding does not give assurance on the uniform placement of seeds. Seed sower machine reduces the time required to broadcast sprouted seed and ensures the uniformity of seed placement.

Table 3 Comparison of seedling raising cost

Cost components	Manual, Tk ha^{-1}	Tray, Tk ha^{-1}	Long mat, Tk ha^{-1}
Tillage	400	-	-
Laddering	50	-	50
Seed	1240	1080	1080
Irrigation	150	200	200
Fungicide	100	100	100
Fencing	200	200	200
Tray cost	-	800	-
Tray transport	-	300	-
Soil collection	-	150	-
Soil sieving	-	150	-
Tray preparation	-	150	-
Polyethylene	-	-	300
Mat preparation	-	-	300
Mat cutting	-	-	150
Total cost	**2140**	**3130**	**2380**

NB: Seed rate: 160 gm per tray; Seed cost: Tk 40 kg^{-1}; laborer wage rate: Tk 300 day^{-1}; Polyethylene cost: Tk 120 kg^{-1}.

CHAPTER IV

MECHANICAL RICE TRANSPLANTING

Introduction

Mechanical transplanting is an emerging technology in Bangladesh and gaining popularity through the different program of government and non-government organizations. Manual transplanting by laborers requires much more time, cost, and the crop maturity become difficult because of the transplanting shock (IRRI, 2007). This shock could be avoided by transplanting infant seedlings. Manual transplanting required 123-150 man-hr ha^{-1} and it would take only 9-11 man-hr ha^{-1} for mechanical transplanting by four-row walking transplanter (Islam *et al.,* 2016b). Farmers are not habituated to use tender age seedlings. Mechanical transplanting in rice cultivation is being practiced around the world for row crop establishment as it allows use of mechanical weeder and reaper to collect good input-output ratio. Haytham *et al.* (2010) reported that rice transplanting was mechanized between 1970s and 1980s in Japan and Korea, respectively. At present more than 99% of paddy fields are cultivated by mechanized transplanting in those countries. In Bangladesh, mechanical transplanting performed satisfactorily by four-row transplanter in small scale at different locations (Islam, 2016). The rice transplanter has already been attracted the interest of many farmers, traders and manufacturers and some farmers are already using this technology. Successful crop establishment is a pre-requisite for good yield, which is achieved through timely transplanting of seedlings. It involves critical issues like availability of man power, cost and time requirement in land preparation and transplanting operation (Mamun *et al.,* 2013). IRRI (2007) reported that plant spacing is important and proper spacing can increase yield by 25 to 40% over random spacing. CSISA (2015) recommended that, fields should be puddled to a depth of 5-7 cm. Puddled fields should be leveled and soil allowed to settle for 12-24 hrs. Light irrigation should be applied and excess water drained off prior to transplanting. Uniform depth of 1-2 cm standing water is favorable for transplanting. Kamboj *et al*. (2013) mentioned that mechanized transplanting performed in immediately puddled conditions often implicates problem of soil settling (loose soil), resulting in missing plants and excess spacing. Hill density is reduced when spacing are higher. Goel *et al.* (2009) studied the comparative performance of three models namely OUAT, CRRI and Yanji rice transplanter in sandy loam soil with four levels of sedimentation period i.e. 24, 32, 48 and 56 hrs. It was found that 32 hrs of sedimentation period was suitable for operation of manual rice transplanter while the same was 56 hrs for Yanji transplanter. Behera *et al.* (2009) reported that, 36-48 hrs of sedimentation period was ideal for transplanting. Earlier, Behera and Varshney (2003) studied the correlation between puddling and mobility of the transplanter and found to be inversely proportional. IRRI (2007) recommended that land must be well prepared for machine transplanting. The soil needs to be leveled and have sufficient bearing strength to carry the machine and support the planted seedlings. Fields may need to be drained one or two days longer than they are for hand transplanting. Islam *et al.* (2016a) studied the effect of selective mechanization and reported that, 18% of transplanting cost and 61% labor (man-hr ha^{-1}) was saved by using Daedong DP480 rice transplanter whereas grain yield was 10% higher than the contemporary traditional plots. Islam *et al.* (2015) studied the performance of 6-row ride on transplanter on commercial basis and reported that, almost 92% trays were required in mechanical transplanting, 2% for gap filling and 6% in pocket area. Seedlings tray requirement in each plot can be reduced by adjusting plant to plant spacing and seedlings density setting. They have also recommended that smaller plot should be avoided to increase the daily area coverage of the transplanter. Islam (2014) reported that, tray requirement in each plot can be reduced by adjusting plant to plant space and seedlings density setting. Biggs *et al.* (2015) recommended that, research in Bangladesh should focus on the yield and economics of mechanical transplanting for allowing extensive use by the rural farmers. Mandal (2014) reported that immediate emphasis is needed for transplanting and harvesting mechanization due to rising wages for labor. Rice transplanters need synchronization of tillage, raising seedlings and planting by individual farmers.

Role of private company

Large initial cost of farm machinery is a barrier in the process of adoption to the root level. Besides, a strong and effective value chain is necessary to reach this machinery in the field from manufacturer's warehouse. Government can provide strategic support, however the formation of farm machinery market and model of revenue streams must be performed by public and private contribution. Farmers or entrepreneurs are a part of the value chain, but the responsibility of large investments must be taken by the industrialists as well as private companies. In Africa, private companies stepped in making availability of machinery to public, generating new working environment for entrepreneurs, operators; customizing contractual arrangements that can play the operational consolidation of small holdings (Mandal, 2014). The management of local manpower in the extraction of local resources requires economic contribution from the companies to achieve sustainable development in farm machinery operated agricultural operations (Sergaki and Nastis, 2011). With the capital and shipment support from private companies, farmers can avail the facilities of mechanical interventions in agricultural operations in an affordable price and produce higher quality products. In this way, private companies play a vital role in the circulation of new technology to the requirements of consumers and in improvement of their placement in marketplace.

Business opportunity

Adoption of mechanical intervention in agricultural operations has been accelerated in Bangladesh since 1980s. Specific areas like tillage, irrigation and threshing are already under mechanization. At the same time, there are many areas untouched by mechanical interventions especially the seedlings preparation, transplanting and harvesting. Mechanizing these activities can serve to achieve greater efficiency, resource conservation and reduction in cost of crop production. The ownership model is quite popular in rich countries.

Custom hire model is the only choice for other countries. Multipurpose use of single machine in peak and off peak season is required in middle and lower middle income countries to maximize output.

The possibilities of commercialization of mechanized transplanting using small scale machinery has also indicated positive results as the farmers showed huge interest (Islam *et al.*, 2015). However the performance of commercial transplanting service was observed lower than the recommendable margin because of various constraints that are already identified in *aman* 2014. Those constraints indicated that there is a need of developing a rigid business model that can check the underlying performance of machine in operation at the farmer's field. By the time a business model is needed to articulate the logic and provide data evidence that demonstrates how a business could be created to deliver value to customers.

Bangladesh has already attained self-sufficiency in rice and now the government of Bangladesh is stepping toward sustainable agriculture (GED, 2015). Development of business ventures and organizational competency accompanying with farmer's need and interest has great scope at this extent. The need for an entrepreneurial culture in agricultural sector thus became a must in the recent years (McElwee and Bosworth, 2010). Accordingly, commercial activity on agricultural operation by mechanized method is going to be the need of the rural farmers to escort the country's goal.

Business model as new one

Unlike tractor, power tiller and shallow engines, rice transplanter has limitation for multipurpose use keeping the machine idle in off season. It is a single use machine usable only for rice transplanting. Efficient rice transplanting in field could be affected by land condition, good management and seedlings quality in tray beside of the machine performance (Islam *et al.*, 2015). The business model for rice transplanter thus includes all these crucial factors. Seedlings preparation and rice transplanting service could be attached together to establish proper synchronization. Seedlings preparation in tray requires skill and knowledge which should be provided to the farmers. Proper diffusion of mechanical transplanting technology is a prerequisite of this business model. Risk related to seedlings establishment must be safeguarded by company policies. Based on the previous findings of constraints of using small rice transplanter in transplanting operation at commercial level a business model should be prepared concerning all the aspects that could influence the sustainability of business in the field.

Islam *et al*. (2017b) conducted the study on the commercial performance of transplanter during late *boro* 2016 season (February – June) at Ghaghatpara, Rangpur sadar and Kaliganjpara, Pairaband near Rangpur city. The study area lies under AEZ-3 (Tista Meander Floodplain). This zone includes most parts of the northern tip of Bangladesh occupying 9,468 km^2 area (BBS, 2012). The climate of this region is of tropical dry and wet type. The average annual rainfall is 2931mm and the average temperature ranges from a minimum of 11°C to a maximum of 32°C. The high yielding rice varieties BRRI dhan28 and BRRI dhan48 having good germination were used to raise seedlings in plastic trays.

Rice transplanter

A four-row walking type rice transplanter (model DP488) was used to perform transplanting. The machine was imported by ACI motors Ltd. Dhaka, Bangladesh (Photo 1). This machine featured ten seedlings density setting (Photo 2a), separate transplanting and operating engage-disengage clutch (Photo2b), six depth control options (Photo 4.2c) and six (12.5, 14, 16, 18.5, 20, 21.5 cm) seedlings interval control (Photo 2d and e). Depth, spacing and density setting are calibrated before proceeding to the main operation to obtain desired output in field. Table 1 presents the detailed specifications concerning performance.

Photo 1 Walking type transplanter

a

b

c

d

e

Photo 2 Operator panel and adjustment system of rice transplanter

Table 1 Specifications of walking type rice transplanter

Parameter	Unit	Value
Make-Model and Year		DAEDONG DP 488, 2015
Origin		South Korea
Field capacity	ha hr^{-1}	0.10-0.20
Weight	kg	183
Engine type		Air cooled, one cylinder
Engine power	kW/(rotation min^{-1})	2.94 kW(4ps)/3200rpm
Fuel		gasoline
Starting system		Recoil starting
Fuel tank	L	4
Driving speed	km hr^{-1}	Forward 0-4, reverse 0-1.55
Operating speed	km hr^{-1}	0-2.77
Driving system	Gears	4
Transplantation unit	Transplanting rows	4
	Hill space within rows(mm)	300
	No. of plants (row m^{-2})	27, 24, 21, 18, 16, 15
	Hill spacing plants (cm)	12.5, 14, 16, 18.5, 20, 21.5
	Transplanting depth(mm)	10-45 (control in 6 steps)
Stem amount control	Horizontal conveying amount(mm/count)	9/32, 11/26, 16/18 (3 step)
	Longitudinal conveying amount(mm)	9-16 (control in 9 steps)
Import price	Tk	3,80,000

Seedling raising

Trays having high density seedling were obtained by combination of proper seed rate application and good nursery management. High density seedlings helped in reducing tray requirement in transplanting.

Tray preparation

The preparation of seedlings was performed by the farmers under instructions of trained personnel. At first vigorous seeds were chosen by specific gravity method. Seeds were immersed in water for 24 hrs and placed in gunny bags (Photo 3a and 3b). The seeds started to germinate within next 48 hrs and those were sown after 72 hrs. Relatively high land was chosen for tray preparation (Photo 3c). Plastic trays were used to frame in the formation of seedling mat. Dry soil was sieved and poured in tray after removing stone, stubble or grass (Photo 3d). Sprouted seeds were distributed uniformly on the soil (Photo 3e). Water was applied twice a day until complete seed emergence (Photo 3f). Mats were ready to transplant when seedlings attained 2-3 leaves and 10-12 cm height. Data were collected on both plot to plot and day to day basis using different data sheet. Plot related information like name of the farmer and previously cultivated variety in those plots with yield were collected and recorded by interviewing farmers. Plot length and width (m) was measured using plastic tape and recorded carefully. Data were further used for calculation of area (ha) and length-width ratio (L/W). Seed rate (gm tray^{-1}), number of trays used in seedling raising, seeding date, transplanting date, seedling age, plot shape, travelling distance (km) from machine shed to field, space setting, missing hill, labor requirement, water height, depth of puddled soil, number of tray required in each plot, daily area coverage of transplanting, machinery trouble were collected by direct monitoring. Depth of puddling and height of standing water was measured just before transplanting operation. Soil settling time was calculated at the time of transplanting from the time of puddling. Seedling density in tray was measured by placing a 2.54 × 2.54 cm square loop in the tray and number of seedling contained by the loop were counted and converted to seedling density m^{-2}. A total of 54 plots were observed among which 40 plots were transplanted by transplanter and the rest were traditionally transplanted as control plots.

Photo 3 Tray preparation

Seedlings density

The amount of seed used in tray preparation varied depending on the variety and germination rate. Seed rate also varied from one farmer to another due to farmer's perception. Amount of seed used per tray by different farmers had direct influence on the seedling density obtained per tray and consequently tray requirement in field. Seed rate applied by the respective farmers in this study was not more than 150gm tray^{-1}. Seedling density depended on the seed rate, germination and uniform placement of seed during tray preparation. Seedlings density followed increasing trend with the increase in seed rate (Fig. 1). Seedlings density reduced when seed rate was higher than 145 gm tray^{-1} indicating that higher seed rate increased the seedlings mortality which supported the findings of Hossain (2016). Islam *et al*. (2015) mentioned that tray requirement, number of seedlings dispensed per stroke and missing hill during transplanting operation were subjected to the seed rate and uniformity of seedling establishment.

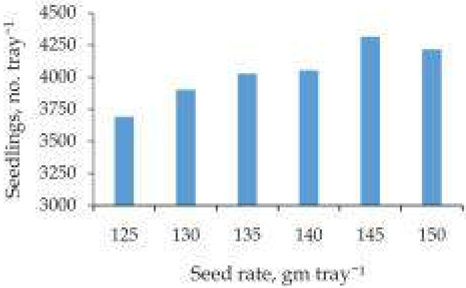


Fig. 1 Effect of seed rate on seedlings density

Seedlings mortality

Figure 2 shows the seedling mortality in respect to various seed rates of two rice varieties. Both the number of seedlings in tray and mortality were increased with the increase in seed rate in tray preparation despite varietal difference. Positive correlation was observed between seedlings density and mortality (%) for various seed rate. The number of seedlings in tray was less for BRRI dhan48 than that of BRRI dhan28, perhaps due to variation of seed germination. High density seedlings influenced slender and low density produced plump seedlings due to micro-environmental space facility.

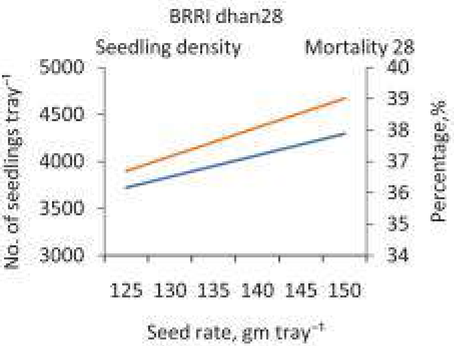


Fig. 2a Effect of seed rate on seedlings mortality

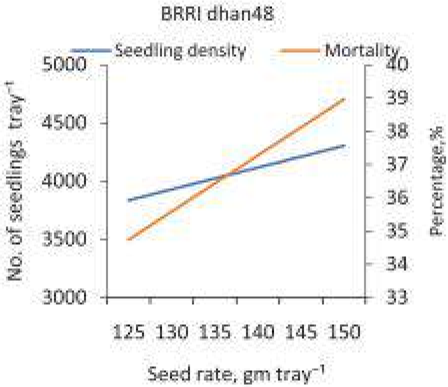


Fig. 2b Effect of seed rate on seedlings mortality

Seedlings quality

Seedlings mat prepared by the farmers were varied in height, density and color due to management skill of the respective farmer and irrigation facility in different nursery locations. Seedling height at 15-20 DAS (Days after seeding) was varied in 10-15 cm, color ranged from yellowish green to light green and the seedling density in tray ranged between 3000-5000 no. tray^{-1}. About 4000-4500 numbers of seedlings were observed in 66% trays (Fig. 3). Seedlings density less than 3000 seedlings tray^{-1} caused excessive missing hills and hence rejected before use. Color of the seedlings depended on the application of sufficient irrigation water to the seedlings trays. Farmers used ponds, low lying areas, drainage channels and plots having 2 cm standing water as nursery management. The quality of seedlings in trays could be improved by accelerating diffusion of mechanical transplanting technology through extension programs and repeated practice session.

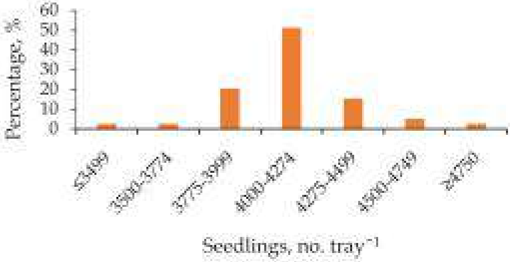


Fig. 3 Seedlings density in farmers' managed tray

Seedlings carrying

Mat formation was good in late *boro* season due to warm environment in the day time. Carrying of seedlings from nursery to field was a labor intensive work as the plots were far from the nursery location. Seedlings were carried by making roll and less space was required to transport in van (Photo 4). Seedlings mat was carried in head and shoulder from road side to main field. Truck may be used to carry the seedlings mat if the nursery location is far away from field.

Photo 4a Seedlings transportation

Photo 4b Seedlings transportation

Transplanter performance

The performance of the transplanter was depended on the size of plot, soil settling time, frequency of loading mat, time required for carrying mat, turning loss, operator and laborer's skill, transplanting layout and machine breakdown or clogging (Islam *et al*., 2015).

Forward speed

Forward speed was depended on the puddled condition of the field, operator's skill and ultimately influenced on field capacity. Puddled field condition and operators' comfort observed to vary with soil settling time (Fig. 4). The forward speed of the transplanter was obtained 1.79 km hr^{-1} in less interrupted plots (i.e. obstacles in plot, irregular shape) which was similar to that reported by Islam *et al.* (2016a). Plots that were puddled at the same day of transplanting observed to reduce 8.84% of the machine speed than those plots which were prepared before 24 hours or more. Loose mud in immediately prepared plots increased slippage of lugged wheel and reduced operator's walking speed as well as forward speed. Dixit *et al.* (2007) stated that the soil settlement period depended on the machine and soil type. They recommended that for manually operated machine, the soil settlement period should be about 24 hours for heavy soils. The puddled field condition largely affected operator's comfort as the machine was walking type. Due to poor understanding of the farmers about machine transplanting, most of the plots were not puddled at the same day of transplanting. This problem could be solved by synchronizing tillage and transplanting operation done by the same service provider.

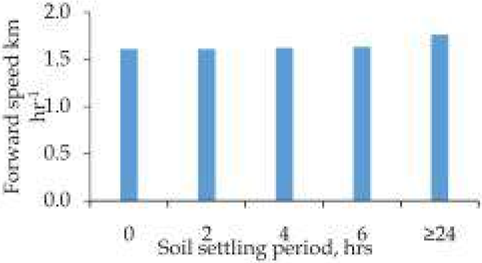


Fig. 4 Forward speed in relation to soil settling time

Field capacity

Plot sizes were varied in the study area ranging from 250 to 2600 m² (Fig. 5a). Most of the plots (56%) under this study were ranged from 250- 750 m². Field capacity was varied on the size of the plots (Fig. 5b). Plots belong to 1000 m² or higher seemed to attain field efficiency of 75% or higher with a field capacity of at least 0.15 ha hr⁻¹. Field capacity was very low for the field size less than 250 m². Larger plots were favorable in increasing daily area coverage than the smaller plots. Smaller plots were not favorable to operate transplanter and not possessed economic feasibility. Plots that were not leveled properly caused zigzag of transplanting line. Field capacity could be improved by maintaining water height of 1-2 cm in puddled field at the time of transplanting, operating transplanter in lengthwise and removing obstacles. Small plots having less than 250m² should be avoided for 4-row walking type transplanter. Islam *et al.* (2015) reported that field sizes less than 400 m² should be avoided to get the good performance of 6-row riding type transplanter.

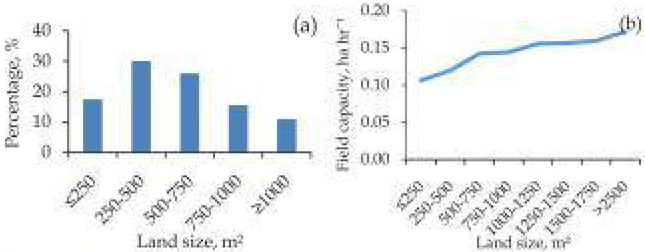


Fig. 5 (a) Plot sizes in the study area (b) Field capacity in respect to plot sizes

Turning loss

The length of plots available in the study area was mostly between 25 to 55 m (Fig. 6a). The loss time during turning in headland depended on the frequency of turning, which was affected by the plot length. As per observation, turning loss was reduced with the increase in plot length (Fig. 6b). The turning loss was observed five times more in the plots having the length of <25 m than that of 45-55 m which could be used to cover an additional area of 0.04 ha at the same time.It is preferable to choose the plot length having more than 25 m for getting the reasonable machine performance especially 4-row walking type rice transplanter. Figure 10a presents the effect of operation path and L/W (Length-width) ratio of plots on the number of turning events. The total number of turns depended on the L/W ratio of the plots and transplanting path (length or width-wise). The L/W ratio for 60% of the plots was observed 1.5-2.5. The least number of turns were observed for L/W ratio of 2-2.5 and length-wise transplanting. With the increasing of L/W ratio, number of turning events reduced in length-wise operation and increased in width-wise transplanting lay out. Taniyama (1975) mentioned that the operation efficiency increased with the increase in L/W ratio. The transplanter should be operated in length-wise of the plots to reduce the turning loss. The turning loss could be minimized if the plot length was higher than 15m and the operators have good skill. Field capacity was influenced by the plot length and increased with the increase in plot length due to less turning loss (Fig. 7b). Besides plot length, turning time was also depended on the operator's skill and shape of turning point and varied 4 to 10 sec in each turning events (Photo 5).

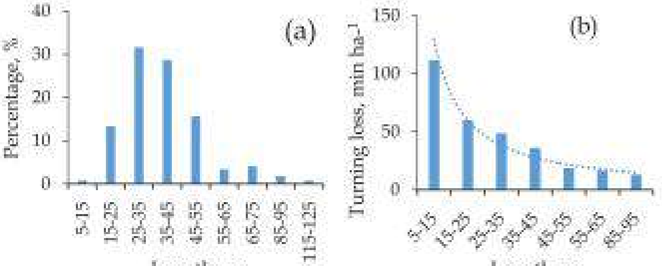


Fig. 6 (a) Plot length in the study area (b) Effect of plot length on turning loss

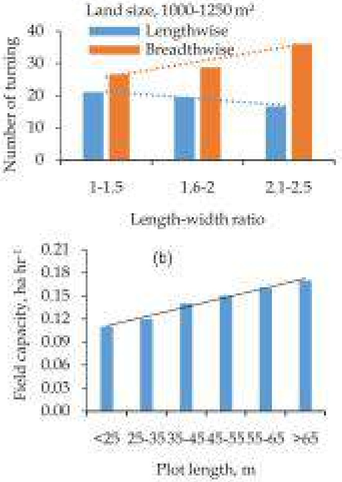


Fig. 7 (a) Effect of L/W ratio on turning events (b) Effect of plot length on field capacity

Photo 5 Turning in plot

Plot length

Length of a plot determined the frequency of turning events during transplanting operation. Larger plots offer higher forward running pitch between two turning events and less occurrence of turning events reduced percentage of turning loss up to 19% with increase of length (Fig. 8).

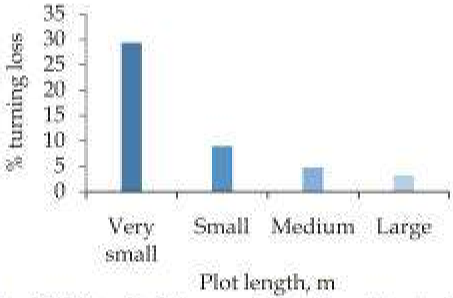


Fig. 8 Relationship between plot length and turning loss

Shape

Most of the plots were of rectangular in shape. About 10% of the plots had irregularity of shape in a range of 1 to 5% of its area. The irregularities were due to curved aisle and presence of temporary or permanent object in plot (Photo 6).

Photo 6 Irregularity in shape

Field efficiency of transplanter in irregular plots was 8% lower than those to regular or rectangular plots without comprising any obstacles (Fig. 9).

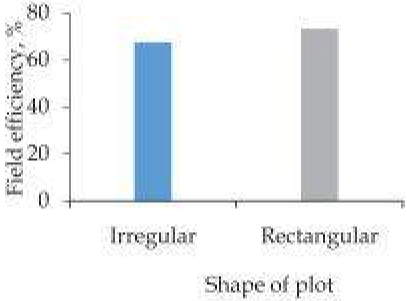


Fig. 9 Relationship between plot shape and field efficiency

Pocket area

Small areas were observed beside large plots ranging from 40 to 120 m^2, considered as pocket area (Photo 7). In such areas, forward pitch was very small (≤ 10 m) and field capacity was 0.11 ha hr^{-1}. Machine cannot perform satisfactorily in pocket areas, hence should be avoided.

Photo 7 Pocket area

Obstacles

Obstacles observed in the fields were of two types, i.e. permanent and temporary or seasonal. Rural infrastructures (e.g. electric pole) are frequently observed in the field occupying 0.5 to $5m^2$ area and cannot be covered by the machine (Photo 8a). Seasonal obstacles are mainly residues of the previous crops and garbage stacked at the middle of the field for decomposition (Photo 8b). Presence of obstacles in the field took travel of the machine consequently spending extra time to perform transplanting and caused extra fuel consumption.

a) Permanent obstacle b) Temporary obstacle

Photo 8 Obstacles in the field

Fuel consumption

The rice transplanter consumed fuel in the range between 3.5 to 5.0 L ha^{-1} depending on the number of turning in plots (which further depends on plot size and shape), distance between plots and additional travelling by the machine (i.e. travelling from machine shed to field and from field to cleaning facility). Fuel was fully utilized in easily accessible regular shape and large size plots because of high field capacity (Fig. 10). Distance from one plot to another caused additional fuel consumption of the machine. The average distance traveled during transplanting operation was 0.13 km day^{-1}. Fuel consumption of transplanter in travelling was obtained 0.33 L km^{-1} (Fig. 11). Fuel consumption would be lower when adjacent plots in the fields were transplanted sequentially.

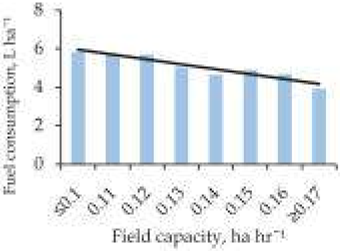


Fig. 10 Fuel consumption in respect to field capacity

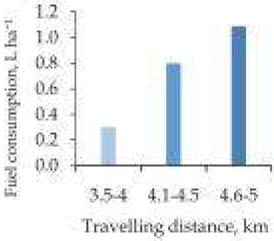


Fig. 11 Fuel consumption in respect to travelling distance

Water level

During transplanting time, sufficient water should be available in the field. Excessive water height increased the floating hill during transplanting. If soil is not properly soaked, the mud sticks with the wheels and difficult to maneuver the transplanter machine. Water height should be maintained 1-2 cm for proper anchorage of the seedlings and easy to maneuver the machine.

Tray requirement

Tray requirement in transplanting is an important measure of input and directly contributes to the input-output ratio of transplanting operation. Table 5.2 shows the tray requirements in transplanting and gap filling.

Effect of seedlings density setting onthe number of seedlings dispensed per stroke

The number of seedlings dispensed per stroke of fork arm is a vital determinant of tray requirement rate in transplanting operation. Selection of the density setting was depended on the tray conditions (i.e. number of seedlings tray^{-1}). Tray requirement varied from 153 to 222 trays ha^{-1} depending on the seedlings density, uniformity in tray, density setting of machine, seedlings dispensed per stroke in the field and number of tray required for gap filling. Islam *et al*. (2015) mentioned that tray requirement in each plot was influenced by both the seedlings density in tray and the density setting in machine. The number of seedlings dispensed in each stroke of picker fork can be controlled from the density setting panel of the transplanter. Higher density setting allowed more seedlings dispensed per hill causing higher tray requirement. The density setting in machine usually set on the basis of seedlings density obtained from trays. Setting 3 was the most frequent selection and 5-6 seedlings were picked up in each stroke. In addition to the density setting, the number of seedlings dispensed in each stroke of picker fork varied for different varieties. Farmers should understand that one healthy seedling is enough to attain the effective hill. Tray requirement can be optimized by adjusting the seedlings density setting of the machine.

Gap filling

The tray requirement was positively correlated with the density setting in machine and negatively correlated with missing hill (Table 2). Missing hill was observed more when density set to 2. The possibility of missing hills reduced with higher density setting as more seedlings (5-6) dispensed per stroke mitigating random gap of seedlings in tray.

Table 2 Effect of seedlings density setting on seedlings dispensed in each stroke

Number of seedlings dispensed stroke^{-1}	Density setting				
	2	3	4	5	7
<3	13%	8%	6%	4%	2%
3-4	75%	9%	13%	9%	8%
5-6	12%	83%	75%	20%	13%
7-8			13%	67%	77%
Tray requirement, no. ha^{-1}	153	163	186	196	222
Missing hills, %	6	5	3	2	<2

Effect of seedlings interval setting

Tray requirement also depended on the space setting and seedlings dispensed per hill in the field. Tray requirement increased with the increase in space setting. At space setting of 21.5×30 cm, 1 m^2 of seedlings area can transplant 331 m^2 areas in the field (Fig. 12).

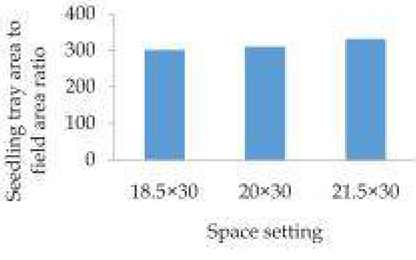


Fig. 12 Effect of plant to plant space setting on field area coverage

Seedlings dispensedin each stroke

The varietal difference caused variation in the seedlings density in tray (Fig. 13) which consequently affected seedlings dispensed per stroke. At the same seedlings density setting, higher seedlings density in tray for BRRI dhan28 caused more seedlings dispensed per stroke than that of BRRI dhan48.

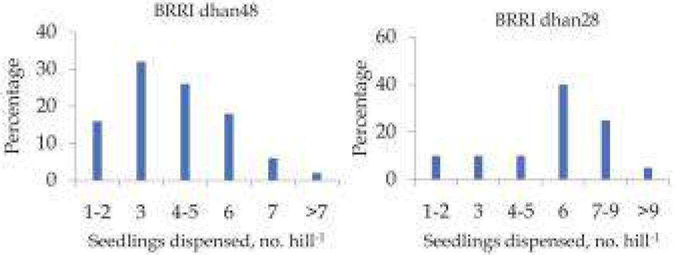


Fig. 13 Histogram of seedlings dispensed in each stroke

Seedlings tray distribution

Tray requirements during transplanting were categorized as tray required in mechanical transplanting, gap filling and pocket area filling (Fig. 14). Almost 90% of the trays were used in transplanting. Tray requirement in transplanting operation was vitally affected by the variation of seedlings density in trays. Amount of trays required in gap filling was largely affected by the seedlings density in trays and density adjustment in the machine (Islam *et al.,* 2015). Besides, extra laborer was required for gap filling. Transplanting in pocket area required almost double time because of frequent turning events, and tray slots unloading time for row adjustment.

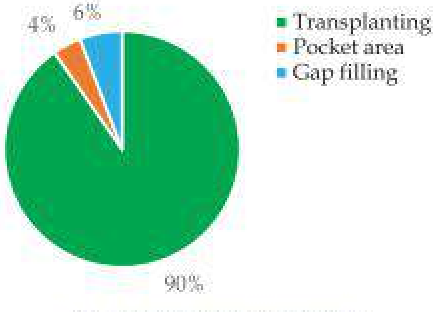


Fig. 14 Seedling tray distribution

Time distribution

The total time distribution was categorized under two groups; daily and plot activities (Fig. 15). Time distribution in plot was further categorized under time required in transplanting, turning and cleaning. The operation time depended on the skill and experience of the operator and laborer. Total mat loading time depended on the frequency of loading mat (which was further affected by seedlings density in tray and seedlings density setting in machine), ability of proper placement of seedlings mat around the border by the laborer and ability of operator to decide where to load mat. Mat loading near the border required less effort than at the middle of the plot. Mat loading time could be reduced by good coordination between operator and laborer. On average, 6% of the time was spent as turning loss due to irregular shape and size of plots. The total turning time required in a plot depended on the number of turning events occurred in a plot. Occurrence of loss time was caused by slippage of lugged wheel, bending of transplanting lines during forward movement and low forward speed in loose mud. Time required for cleaning (de-clogging) mud and garbage from the tray shifter depended on the frequency of clogging events. Plots which were not puddled and leveled properly with residues of previous crops faced such problem more frequently than clean and properly leveled plots.

Daily work time depended on the availability of prepared land to be transplanted on that day. Idle time was observed as the second most time consuming category in the daily time distribution, was completely a managerial function. Idle time could be minimized if the plots were properly ready (puddled and leveled). Plot to plot movement time (5%) in the present study was less (19%) than as mentioned in Islam *et al.* (2015) due to the plots were nearer to each other.Besides the operation and idle time, additional time was spent in movement because of plots were far from one plot to another. Cleaning time ranged between 15-30 minutes in each day depending on the availability of water source in the field (Photo 9). Transplanter performance was observed to be improved by reducing loss time applying proper transplanting layout, minimizing tray carrying time by keeping sufficient tray in the specific side of the plot, ensuring properly puddled field with sufficient time for soil settlement and avoiding irregular shape and pocket areas.

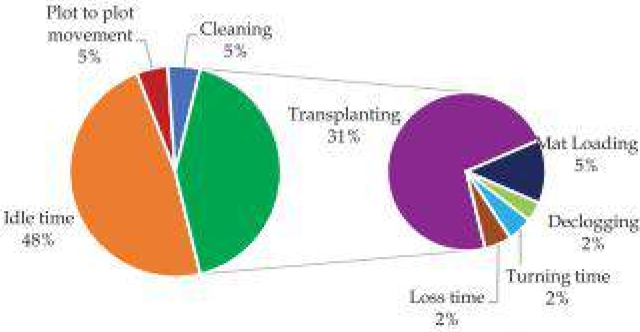


Fig. 15 Time distribution

Photo 9 Machine cleaning from irrigation pump

Farmer's choice on variety

Among the two varieties, BRRI dhan28 was more preferable to the farmers because of color, density and height of the seedlings in trays (Photo 10). Root formation of BRRI dhan48 was better than BRRI dhan28 and number of seedlings per tray was varied in the same nursery due to variation in germination.

Photo 10 Effect of variety on seedlings characteristics

Crop establishment

Poor crop establishment is usually caused by dense population and random spacing. Proper establishment demanded optimum spacing and number of seedlings per hill.

Plant to plant spacing

Plant spacing is the major driving factors affecting productivity. The distribution of plant to plant spacing in mechanically transplanted plot (Fig. 16). Transplanter was operated in three plant to plant space setting (18.5, 20 and 21.5). In actual field condition, plant spacing was not confined on the setting value due to slippage and skidding of the transplanter. Soil settlement in immediately puddled soils also influenced the plant to plant spacing. The distance between plants determined the tray requirement in a transplanting operation and controlled by the space setting options depending on the seedlings density in trays. In mechanically transplanted plots, plant to plant spacing was obtained between 17-20 cm which was depended mainly on soil type, soil settling time, water height and depth of puddling (Photo 11a). In manually transplanted plots, plant spacing was observed 27 × 25 cm (Photo 11b).

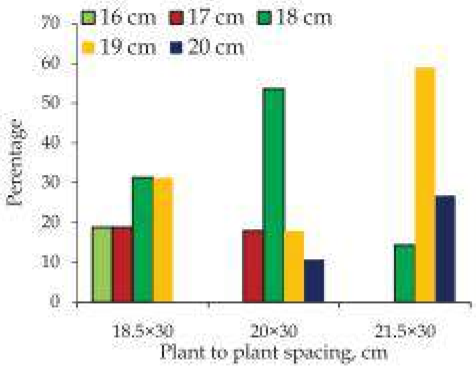


Fig. 16 Histogram of actual plant to plant spacing

a. Mechanical transplanting

b. Hand transplanting

Photo 11 Mechanical and hand transplanted field

Hill density

The number of hills obtained in the transplanted field was affected by the plant to plant space setting and puddled condition (Fig. 17). Crop establishment in the field was denser in plots transplanted in the same day (≤6 hrs) of puddling than after one day (<24 hrs), perhaps due to slippage of the wheels.

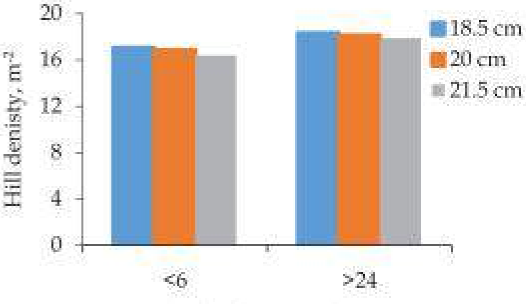


Fig. 17 Hill density in respect to soil settling time

Both the plant to plant and line to line spacing contributed to hill density in the field. Hill density affected the plant growth, tiller formation and yield. Hill density achieved by three space settings in rice transplanter was mostly around 17 hills m^{-2} in a range between 16-19 hills m^{-2} (Fig. 21). On the otherhand, hill density in manually transplanted plots was at least 8% less than the mechanically transplanted plots.

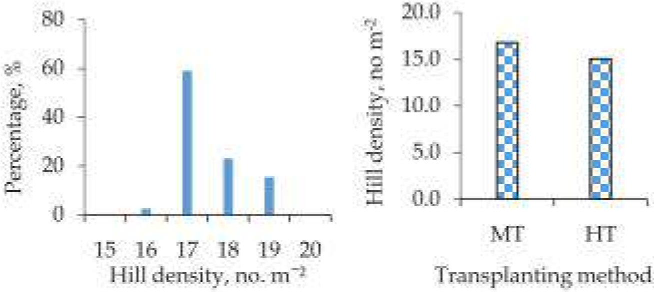


Fig. 18 Hill density in respect to translanting method

Effect of plant spacing on grain yield

The line to line spacing was fixed to 30 cm and plant to plant spacing can be varied in mechanical transplanter. During transplanting, three seedlings interval setting (18.5 × 30, 20 × 30 and 21.5 × 30 cm) was applied from space setting panel of the transplanter. Yield data of those plots in respect to space setting were compared with manually transplanted rice. It was observed that yield was slightly increased with the increase in plant to plant space setting (Fig. 19). El-Kassaby *et al*. (2012) conducted field experiment on plant density and seedlings age on two cultivars in Egypt and observed that the highest values of all traits were recorded when using Egyptian Hybrid1 cultivar, youngest seedlings age (15-day-old) and widest spacing between hills (30 × 30 cm). On the other hand, the lowest values were recorded when using Giza 178 cultivar, the oldest seedlings age (25-day-old) and closest spacing between hills 20 × 20 cm. The yield variation was occurred not only by the variation of spacing as there were many other factors (e.g. seedlings quality, post transplanting crop nourishment, insect infestation, etc.). Plant spacing set by machine could not be maintained in the field due to variation of soil type, puddle condition, soil settling time, plow pan and water height. Data on actual plant spacing was collected immediately after transplanting from each field and corresponding yield data were recorded after harvesting (Fig. 20). In BRRI dhan28, yield variation was observed among different plant to plant spacings. However, in BRRI dhan48, yield variation showed inconsistentdue to variation of plant spacing.The seedlings age was higher in traditional than mechanically transplanted rice. The existing spacing seemed to be higher than the BRRI recommended spacing of 25 ×15 cm. Tillering ability was higher in tender age seedlings and more spaces were required to grow. Pasuquin *et al.* (2008) reported that tiller production could be optimized by transplanting seedlings at younger ages.

The maximum number of tillers produced by the rice plant was inversely proportional to the length of the phyllochron (Katayama, 1951; Nemato *et al.*, 1995), which was depended upon the extent of stresses. Wider spacing, availability of solar radiation, medium temperature, soil aeration, and nutrient supply promoted shorter phyllochrons, which increased the number of tillers in the rice plant (Anonymous, 2004). The results supported that there was no yield penalty on the use of wider space setting (21.5 cm) in mechanically transplanted rice. Of course, there must have boundary limit of plant spacing on grain yield. From commercial point of view, it was very much important to reduce the seedlings tray requirement in each area of transplanting to make the business venture profitable. Use of higher spacing reduced the seedlings tray requirement (Islam *et al.*, 2015).

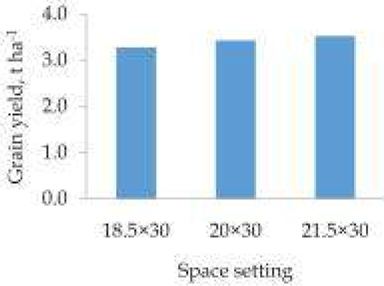


Fig. 19 Effect of seedling interval setting on grain yield

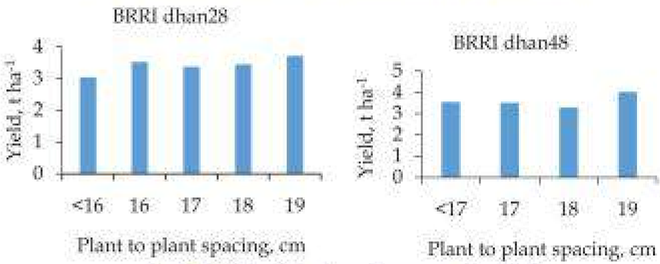


Fig. 20 Effect of plant spacing on grain yield

Effect of transplanting method on grain yield

Among the different factors responsible for realizing potential yield of rice, the transplanting time, method and seedlings age at the time of transplanting are important non-monetary inputs. Seedlings age at transplanting is an important factor for uniform stand of rice (Paddalia, 1980). Mechanically transplanted rice produced 4-6% higher grain yield than the hand transplanted rice for both the variety due to use of tender aged seedlings (Fig. 21). This result is in accordance with the findings of Islam (2016) and Islam *et al*. (2016b). Makarim *et al*. (2002) stated that the performance of tender aged seedlings showed better than older seedlings. Tillering influenced the panicle intensity as well as grain yield of rice (Quyen *et al*., 2004). McHugh *et al*. (2002) and Thiyagarajan *et al*. (2002) observed that 8-15 days and 10-day-old seedlings transplanted at 25 hills m^{-2} produced the highest grain yield in Madagascar and Sumatra. Krishna and Biradarpatil (2009) observed high grain yields of 3.25 t ha^{-1} with 12-day-old seedlings than 8-, 16- and 25-day-old seedlings and the yield decline of seedlings of latter three ages was primarily attributed to the reduction in the number of tillers. Younger seedlings could relieve the transplanting stress in a shorter period of time compared to that of older seedlings (Yamamoto *et al*., 1998) due to the higher nitrogen content in the former (Yamamoto *et al*., 1998), and the plants' ability to faster resumption of the rate of phyllochron development (Anonymous, 2004).

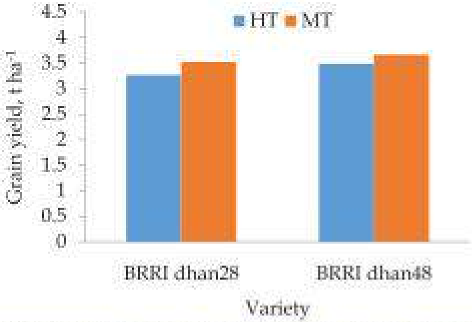


Fig. 21 Comparative yield scenario of mechanically and hand transplanted rice

Labor requirement

Table 3 shows the labor requirement in transplanting activities. Labor requirement in transplanting was crucially related to the field capacity of machine. Only 19 man-hr^{-1} ha^{-1} was required to perform transplanting, carrying and loading mat in the field. Labor requirement in gap filling was obtained 20 man-hr ha^{-1} to cover 2% missing hill. Labor requirement in cleaning was not varied over area coverage, nonetheless depended on the mud attached on the machine.

Table 3 Labor requirement in transplanting activity

Activity	Labor type	man-hr ha^{-1}
Transplanting	Operator	18
Mat carrying, loading	Skilled laborer	1
Machine transport (plot to plot)	Operator	0.30
Cleaning	Skilled laborer	0.31
Gap filling (2%)	Traditional laborer	20

Cost analysis

Cost of transplanting

Transplanting cost includes fixed and variable cost. Fixed cost includesthe machine purchase cost, depreciation, salvage value, interest on investment, repair and maintenance (R & M). Yearly fixed cost also depended on the annual area coverage and reduced with the increase in annual area coverage. Variable cost included fuel, transport, operator's charge and labor wage. Cost could be saved by reducing loss of time and travelling distance as well as fuel consumption and increasing daily area coverage. The relationship existed between transplanting cost and field capacity (Fig. 22). As mentioned earlier, field capacity depended on the plot size and shape. Regular plot size reduced the loss of time as well as fuel cost hence increased the field capacity and decreased the transplanting cost.

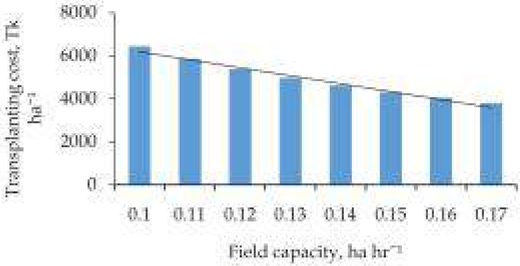


Fig. 22 Cost variation over field capacity

Cost comparison between manual and mechanical transplanting

The cost of seedlings raising in tray and long mat was 46 and 11% higher than the traditional seed bed preparation (Fig. 23). Mechanical transplanting using tray and long mat seedlings saved 4 and 13% cost compared to hand transplanting using tradition seedlings.

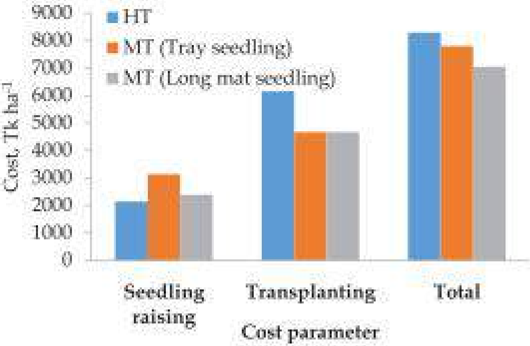


Fig. 23 Cost of seedling raising and transplanting

Constraints in transplanting operation

The following constraints were observed during commercial operation of the rice transplanter.

- Fragmented land sizes
- Absence of passage for machine movement in field
- Various types of obstacles in the field
- Farmers in rural area lacks in adequate knowledge and nursery management skill for preparing good seedlings trays
- Farmers have the tendency of using more seed rate and application of chemical pesticide and fertilizers to enhance seedlings growth
- Plastic trays for seedlings preparation are not available in the local market
- The socio-economic culture of the farmers is usually against new technologies
- Lack of knowledge and experience inoperating the rice transplanter
- Farmers were worried about the crop establishment and yield due to use of tender aged seedlings

- Transplanting schedule often broken down or delayed due to delayed land preparation, seedlings age and farmer's attitude toward timely transplanting
- Load shedding delayed the irrigation water supply for puddling the land
- Picker frequently jammed due to dry seedlings mat
- Farmers often tried to delay or escape from paying fees.

Suggestion for the entrepreneur

Business friendly transplanting operation could not perform in every land size with low skill operator and poor management. Entrepreneurs must be aware of the critical points of operation which could lead the task to a complete failure.

Land selection

For efficient transplanting operation, land size has to be greater than 400m^2, shape has to be rectangular and length-width ratio has to be as higher as possible. Contracts for transplanting could be based on irrigation command area from a pump via 'water-lords' to obtain plots belonging to the same field. Plots have to be selected based on the accessibility of machine.

Seedlings density and uniformity

Seedlings tray requirement depended on the seedlings density in tray and uniformity of seeding. Tray requirement per hectare could be decreased by using high density seedlings trays (≥5000 seedlings tray^{-1}).

Operator

Properly trained operator should be recruited and instructed to minimize turning loss and missing hill, reduce tray requirement and avoid free run around the plot.

Management

Management largely affected the transplanter performance and satisfactory area coverage. Arrangement of materials like seedlings trays and fuel should be available in the fields before proceeding to main operation to avoid idle time. Transportation of machine from warehouse to field, additional laborer to support operator for carrying and loading mat, transferring machine from one plot to another are essential parts to arrange during transplanting service. Attractive presentation of the deal could increase number of interested farmers to avail the service.

The study was performed to explore the entrepreneurial opportunity of commercial mechanical rice transplanting service for small holder in Bangladesh. Effective use of transplanter machine, proper raising and good nourishment of seedlings and decent tray management of from farmer's nursery to the field were found as the major impact points and should be carried cautiously to obtain successful business environment on small scale transplanting service. Skilled and experienced operators have to be recruited and larger plots having uniform shape has to be selected to uphold the machine performance. Plots have to be selected that belongs to same field or adjacent to each other. Scattered plots increased travelling distance hence fuel consumption raised and reduced daily area coverage. Soil setting time has to be allowed for 12-24 hrs. Missing hill can be avoided by carefully selecting density setting. Number of turning events in plots can be minimized by selecting larger plot and operating transplanter in length-wise. The field capacity and field efficiency of rice transplanter was obtained 0.15 ha hr^{-1} and 72%, respectively. Fuel consumption was obtained 5 L ha^{-1} and varied over plot size, soil settlement time, presence of obstacle, plot to plot travelling distance and operator's skill. The tray requirement depended on the combination of seedlings density in tray and density setting in machine. Tray distribution observed as 90% in transplanting, 6% in gap filling and 4% pocket area. Gap filling by manual labor required 18-20 man-hr ha^{-1}. Time distribution depended on managerial combination and relation between transplanting team and farmers. Most of the time was spent as idle time due to poor preparation of plots. Seed rate showed negative correlation with seedlings population in tray and positive correlation with seedlings mortality. Mechanical transplanting took 18 man-hr ha^{-1} whereas mat loading, machine transport and cleaning took 1.6 man-hr ha^{-1} labors. Small plots having less than 250 m^2 have to be avoided for 4-row walking type rice transplanter to get the good machine performance.

CHAPTER V

BUSINESS CONSIDERATION

The entrepreneur must be aware of the following glimpses for successful operation of mechanical rice transplanting business.

Selection of transplanter

- Walking type
- Riding type

Fuel parameter

- Diesel engine
- Petrol engine

Number of transplanting rows

- 4 rows
- 6 rows
- 8 rows

Seed parameter

- Seed germination (>95%)
- Seed selection (removal of unfilled grain)
- Seed treatment (Autostin a.i. carbendazim)
- Seed soaking time (24 hrs)
- Seed sprouting time (depends on temperature)
- Proper seed rate
  - 130 g for bold grain
  - 140 g for medium and slender grain
  - 120 g for extra-long and slender
- Uniformity of seeding

Soil parameter

- Fertile soil
- Clod breaking
- Removal of stone, stubble or grass
- Soil sieving
- Mud can be used in rainy days

Nursery management parameter

- Availability of sunlight, land and labor
- Irrigation and drainage facility
- Protection from poultry, bird and animal
- Management of pest infestation
- Management of nutrient deficiency

Seedlings mat parameter

- Mat thickness (2.5 cm)
- Seedlings height (10-12 cm)
- Seedlings density (>5000 seedlings per tray)
- Uniformity of seedlings
- Seedlings color and vigor
- Proper root formation
- Rolling capacity of mat
- BRRI dhan28 and BRRI dhan29 required 25 and 30 days, respectively for proper mat formation due to cold
- Seedlings age
  - 12-15 days in *aman* and *aus* season
  - 25-30 days in *boro* season

Field parameter

- Accessibility of machine to the field
- Avoid small size (<250 m^2)
- Rectangular shape of plot
- Avoid irregular shape of plot
- Plot length has to be more than 25 m
- Length-width ratio should be more than two
- Soil bearing capacity
- Must have plow pan to avoid sinkage of men and machine
- Less turning events
- Obstacles in the field
- Irrigation and drainage facility

Land preparation

- Before tilling, inundate the plot with 5-6 cm of water for well soaked
- Dicompose the biomass
- Well puddled by tractor/power tiller rotavator
- Depth of puddling (<10 cm)
- Land leveling (degree of flatness would be ±5 cm)

Machine parameter

- Depth adjustment
- Seedling density adjustment
- Plant to plant space adjustment
- More options on plant to plant space setting

Repair and maintenance

- As per instruction manual
- Tightening loose nut-bolts
- Greasing the moving parts
- Hydraulic oil level and quality
- Mobil level
- Lubrication
- Rust prevention
- Picker movement
- Replacement of picker due to decay
- Clean the transplanter after each day operation
- Availability of most frequently damaged parts

Fixed cost (independent on hourly use)

- Purchase price
- Depreciation
- Salvage value
- Interest on investment
- Repair and maintenance cost
- Shelter

Variable cost (depends on hourly use)

- Fuel cost
- Lubrication cost
- Labor cost
- Minor repair and maintenance cost

Transplanting operation

- Sufficiently wet soil
- Drain excess water
- Water height (1-2 cm)
- Soil settling time (≥ 24 hrs)
- Sufficeint water to prevent soil sticking on the wheels.
- Adjustment on depth of seedlings placement
- Adjustment on plant to plant spacing
- Adjustment on the number of seedlings dispensed in each stroke
- Operate machine in the nearer plots to reduce movement time

Monitoring transplanter performance

- Planting geometry
- Headland operation
- Fuel consumption
- Seedlings tray requirement

- Number of seedlings dispense in each stroke
- Floating, missing and buried hill
- Area coverage in each day
- Theoretical field capacity
- Effective field capacity
- Travelling distance from machine shed to field
- Length wise operation of the transplanter

Other tips

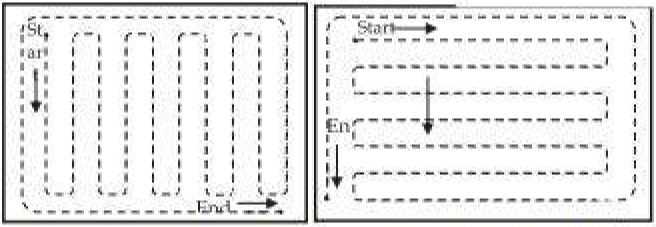
- Availability of spare parts
- Fuel stock in the field
- Seedlings tray loading and unloading
- Skilled operator and labor
- Skilled on head land transplanting
- Slow movement of the transplanter

Straight line transplanting

DP488 model has five markers. Marker is used to maintain the straight line transplanting. Center marker is situated on the top of the transplanter body. Operator's vision should be concentrated on the center mark to maintain the transplanting line straight way. Another two markers are placed on the rear of the transplanter and controlled by lever to make position of the markers. These markers are used to make scratch on the land, which facilitated the operator to maintain straight line transplanting in the next turn. Another two markers are situated on the float. These markers should be placed on the nearest position of the transplanted seedlings. It would not be wise to operate transplanter without using marker. Straight line transplanting is preferable to the farmers. Farmers do not accept the zigzag transplanting.

Transplanting operation

Two types of transplanting layout can be applied to the fields, which were breadth and lengthwise (Fig. 1). The transplanting layout in a plot depended on plot shape and barriers around the plot. Barriers could be ponds, electric poles or adjacent plots having different crops.



a. Two-side barrier (Breadth wise)b. Three-side barrier (Length wise)

Fig. 1 Transplanting layout

Transplanting in headland

During operation, U turn was taken at the end of each line putting pickup forks inactive at the headland (Fig. 2a). In case of side turning, the machine is turned, pulled back, made position and started to transplanting (Fig. 2b). Headland transplanting was done after completion of main land transplanting.

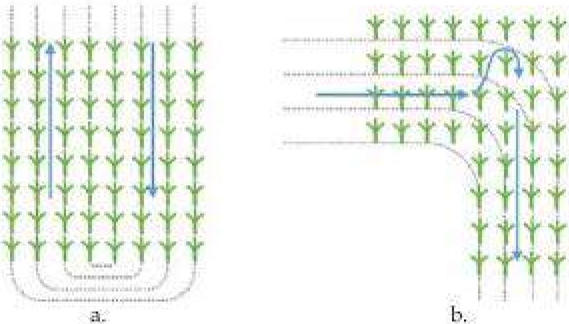
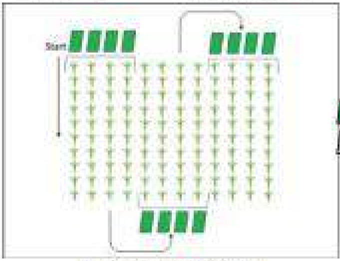


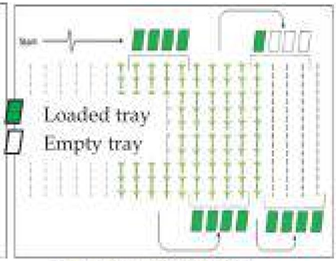
Fig. 2 (a) U turn and (b) Side turn

Covering any number of rows in field

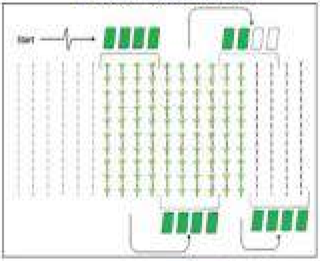
The number of rows covered by transplanter is four. It is suitable for the machine to cover any number of rows multipliable by 4. When the numbers of rows are not multipliable by 4, rows are adjusted by keeping tray slots empty (Fig. 3).



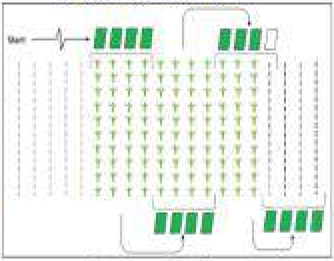
a. row number 4n



b. row number 4n+1



c. row number 4n+2



d. row number 4n+3

Fig. 3 Operational procedure in any row number

Operator skill

Successful operation of transplanting largely depends on operator's skill. Lack of skilled operator can cause zigzag line, missing hill, time loss and extra fuel consumption (Photo 1). Zigzag line and missing hill created negative impact among the farmers about mechanical transplanting.

Photo 1 Transplanting by different operators

Maintenance of the transplanter

Maintenance work of the rice transplanter must be done regularly to ensure economical, efficient, and safe operation (Photo 2). As a new machine, mobil was drained out and changed after few hours of operation. Transplanter was covered by polythene to protect from dust. Loss time, breakdown, wear and tear will be reduced by servicing at the specified time. Rice transplanter should be cleaned thoroughly at least once in a year, when it becomes excessively dirty. Following steps are important for long term maintenance:

- Machine should be checked thoroughly based on operator's manual.
- Moving parts should be lubricated as per need before proceeding to main operation.
- After completion of transplanting, the machine should be washed and dried.
- For engine maintenance, all fuel is drained out. If fuel is remained it will be evaporated in the fuel tank or carburetor. It makes difficult to start.
- The fuel cock should be closed.

Photo 2 Maintenance activity

Problem and probable solution

Problem	Solution
Low soil height in tray	Unable to form proper bonding. Reduce the gap of seedlings holder to hold the seedlings
Low seed rate	Low seed rate created patchy seedlings ultimately increase the missing hill. Seedlings density setting in high position may solve the problem.
Excessive seed rate	Excessive seed rate increase the seedlings mortality although the number of seedlings in each tray was increased.
Low seedlings density	Low seedlings density increases the missing hill. Seedling density setting should be in high position to regulate the optimum number of seedlings dispensed in each stroke.
High seedlings density	Seeding density setting should be in low position to regulate the optimum number of seedlings dispensed in each stroke.
Low water height	Seedlings are unable to anchor properly in

	the soil due to low moisture content of soil. Water level should be maintained at 1-2 cm.
Excess water level	Excessive water height in the field creates floating hill due to water wave during operation transplanter.
Land condition is dry	Unable to anchor the seedlings in dry land, which creates more missing hill.
Low seedlings height	Seedlings having low height creates more buried hill. Depth of seedling placement should be reduced by setting the depth control lever in lower position. Seedling height should be 10-12 cm.
Excessive seedlings height	Seedlings height should be less than 17 cm. Otherwise cutting of the seedlings height is needed to less than 12 cm.
Jam in picker fork	Picker may be jammed due to straw and gravel attached in the picker during transplanting. Remove the straw from the picker.
Picker worn out	Picker decays due to continuous operation. Replace with new one.

CHAPTER VI

BUSINESS MODEL

Establishment of a transplanting service and further sustenance is not a simple process, but involves versatile activities and approaches which are essential for running the transplanting business for the small holder farmers.

Importance of business model in farm machinery diffusion

Agriculture in Bangladesh has its challenges for poor infrastructure in rural areas, complex social formation comprising wide range of classes and points of views and insecure business environment due to weak national policy. Most of the farmers have limitation of funding, fragmented land holding, adoption to new technologies keeping mechanization beyond reach. Still, challenges come with opportunities. Business model guides challenges to opportunities. Determination of optimum value chain of agricultural machinery suiting to low income farmers and establishment of safe environment for investment by entrepreneurs is essential to extract the most from limited resources. Usage of custom-hire model for power tiller, tractors, and power threshers have already been successful in establishment of good business (Fig. 1).

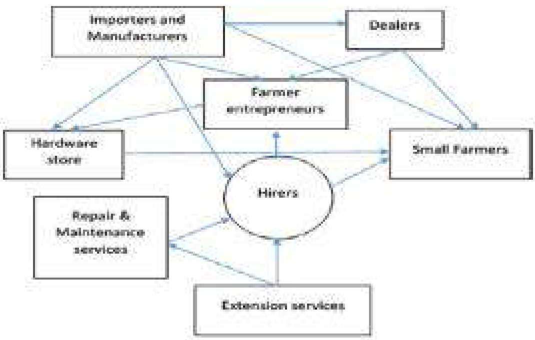


Fig. 1 Tractor custom hire value chain (adopted from FAO, 2009)

Adoption of business model in agricultural business ventures has been a well-accepted trend in corporate community of Bangladesh. Business model is an integral part of economic and trading practices since ages. The concept has gained its identity in mid 1990s (Zott *et al.*, 2011). It represents an organized form of plan articulating revenue source, identification of target customers, operational design, product clarification and details of financing. It is the idea implemented by a company to generate revenue and make a profit from operations (Zott *et al.*, 2010). Business model also describes how a business venture can provide socially beneficial goods, services or livelihoods and recover its costs (Kubzansky, 2012). From a proper model, perspective on market acceptability of commercial agricultural operations could be forecasted and steps essential for risk mitigation could be taken before launching any business venture. Business model innovation can itself be a pathway to competitive advantage if the model is sufficiently differentiated and hard to replicate for incumbents and new entrants alike (Teece, 2010). It should outline how the enterprise creates and delivers value to customers, and then converts payments received to profits. To profit from new innovation like commercial rice transplanting, business pioneers need to excel not only at product innovation but also at business model design, understanding business design options as well as customer needs and technological trajectories.

Business planning

A business plan defines goals and objectives of the business venture. Initially, the process starts with idea generation followed by incubation of the idea and in final stage, leading to commercialization of that business idea. These steps are rigidly interlinked and needed to handle cautiously.

Problem identification and solution

The problems and prospects of mechanical transplanting were collected by observing field operations and interviewing farmers in some areas of Bangladesh (Islam *et al.*, 2017b). Table 1 summarizes the problem and probable solution of the mechanical transplanting activities.

Table 1 Problem and solution of mechanical rice transplanting

Problems	Solution
Can farmers order for transplanting readily?	No, they have to confirm order at least 30 days before in *boro* season, 20 days before in *aman* and *aus* season
Is it feasible to supply seedlings trays from distant warehouse?	No, carrying of seedlings is not economically feasible and quality of mat deteriorates while transferring over long distances.
Is it possible for the farmers to prepare seedlings trays themselves?	Yes, with little guidance of trained person, farmers can raise good quality seedlings.
Do the farmers prepare land well ahead before transplanting?	20% of the farmers prepare land well ahead of transplanting. Monitoring is required to ensure enough soil settling time.
Do they possess interest to adopt this technology?	Yes, 80% of the farmers understands the advantages of adopting mechanical transplanting and are interested to adopt the technology
Do they possess interest of buying seedlings trays for further use?	Very few of them were interested in buying seedlings trays for future use and the rest were interested in using seedlings trays on rental basis
Do the farmers pay for the service on-time?	90% of the farmers paid on time. 10% of the farmer delayed. Such farmers could be avoided by the help of leader farmer.
Do the farmers return seedlings trays in good condition after use?	Yes, 90% of the trays were returned to the warehouse in good condition, but the rest were broken or missing.

SWOT analysis

In this step, idea is turned into reality. The idea may be turned into a product only after making the idea stronger and more viable by clustering workers together in collaborative environments. Proper identification of strengths and weaknesses of the idea results in a stronger finished product. Table 2 presents strengths, weaknesses, opportunities and threats (SWOT) analysis of the ideas incorporated with the commercialization of the mechanical rice transplanting.

Goals

Specific goals are required to set the performance targets. The goals for small scale rice transplanting could be as follows:

- To increase daily coverage
- To get seedlings trays prepared by the farmers
- To develop customer base comprising different groups

Strategy formulation

By the process of strategy formulation, an entrepreneur chooses appropriate course of action to achieve its goals. It provides a framework for the actions that will lead to the anticipated results. Distinct steps required for successful formulation of the strategies are discussed below:

Development of entrepreneurship for tray preparation

Lead farmer may be selected among the farmers who is early adopter, understands the virtue of mechanical transplanting technology and willing to learn and play the role of entrepreneurship in seedlings preparation. The entrepreneur should be willing to buy trays, manage other farmers to contribute and able to produce good quality seedlings according to their requirement. In such case, role of entrepreneur would be limited in preparation of seedlings. Farmers will select variety and amount of trays themselves. Plastic trays would be supplied by the entrepreneur when farmers want to purchase. The entrepreneur will provide the machine on rental basis.

Development of transplanting culture in the same day

A trend should be developed among the farmer that all the plots in a field should be prepared in the same day so that transplanting could be done in adjacent plots in single travel of machine. Thus, travelling distance would be minimized and daily area coverage as well as operational capacity will be increased.

Table 2 SWOT analysis of ideas

Idea	Strength	Weakness	Opportunity	Threat
Seedling raising by the entrepreneur	Risks with allotting trays to the farmers are minimized. Uniformity of seeding on tray can be ensured. Bulk tray preparation can be ensured by using seed sowing machine.	Staff requirement increases to maintain seedlings. Additional cost for transporting seedlings from entrepreneur's nursery to farmer's field will be added	Scheduling of tray preparation can be done according to the demand. Comparatively easy to manage seedlings nursery. Seedlings quality and density ensured.	Risks of seedlings wastage increases. Cost increases in raising mat type seedlings.
Seedling raising by the farmer	Expenses and staff requirement of seedlingstray preparation and carrying are minimized. Farmers raise the seedlings according to their own area coverage	Risk with allotting trays to the farmers increases. Varies seed quality and germination.	Nursery management cost is reduced.	Proper preparation of seedlings trays cannot be ensured.
Fee collection after transplanting	Builds a soft image of the company and farmers	Few of the farmers won't pay during collection.	Continuous dealing is favored	Missing of fee collection could be increased
Fee collection in advance before transplanting	Collection of fees is secured.	Some farmers may not agree to pay in advance.	Farmers would be sincereon preparing land well ahead of time.	Possibility of less area coverage under transplanting service

Arrangement of materials and resources

Proper arrangement of materials is compulsory to ensure that every support service should be available at the right place on right time. It is the precondition of successful operation of the transplanting service. The machine and logistic support should be available near the transplanting field to avoid time loss. Manager should visit seedlings nursery and transplanting field at the day before transplanting to ensure that the seedlings trays and plots are ready for transplanting.

Commercialization

Commercialization of small scale rice transplanting only takes place when the following aspects are distinctly clarified.

Place selection

Areas with acute labor scarcity during transplanting should be selected to start business. The location of launching transplanting service could be in a single place or several regions depending on the entrepreneur's resources, in terms of capital, managerial confidence and operational capacity.

Land selection

Machine performance largely depended on the plot size and shape (Islam, 2016). Smaller size of plot requires more turning events, which inturn increases the time loss. Irregular shape of plots also affected the machine performance. It would not be wise to select the smaller size (<400 m^2) and irregular shape of plot to start transplanting business. Low lands where water remains stagnant during transplanting period have to be avoided carefully.

Target group

Early adopters, innovators, heavy users and opinion leaders among the farmers should be carefully picked out and put in the target group at first session. This will aid in motivation to other farmers in adopting rice transplanting service during the business growth period.

Value proposition

The company should generate value for the farmers by combining resources and other elements catering to their need. Values could be quantitative (e.g. low price and fast delivery of transplanting service) or qualitative (e.g. post transplanting support).

Generation of value

In this case, generation of values could be achieved at two points. The first point is providing rapid transplanting service at low cost, and the second is to supply trays for seedlings preparation on rental basis or selling. According to a widely used strategy, low value could be extracted from the high value input (which is the transplanter machine) to initiate the necessity of seedlings trays to the farmers. Then high value would be extracted from the low value input (seedlings trays) and merging the total output.

Value factors

Price is the first factor that would affect service values mostly. Transplanting service offered by the company must help farmers to reduce their cost from their usual practice. The initial pricing should be as low as possible and fixed for a unit area of land. The unit of pricing should be applicable to the convenient land sizes. In Bangladesh, agricultural land sizes vary in the range of 400-3500 m^2. There could be a minimum pricing margin. Performance of transplanter machine and yield of transplanted crops also affects service value. The machine should perform without much breakdown and must be ensured the crop establishment in the field. Transplanting quality is usually measured by the percentage of missing hill. Such missing areas should be immediately covered by manual gap filling. Farmers won't be happy to do or manage labor for gap filling after paying for the mechanical transplanting. Lead time is another measure in determining service values. It is the total time required by the company to transplant rice in the field from the time of farmer's order or booking. The lead time largely depends on the managerial capability of the company and should be as less as possible. Bringing new technology to the farmers is an important value factor. In this case, value propositions will satisfy an entirely new set of service that customers previously didn't perceive because there was no similar offering.

Revenue streams

Proper cash flow relies on the successful proposition of values offered to the customers. Revenue stream is thus represents the cash, a company generates from each farmer groups. In this case, business model can involve two types of revenue streams:

a. Revenues resulting from one-time customer payments after transplanting.

b. Recurring revenues resulting from ongoing payments for transplanting and post-transplanting supports.

Budget

Budgeting for commercial rice transplanting involves fixed costs like machine purchase cost, repair-maintenance and lubrication cost, staff and logistic expenses and other miscellaneous costs. Variable costs include expenses for spare parts and fuel costs. Expenses from broken parts could occur from hazardous situations and interlinked with risk management. Fuel cost was kept out of the budget as it depended directly on the area to be covered by the machine in a season and cannot be predicted to bring under a fixed frame.

Transplanting schedule

Mechanized rice cultivation in Bangladesh has been classified into three major ecosystems based on season and seedlings age (Table 3). These ecosystems are a) *boro,* b) Transplanted *aus* (*T. aus*) and c) Transplanted *aman* (*T. aman*). Boro rice is grown in the dry period (January to May) while *T. aman* (July to November) and *T. aus* (May to August) in wet period.

Table 3 Transplanting schedule

Date	Season	Activity	Transplanting duration, days
March 15-30	*T. aus*	Seedling preparation	
April 15-30	*T. aus*	Transplanting	15
June 10-25	*T. aman*	Seedling preparation	
July 15-30	*T. aman*	Transplanting	15
Dec 1-15	*Boro*	Seedling preparation	
Jan 1-15	*Boro*	Transplanting	15
Total			**45**

Performance indicators

Daily area coverage (ha day^{-1}) is the most significant performance indicator for the business. To cover a target of 15 ha (45 ha yr^{-1}) in one season, the machine would have to cover at least 1 ha each day. Fuel consumption is the second most important factor which could be outrageously higher when plots are scattered covering a large area. The transplanting schedule should be formed in a way that plots belonging to one area could cover at the same day.

Rental charge calculation

The rental charge for unit (1ha) area is a function of machine price, fuel, labor, shed, transport cost and annual usage.

Assumptions

Following assumptions are taken for calculating rental charge of rice transplanter:

- Purchase price of the 4-row walking type transplanter is Tk 4,00,000
- It is assumed that the machine is in good condition to perform its task in same rate (ha hr^{-1}) without varying over its lifetime
- The bank rate for interest on investment is 12%
- The repair and maintenance cost of rice transplanter is taken as 5% of its purchase price
- The life of the transplanter is considered six years
- Fuel price is taken as Tk 90 L^{-1}
- Operator charge is considered Tk 500 day^{-1}
- Labor cost can fluctuate depending on location and labor availability and taken as Tk 300 day^{-1}

Measuring only the hourly fixed cost doesn't completely cover practical situations, but the range of field capacity availed in varying field conditions (i.e. land shape, size, operator skill, soil settling condition, etc.) also has competency to be taken into account while calculating cost per hectare. The occurrence of field capacity values were plotted based on the field observation and found maximum occurrence of events at 0.15 ha hr^{-1} (Fig. 2). These values were used to determine the annual area coverage and transplanting cost. Figure 3 shows the fixed cost and variable cost of the mechanical transplanter. Fixed cost decreased with the increase of annual area coverage. Entrepreneur will consider these two graphs to calculate the rental charge of mechanical transplanting. Rental charge of the mechanical transplanting service depended on the annual and daily area coverage, fuel and labor price, machine breakdown, puddled condition, time loss minimization and payback period. Islam (2016) mentioned that at the initial stage of mechanization, transplanting business would be profitable with 70% cash incentive and 30% loan at reduced interest rate to procure transplanter for the annual area coverage of 30 hectare of land. Therefore, entrepreneur must be aware to increase the annual area coverage in order to fix up the competitive rental charge.

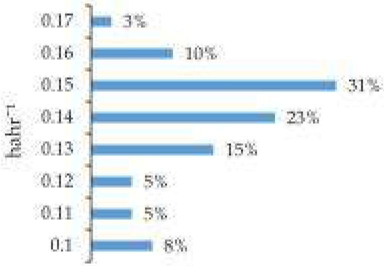
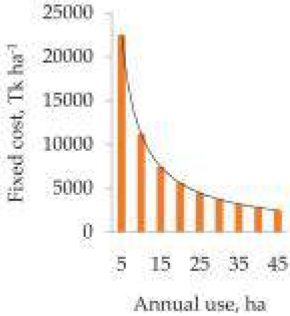


Fig. 2 Field capacity in 50 trials



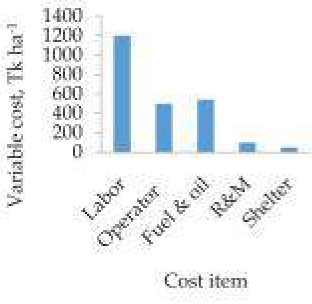


Fig. 3 Transplanting cost scenario over small scale coverage

Limitations

The business model developed for small scale based on data and attributes collected from one district. This model could impose following limitations:

- The model doesn't initiate any control on farmer's attitude and post-transplanting management of field to secure good yield.
- The daily area coverage (1.0 ha day^{-1}) is difficult to meet if farmer's doesn't prepare land in time or fails to prepare good seedlings trays (≥ 5000 seedlings $tray^{-1}$).
- The socio-cultural status of farmers is not sufficiently up-to-date to harness mechanical transplanting as well as the business model.

The business model was developed based on the cultivation trend, performance of machine, strength, weakness, opportunity and threats of operations and farmer feedback. Cost effective pattern for transplanting was identified during operation. Growing proper understanding of benefits of mechanical transplanting among the farmers can help generation of value for business. Increasing daily coverage area would help to bring more farmers under service. Entrepreneurial role for the advanced farmers could be developed in seedlings preparation. Launching of transplanting service should be in right place and time. Target group of service receiving farmers should include the early adopters. Values could be generated through machine transplanting and providing plastic trays. Revenue stream could be of onetime payment basis or continuous service basis including post transplanting intercultural services. The target area coverage, unit price of transplanting service, unit price of trays, business period were found interconnected with each other and jointly affected profit generation. Versatile customer groups, reasonable staff expenses and competitive price of service were found essential in mitigating risk. Streaming of revenue was successful through transplanting service indicating the positive environment for business ventures. After transplanting, the service receiving farmers were satisfied and interested to repeat in next season at any reasonable price. Low cost, fast operation and minimization of missing hills was determined as the key factor business value proposition. Diversifying customer groups, filtering for early adopters, competitive pricing of services were identified as important steps for risk mitigation. Increasing daily coverage, minimizing fuel consumption and selection of sensible consumer group can draw good return from marginal input and establish business in secure environment.

CHAPTER VII

LAND SIZE AND TRANSPLANTER OPERATION

Introduction

Lands in Bangladesh are mostly fragmented, numerous plots, scattered and critically irregular in shape. Land fragmentation that farmers achieved inherently appeared as a big challenge to the successful implementation of the farm mechanization activities. The land is divided further as the ownership changes with the increase in population. Small farm lands included several obstructions in the profitable farming. Fragmented lands are mostly inaccessible to farm machinery and become fellow or non-irrigated land. Land owners are mostly careless about proper farming activity due to small land holdings. The shape of the land is a major cause that reduces the efficiency of farm machinery. Plot size, shape, farm roads and soil bearing capacity have become more crucial in determining the efficient use of farm machines. Islam *et al*. (2015) stated that daily area coverage of the transplanter depended on the plot to plot distance, plot size, seedlings tray supply and number of plots under transplanting activity. Fuel consumption also depended on the plot size, shape, transplanting area, movement from one field to another, plot to plot distance and distance from machinery shed to transplanting field. Field capacity of transplanter had direct influence on the fuel consumption, labor and transplanting cost. Fuel was fully utilized in easily accessible regular shape and large size plots because of high field capacity. Distance from one plot to another caused additional fuel consumption of the machine. Higher field coverage ensured full utilization of labor, minimal fuel consumption and hence reduced transplanting cost (Islam *et al.*, 2017). Taniyama (1975) stated that the operation efficiency of machines generally becomes higher in proportion to the size of field plots and the length-width (L/W) ratio of plots. The operational efficiency of rotary cultivation with 30-40 PS wheel tractor increased a little when the size of field lots exceeds 0.3 hetare and remarkably decreased when the size of plot were below that level. The efficiency increased with the increase in L/W ratio. Larger plots were favorable in increasing daily area coverage than smaller plots. Smaller plots were not favorable to operate transplanter and not possessed economic feasibility. Small plots having less than 250 m^2 should be avoided for 4-row walking type transplanter (Islam *et al.*, 2017). In addition, field sizes less than 400 m^2 should be avoided to get the good performance of 6-row riding type transplanter (Islam *et al.* 2015). Ganewatta (1974) mentioned that an average farmer owned 1.7-3.5 plots and the plot size ranged from 0.2-0.4 acres in dry zonal village of Srilanka. The ownership of plots ranged 1-10 which was similar to that of Japan before the implementation of land improvement project. Nagata (1973) mentioned that each farmer owned 1-17 plots often located in different places of Okijima village (Kahoku project area), Japan before land consolidation and farmers owned a relatively large farm size having on average plot size of 0.5 ha after farm land consolidation. In Japanese villages, the average family holdings consisted of some 15 or 20 farm plots in the 1940s. The average plot was only about 500 m^2 and the distance between two plots belonging to one farmer was several kilometers (Williamson, 1951). High degree of land fragmentation i.e. 3.2 plots per farm with average plot size of 0.16 ha were observed in Bangladesh (Mandal, 2014). Fragmented land is the effect of population explosion over the country and possibilities to control the land fragmentation is less due to socio-economic impact. The land is divided further as the ownership changes with the increase in population. Islam *et al.* (2015) studied the plot shape in Bogra and Natore district while transplanter was operated commercially in the farmer's field and mentioned that among the transplanting plots, 70, 25 and 5% plots were uniform, irregular and mostly irregular, respectively. Ulluwishewa *et al.* (1985) emphasized the need of enlargement of plot size to reduce the turning events inorder to increase the operational efficiency of farm machine. The use of modern machinery is difficult or may be impossible in tiny plots and may require an excessive amount of manual work in the corners and along the boundaries (Karouzis, 1977 and Burton, 1988). Tsuchiya (1976) stated that land improvement encouraged the introduction of modern farm machinery due to better irrigation and drainage facility and enlarging plot size by rearranging the existing paddy fields. Nagata (1973) mentioned that in Japan, one farmer had many small plots which were scattered before the implementation of land improvement projects. This impeded the mechanization by creating small field plots and by increasing the time that has to be taken for travelling from one plot to another. The small size and irregular shape of plots is another dominant problem associated with land fragmentation (Yates, 1960).

Field surface must be perfectly flat in lowland farming whereas it is not necessarily to be flat in the case of upland farming. The recommended degree of flatness in Japan is less than ±5 cm in a field plot (Tsuchiya 1976). Small plots have the advantages of proper water management especially in drought prone and hilly areas where water supply is scant or unavailable. It is easy to make and maintain flat soil surface in smaller field plots and enhances better water control. However, it is very difficult to maintain leveling ofthe field properly in large size plots and challenging for rapid drainage of surface water compared to small plots. On the other hand, most of the plots are not leveled properly. Consequently, inefficient drainage system impedes the operation of farm machine. Paddy field condition should be improved to get the good machine performance. Land leveling is needed in paddy farming to manage irrigation water. Therefore, farmers construct temporary levee in the bigger size of plots after land preparation for good water management. Small sizes of plots are preferable to the rice farmers due to good management of water. Inaccessibility of farm machine in the field is of another limiting factor on successful farm mechanization. It is necessary to construct farm road to reach farm machine to every plots without causing damage to the existing crops to other fields, levees, irrigation and drainage channel. Land consolidation is a way to avoid operational complexities in crop land and uphold its production through low cost. Non-improved paddy fields caused low work performance and reduced work output of machines.

Land fragmentation exists in many countries in the world. Most of studies concluded that fragmentation hindered the efficient crop production. Japan implemented the land improvement projects under the Land Improvement Law of 1949 to enlarge small fragmented plots, consolidated the scattered paddy plots into large plot and constructed farm roads to enhance the easy access of farm machinery and promoted farm mechanization program. Countries like Japan, South Korea, Philippines and Thailand had already prospected their agricultural production by land management. Experience in other countries suggests the importance of land improvement schemes to expand farm mechanization program.

Existing land size, shape and uniformity

Islam *et al*. (2017c) carried out field survey in 54 villages under 54 upazilas in 52 districts under eight administrative divisions of Barisal, Chittagong, Dhaka, Khulna, Mymensingh, Rajshahi, Rangpur and Sylhet to know the existing plot size, shape and length-width ratio of each plot in January-May 2017. The village in each district was selected by using simple random sampling (SRS) method. The total number of sample size was 5,400 and the data on plot size, shape and cropping systems were collected from 100 adjacent plots in each village of the respective upazilas. Table 1 shows the cropping systems of the selected villages, unions and upazilas in each division. Shape characteristics of the agricultural plots were divided into four categories depending on the percent uniformity of plot shape which was measured by eye estimation. The categories were as irregular (>4%), moderately irregular (2-4%), moderately regular (1-2%) and regular (<1%). Descriptive statistics was applied to analyze both qualitative and quantitative data. Four-row walking type transplanter was considered to interpret the field performance on the existing plot size, shape and plot L/W ratio.

Table 1a Cropping systems in the survey areas of Barisal division

District	Upazila	Union	Village	Cropping system
Barguna	Amtali	Chawra	Chalitabunia	*Aman*-Mungbean
Barisal	Sadar	Charamoddi	Charamoddi	*Aman*-Mungbean
Jhalokathi	Sadar	Kirtipasha	Orposha	*Boro-Aman*
Patuakhali	Galachipa	Amkhola	Basbonia	*Aman*-Mungbean
Pirojpur	Nazirpur	Nazirpur	Mativanga	*Aman*-Mustard-Jute

Table 1b Cropping systems in the survey areas of Chittagong division

District	Upazila	Union/ municipal	Village	Cropping system
Brahmanbaria	Sadar	Pourashavha	Hatihata	*Boro- Aman*
Chandpur	Sadar	9 no. ward	Anathpur	*Boro-Aman*
Chittagong	Mirersorai	2 Engoli	Paschim Engoli	*Aman*-Mungbean
Comilla	Chauddagram	Alkora	Uttar Latimi	*Boro-Aman*
Feni	Daganbhuiyan	2 no. Rajapur	Paschim Joy narayanpur	*Boro*
Lakshmipur	Sadar	9 Chandraganj	Shekhpur	*Aman*
Noakhali	Sadar	Pourashavha	Maijdi	*Boro-Aman*

Table 1c Cropping systems in the survey areas of Dhaka division

District	Upazila	Union	Village	Cropping system
Dhaka	Dohar	Bilashpur	Dohar uttarpara	*Boro-Aman*
Faridpur	Bhanga	Sadar	Hasemdia	*Boro*-Jute/Wheat
Gazipur	Sadar	Shimultali	Faokal	*Boro-Aman*
Gopalganj	Kasiani	Rajpat	Paschim para	*Boro*-Lentil
Gopalganj	Muksedpur	Tengrakhola	Provakordi	*Boro-Aman*
Kishoreganj	Sadar	Latifabad	Mokshedpur	*Boro-Aman*
Madaripur	Rajoir	Bajitpur	Bajitpur	*Boro-Aman*
Rajbari	Kalo khali	Sadar	Goalia	*Aman*-Jute
Tangail	Ghatail	3 no. Jamuria	Gungram	*Boro-Aman*/fellow
Tangail	Dhanbari	Dhanbari	Jhopna	*Boro-Aman*

Table 1d Cropping systems in the survey areas of Khulna division

District	Upazila	Union	Village	Cropping system
Bagerhat	Fakirhat	Fakirhat	Pagla uttar para	*Boro-Aman*
Chuadanga	Sadar	Katulpur	Boalia	*Boro-Aman*
Jessore	Kotoali	Noapara	Atal pachbaria	*Boro-Aman*
Jhenaidah	Sailkupa	Sailkupa	Khalkula	*Boro-Aman*
Khulna	Dumurai	Baratia	Kulbaria	*Boro-Aman*
Kushtia	Khoksha	Goppara	Satpakhia	*Boro-Aman*
Magura	Sadar	Hajrapur	Esha khada	*Boro-Aman*
Meherpur	Gangi	Matmura	Akabpur	*Boro-Aman*
Satkhira	Tala	Zialanta	Charibhanga	*Boro*

Table 1e Cropping systems in the survey areas of Mymensingh division

District	Upazila	Union	Village	Cropping system
Mymensingh	Sadar	Sirta	Char Sirta	*Boro-Aman*
Sherpur	Nakla	Nakla	Nakla Bazardi	*Boro-Aman*
Jamalpur	Sorishabari	Aauna	Ponchashi	*Boro*
Netrakona	Sadar	Collisha	Sakua	*Boro-Aman*

Table 1f Cropping systems in the survey areas of Rangpur division

District	Upazila	Union	Village	Cropping system
Rangpur	Sadar	15 no. ward	Ghaghotpara	Late *Boro-Aman*-Potato
Lalmonirhat	Sadar	Panchagram	Haridev	Late *Boro-Aman*
Dinajpur	Sadar	Sadar	Paschim Khudihar para	Late *Boro – Aman*-Potato
Thakurgaon	Sadar	16 no. Nargun	Kismat Daulatpur	Late *Boro-Aman*-Maize
Panchgarh	Sadar	10 no. Gorinabari	10 no. Gorinabari	*Boro-Aman*-Chili
Gaibandha	Gobindaganj	Kamardaha	Digholkandi	Late *Boro – Aman*-Potato/Onion(Banana)
Kurigram	Sadar	Mogolbasha	Uttar Naowabas	*Boro-Aman*-Brinjal/Onion

Table 1g Cropping systems in the survey areas of Rajshahi division

District	Upazila	Union	Village	Cropping system
Bogra	Sadar	Fapore	Kanar	*Late Boro- Aman*-Potato
Chapainawabganj	Shibganj	Shibganj	Shekhtola	*Boro-Aman*
Joypurhat	Sadar	Bambvu	Hismi Bazar	*Boro-Aman*
Naogaon	Sadar	2 no. Halain	Toruk	*Boro-Aman*
Natore	Sadar	11 Kaforia	Khandarpar	*Boro-Aman*
Pabna	Bera	Aminpur	Fokirkandi	*Boro-Aman*
Rajshahi	Paba	8 Horian	Mohonpur	*Aman*-Mungbean
Sirajganj	Ullapara	Hatikumrul	Choria chockpara	*Boro-Aman*

Table 1h Cropping systems in the survey areas of Sylhet division

District	Upazila	Union	Village	Cropping system
Habiganj	Sadar	8 no. Habiganj	Khalpar	*Boro-Aman*
Moulavibazar	Sadar	1 no. Amorkona	Daudpur	*Aman*
Sunamganj	Sadar	6 no. Lakshmanjir	Bahadurpur	*Boro-Aman*
Sylhet	Sadar	Khadimpara	Kollya	*Boro-Aman*

Plot number and size

Table 2 shows plot number per hectare and plot size in the sample location. Number of plots per hectare and plot size was considered as the indicator of land fragmentation. In Barisal division, the number of plot per hectare indicated that the land fragmentation was higher in Jhalokathi (16 plots per ha) district followed by Pirojpur, Barisal, Barguna and Patuakhali districts (Table 2a). The plot sizes were rangedfrom 0.09 to 0.13 ha and the smallest plot sizes (0.06 ha) were observedin Jhalokathi district. The plot size was less than 0.10 ha in Barisal, Pirojpur and Jhalokathi districts. Wide range of variations was observed in the plot sizes (152-4234 m^2). The height of rural road from the plot surface was 1-2 m. Plots were not leveled properly. Canals were observed nearer to the plot and machinery move to the field after crossing the canal.

Table 2a Plot number per hectare and plot sizein the sample location of Barisal division

District	Plot, no. ha^{-1}	Plot size, ha	Range, m^2
Barguna	10	0.10 ± 0.008	152-3542
Barisal	11	0.09 ± 0.005	230-2212
Jhalokathi	16	0.06 ± 0.004	153-2365
Patuakhali	8	0.13 ± 0.007	171-4234
Pirojpur	12	0.09 ± 0.005	322-2806
Average	**11**	**0.09 ± 0.003**	**152-4234**

Source: Field survey 2017

In Chittagong division, land fragmentation was higher (more than 10 plots per ha) in most of the districts except Brahmanbaria and Chandpur districts (Table 2b). High degree of land fragmentation was observed in the survey area of Chittagong followed by Lakshmipur, Noakhali and Comilla districts. The plots sizes were varied from 0.05 to 0.12 ha. The survey areas of Comilla, Feni, Chittagong, Noakhali and Lakshmipur districts dominated the plot sizes below 0.10 hectare and Chittagong district reported the smallest plot sizesof 0.05 ha. The plot sizes were varied widely in Chittagong division. In the survey area of Comilla district, the height of the rural road from the plot surface was 2m. However, the height of the rural road from the plot surface was observed more than 3 m in the survey areas of Feni, Chandpur and Chittagong districts. Farmers faced problem to move the machine from road to plot due to high elevation. The survey plots were more than one km far from the rural road. The machinery moved into the plots by crossing other plots, levees and irrigation canal.

Table 2b Plot number per hectare and plot size in the sample location of Chittagong division

District	Plot, no. ha^{-1}	Plot size, ha	Range, m^2
Brahmanbaria	8	0.12 ± 0.005	158-2997
Chandpur	8	0.12 ± 0.006	255-3690
Chittagong	20	0.05 ± 0.004	83-2725
Comilla	12	0.08 ± 0.005	158-2997
Feni	11	0.09 ± 0.005	204-2495
Lakshmipur	14	0.07 ± 0.005	136-3330
Noakhali	13	0.08 ± 0.004	134-2440
Average	**11**	**0.09 ± 0.002**	**83-3690**

Source: Field survey 2017

Table 2c describes the land fragmentation and plot sizes in the survey areas of Dhaka division. The high degree of land fragmentation (more than 10 plots per ha) was observed in the survey areas of Tangail-Ghatail, Kishoreganj, Faridpur and Rajbari districts. Among the survey areas, the high degree of land fragmentation was in the survey area of Tangail-Ghatail (27 plots per ha). The lowest degree of land fragmentation was observed in the Gopalganj-Kashiani and Madaripur districts. Gopalganj-Kashiani, Madaripur, Gopalganj-Muksudpur and Gazipur areas dominated the plot sizes of greater than 0.10 ha.The large variation of plots sizes (0.04-0.14 ha) were observed in the survey areas in Dhaka division. In the survey area of Gopalganj, Rajbari, and Madaripur districts, the height of rural road from the plot surface was observed more than 2m. In Faridpur district, the height of rural road from the plot surface was observed more than 3m. Farmers faced problem to move the machine from road to plot due to high elevation. Sometimes, four persons were required to move power tiller in sloppy surface. On the other hand, the plots were not in the same elevation. Machinery moved to the plots by causing damage to the levees. Machinery parts were damaged due to the movement in undulated land. The survey plots were more than 2-3 km far from the main road.

Table 2c Plot number per hectare and plot size in the sample location of Dhaka division

District	Plot, no. ha^{-1}	Plot size, ha	Range, m^2
Dhaka	11	0.09 ± 0.006	86-4590
Faridpur	16	0.06 ± 0.005	33-2879
Gazipur	10	0.11 ± 0.006	220-3252
Gopalganj-Kashiani	7	0.14 ± 0.008	383-4226
Gopalganj-Muksudpur	9	0.11 ± 0.007	221-4926
Kishoreganj	18	0.06 ± 0.004	101-2451
Madaripur	8	0.12 ± 0.007	183-4219
Rajbari	14	0.07 ± 0.004	172-2033
Tangail-Dhanbari	14	0.08 ± 0.005	132-3245
Tangail-Ghatail	27	0.04 ± 0.003	64-1465
Average	**11**	**0.09 ± 0.002**	**33-4926**

Source: Field survey 2017

Table 2d indicates that high degree of land fragmentation (more than 10 plots per ha) was observed in all the districts except Jessore and Satkhira in Khulna division. The highest degree of land fragmentation was observed in Khulna (19 plots per ha) followed by Meherpur (18 plots per ha) district. The plots sizes are less than 0.10 ha in all the survey areas except Jessore and Satkhira districts. The plot sizes were varied from 0.05-0.10 ha. The smallest size of plots (0.05 ha) were observed in Khulna district. Very smaller to larger sizes of plots (102-5278 m^2) were observed in the survey areas of Khulna district. In Kushtia, Magura, Jhenaidah and Jessore districts, the height of rural road from the plot surface was observed more than 1 m. In Meherpurand Chuadanga districts, the height of rural road from the plot surface was observed more than 2 m. More than 65% plots were observed plain and rest of the land were undulated in the survey area of Khulna division.

Table 2d Plot number per hectare and plot size in the sample location of Khulna division

District	Plot, no. ha^{-1}	Plot size, ha	Range, m^2
Bagerhat	16	0.06 ± 0.003	125-1700
Chuadanga	14	0.07 ± 0.005	132-3477
Jessore	10	0.10 ± 0.006	197-3099
Jhenaidah	16	0.06 ± 0.005	135-3520
Khulna	19	0.05 ± 0.003	168-2148
Kushtia	15	0.07 ± 0.005	102-3002
Magura	13	0.08 ± 0.005	123-2981
Meherpur	18	0.06 ± 0.004	152-1713
Satkhira	10	0.10 ± 0.009	131-5278
Average	**14**	**0.07 ± 0.002**	**102-5278**

Source: Field survey 2017

Table 2e states that land fragmentation was more pronounced in the survey areas of Mymensingh division. The plots per hectare were observed more than 10 in the survey areas of all the districts in Mymensingh division. The highest number of plots per hectare was obtained in Jamalpur (21 plots per ha) followed by Mymensingh (17 plots per ha), Netrakona (15 plots per ha) and Sherpur (11 plots per ha) districts. The plot sizes in all the locations in Mymensingh division were found less than 0.10 ha. The average plot sizes varied from 0.06-0.09 ha. The wide range of variation of plot sizes (62 to 3804 m^2) was observed in the survey areas of Mymensingh division.

Table 2e Plot number per hectare and plot size in the sample location of Mymensingh division

District	Plot, no. ha^{-1}	Plot size, ha	Range, m^2
Jamalpur	21	0.06 ± 0.005	99-3055
Mymensingh	17	0.06 ± 0.004	62-1980
Netrakona	15	0.07 ± 0.004	125-2863
Sherpur	11	0.09 ± 0.007	109-3804
Average	**15**	**0.07 ± 0.002**	**62-3804**

Source: Field survey 2017

Table 2f shows that the number of plots per hectare was observed more than 10 in the survey areas of all the districts except Joypurhat in Rajshahi division. High degree of land fragmentation was observed in Chapainawabganj district (22 plots per ha). The lowest degree of land fragmentation was observed in Joypurhat (9 plots per hectare) and Naogaon (10 plots per ha) districts. The average plot sizes were varied from 0.05-0.11 ha. The average plot size was more than 0.10 ha in Joypurhat and Naogaon districts. The plot sizes were observed the lowest in Chapainawabganj district (0.05 ha). The plot sizes were varied from 53 to 2,830 m^2 in the survey areas of Rajshahi division.In Rajshahi, Chapainawabganj, Naogaon, Natore, Joypurhat districts, the height of the rural road from the plot surface was 1m. However, the height of the rural road from the plot surface was observed more than 2 m in the survey areas of Sirajganj and Pabna districts. Farmers faced problem to move the machine from road to the plot due to high elevation especially in Naogaon, Natore, Pabna and Sirajganj districts. In Rajshahi district, more than 70% plots were terrain where farmers faced difficulty to move machine. However, in other districts, 55-65% of the total plots were elevated than the other plots. The survey plots were more than two to three km far from the rural road. The machinery moved into the plots by crossing the other plots, levees and irrigation canal.

Table 2f Plot number per hectare and plot size in the sample location of Rajshahi division

District	Plot, no. ha^{-1}	Plot size, ha	Range, m^2
Bogra	16	0.06 ±0.004	112-2192
Chapainawabganj	22	0.05 ± 0.003	113-1403
Joypurhat	9	0.11 ± 0.006	302-2830
Naogaon	10	0.10 ± 0.005	245-2787
Natore	17	0.06 ± 0.002	53-1380
Pabna	14	0.07 ± 0.005	187-2674
Rajshahi	16	0.06 ± 0.003	123-1653
Sirajganj	12	0.08 ± 0.005	105-2450
Average	**13**	**0.07 ± 0.002**	**53-2830**

Source: Field survey 2017

The number of plots per hectare was observed 28-35 in the survey areas of Dinajpur, Panchgarh and Kurigram districts under Rangpur division. It indicates that the highest degree of land fragmentation was observed in these areas (Table 2g). In this division, Kurigram and Gaibandha districts are mostly flood prone. The major rivers located in Kurigram are Brahmaputra, Dharla, and Tista. In flood prone Kurigram district, plots were found larger in size in the studied area due to single cropping system. Land sizes were found very small (0.03 ha) in Dinajpur, Panchgarh and Kurigram districts. Larger plot sizes were found in the Thakurgaon district. In Panchgarh district, plots elevation was found higher and few areas were covered by *boro* than *aman* rice cultivation. The larger size of plots (0.11 ha) were observed in Rangpur district. The average plot sizes were observed from 0.03-0.011 ha in the survey area of Rangpur division. The plot sizes were observed very small to large in size (54-4451 m^2). Farmers divided the large plot into smaller due to maintain proper leveling of land. The height of main road from plot surface was very much high.

Table 2g Plot number per hectare and plot size in the sample location of Rangpur division

District	Plot, no. ha^{-1}	Plot size, ha	Range, m^2
Dinajpur	29	0.03 ± 0.001	149-682
Gaibandha	17	0.06 ± 0.003	99-2071
Kurigram	29	0.03 ± 0.002	78-1436
Lalmonirhat	11	0.09 ± 0.004	218-2295
Panchgarh	35	0.03 ± 0.002	54-1134
Rangpur	9	0.11 ± 0.007	132-4451
Thakurgaon	15	0.07 ± 0.004	100-2008
Average	**17**	**0.05**± 0.001	**54-4451**

Source: Field survey 2017

Table 2h shows that the number of plots per hectare was the highest in the survey areas of Sylhet district indicating the highly fragmented lands existed in those areas under Sylhet division. The number of plots per hectare was observed 20, 14 and 12 in Sylhet, Moulavibazar and Habiganj districts. The survey areas of Sunamganj district dominated the larger sizes of plot (0.12 ha) compared to other district in Sylhet division due to single cropping system in *haor* areas.The average plot sizes ranged from 0.05 to 0.12 ha. The distribution of plot sizes reflected that different sizes of plots (73 to 3699 m^2) prevailed in the survey areas of Sylhet division. In Moulavibazar and Sylhet districts, the height of rural road from plot surface was. However, in the survey area of Sunamganj and Habiganj districts, the height of rural road to plot surface was more than 1 m. Farmers faced problem to move the machine from road to plot due to high elevation. Plots were not in the same elevation. Therefore, machinery movement was restricted due to difference in elevation between the plots.

Table 2h Plot number per hectare and plot size in the sample location of Sylhet division

District	Plot, no. ha^{-1}	Plot size, ha	Range, m^2
Habiganj	10	0.10 ± 0.004	265-2433
Moulavibazar	14	0.07 ± 0.004	163-1862
Sunamganj	9	0.12 ± 0.007	233-3699
Sylhet	20	0.05 ± 0.003	73-1315
Average	**12**	**0.08 ± 0.003**	**73-3699**

Source: Field survey 2017

In short, the highest degree of land fragmentation was observed in Rangpur (17 plots per ha) and some way ahead Mymensingh (15 plots per ha), Khulna (14 plots per ha), Rajshahi (13 plots per ha) and Sylhet (12 plots per ha) divisions (Table 2i). The number of plots per hectare was at par in Barisal, Chittagong and Dhaka divisions. On average, one hectare land was divided into 13 plots in the survey areas of Bangladesh. The smaller sizes of plots were dominated in the survey areas of Rangpur districts. The average plot sizes varied from 0.05 to 0.09 ha in eight administrative divisions. The average plot sizes were observed 0.08 ha in the survey areas of Bangladesh. Mandal (2014) observed the average farm size of 0.5 ha, which was below the present findings. This might be due to the variation of sample size and survey methodology. Wide range of variation of plots sizes (33-5278 m^2) was observed in the survey areas of Bangladesh. Farmers divided the larger sizes of plots by creating artificial levee to maintain water.

Table 2i Plot number per hectare and plot size in eight administrative divisions

District	Plot, no. ha^{-1}	Plot size, ha	Range, m^2	Sample size, no.
Barisal	11	0.09 ± 0.003	152-4234	500
Chittagong	11	0.09 ± 0.002	83-3690	700
Dhaka	11	0.09 ± 0.002	33-4926	1000
Khulna	14	0.07 ± 0.002	102-5278	900
Mymensingh	15	0.07 ± 0.002	62-3804	400
Rajshahi	13	0.07 ± 0.002	53-2830	800
Rangpur	17	0.05 ± 0.001	54-4451	700
Sylhet	12	0.08 ± 0.003	73-3699	400
Average	**13**	**0.08± 0.003**	**33-5278**	**5400**

Source: Field survey 2017

Distribution of farm plot size

Chapter IV revealed that plot size has great influence on the efficient operation of 4-row walking type transplanter. Plot size having less than 250 m² increased the frequent turning events and decreased the performance of the transplanter (Fig. 5b in chapter IV).

Table 3a presents classification of plot by size in Barisal division. Most of the plots in the survey locations of Patuakhali (74%), Barisal (58%) and Barguna (52%) districts belonged to the sizes more than 750 m². The percentage of small plots (<250 m²) was higher in Jhalokathi (13%) district, while the percentage of large plots (>1000 m²) was higher in Patuakhali (57%) district. Currently, 74% of total plots ranged 500->1000 m² which were suitable for operating the 4-row walking type transplanter. Besides, 22% plots were under classification size ranged between 250-500 m² which were needed to enlargethe plot size for operating 4-row walking type transplanter in an efficient manner. On the other hand, 4% plots were belonged to the size less than 250 m² in Barisal division, which were not suitable to operate the 4-row walking type transplanter.

Table 3a Classification of plot based on size in the survey locations of Barisal division

District	Plot size, m²				
	<250	250-500	500-750	750-1000	>1000
	% of total sample in the respective district				
Barguna	7	23	18	19	33
Barisal	1	22	19	20	38
Jhalokathi	13	37	21	10	19
Patuakhali	1	9	16	17	57
Pirojpur	0	19	32	22	27
Average	**4**	**22**	**21**	**18**	**35**

Source: Field survey 2017

Table 3b shows that the survey locations of Chittagong (22%) and Lakshmipur (10%) districts dominated the largest share of smaller plots (<250m²) than other districts in the survey areas of Chittagong division. Most of the plots in Brahmanbaria (82%), Chandpur (82%) and Feni (58%) possessed the sizes more than 750 m². It was observed that very few plots belonged to the sizes more than 1000 m² in Chittagong district. In the survey locations, 73% of total plots ranged between 500->1000 m², which were suitable for operating the 4-row walking type transplanter. On the other hand, 21% plots were categorized under 250-500 m² which were needed further enlargement of plot size to operate the 4-row walking type transplanter in an efficient manner. On average, 7% plots were categorized as below 250 m² in Chittagong division, which was not suitable to operate the 4-row walking type transplanter.

Table 3b Classification of plot based on size in the survey locations of Chittagong division

District	Plot size, m²				
	<250	250-500	500-750	750-1000	>1000
	% of total sample				
Brahmanbaria	0	3	15	27	55
Chandpur	0	8	10	18	64
Chittagong	22	40	20	11	7
Comilla	9	23	19	17	32
Feni	4	17	21	24	34
Lakshmipur	10	30	26	13	21
Noakhali	3	23	29	20	25
Average	**7**	**21**	**20**	**19**	**34**

Source: Field survey 2017

Table 3c describes that the survey locations of Tangail-Ghatail (45%), Faridpur-Bhanga (22%) and Kishoreganj (16%) districts dominated the largest share of smaller plots (<250m²). Most of the plots in Madaripur (88%), Gopalganj-Kashiani (76%), Gopalganj-Muksudpur (68%), Gazipur (66%) and Dhaka (62%) districts possessed the sizes more than 750 m². On average, 69% plots were categorized as 500->1000 m² in Dhaka division. Those plots were suitable to operate 4-row walking type transplanter efficiently with reducing the turning events. On the other hand, 20% plots were categorized under 250-500 m², which needed further enlargement of plot size to operate the 4-row walking type transplanter in an efficient manner. However, 11% plots were categorized as below 250 m² in the survey locations of Dhaka division which were not suitable to operate the 4-row walking type transplanter.

Table 3c Classification of plot based on size in the survey locations of Dhaka division

District	Plot size, m^2				
	<250	250-500	500-750	750-1000	>1000
	% of total sample				
Dhaka	9	13	16	20	42
Faridpur	22	36	13	12	17
Gazipur	0	11	23	17	49
Gopalganj-Kashiani	0	9	15	18	58
Gopalganj-Muksudpur	3	11	18	19	49
Kishoreganj	16	36	23	13	12
Madaripur	1	4	17	26	52
Rajbari	4	26	35	12	23
Tangail- Dhanbari	8	27	25	15	25
Tangail- Ghatail	45	24	17	8	6
Average	**11**	**20**	**21**	**16**	**32**

Source: Field survey 2017

In the survey locations of Khulna division, morethan 10% plots in Khulna (22%), Jhenaidah (15%), Bagerhat (14%), Chuadanga (12%), Kushtia (13%) and Satkhira (12%) districts belonged to the sizes of <250 m^2 (Table 3d). Most of the plots in Jessore (67%) and Satkhira (51%) districts possessed the sizes more than 750 m^2. At present, 58% plots were categorized as 500->1000 m^2, which were suitable to operate 4-row walking type transplanter efficiently. On the other hand, 31% plots were categorized under 250-500 m^2, which needed further enlargement of plot size to operate the 4-row walking type transplanter in an efficient manner. On average, 11% plots were categorized as below 250 m^2 in Khulna division which were not suitable to operate the 4-row walking type transplanter.

Table 3d Classification of plot based on size in the survey locations of Khulna division

District	Plot size, m²				
	<250	250-500	500-750	750-1000	>1000
	% of total sample				
Bagerhat	14	29	20	26	11
Chuadanga	12	32	25	13	18
Jessore	1	9	23	30	37
Jhenaidah	15	37	22	15	11
Khulna	16	42	24	10	8
Kushtia	13	34	18	18	17
Magura	5	27	27	12	29
Meherpur	14	45	19	7	15
Satkhira	12	24	13	12	39
Average	**11**	**31**	**21**	**16**	**21**

Source: Field survey 2017

Table 3e shows that plot sizes of less than 250 m² accounted more than 10% in the survey areas of Jamalpur (21%), Mymensingh (17%) and Sherpur (13%) districts. The plot sizes of 500->1000 m² accounted 53% in the survey areas of Mymensingh division. Those plots were suitable to operate 4-row walking type transplanter. On average, 32% of total plots were categorized under 250-500 m², which were needed further enlargement to operate the 4-row walking type transplanter in an efficient manner. Table 3f also shows that the suitability of 4-row walking type transplanter was restricted in 15% plots due to smaller in size (<250 m²) in Mymensinghdivision.

Table 3e Classification of plot based on size in the survey locations of Mymensingh division

District	Plot size, m²				
	<250	250-500	500-750	750-1000	>1000
	% of total sample				
Jamalpur	21	34	20	12	13
Mymensingh	17	35	19	15	14
Netrakona	9	34	28	15	14
Sherpur	13	25	21	9	32
Average	**15**	**32**	**22**	**13**	**18**

Source: Field survey 2017

The distribution of plots sizes reflected that different sizes of plots were prevailed in the survey areas of Rajshahi division (Table 3f). Chapainawabgonj (21%) and Bogra (10%) districts possessed the highest small plots (<250m²) than other districts of Rajshahi division. Most of the plots in Joypurhat (67%), Naogaon (62%) and Sirajganj (50%) districts dominated the sizes more than 750 m². Very few larger sizes of plots (>1000 m²) were observed in the survey areas of Chapainawabganj and Natore districts. At the moment, 65% plots were categorized under classification of 500->1000 m². Those plots were suitable to operate 4-row walking type transplanter efficiently. However, 28% of total plots were categorized as 250-500 m²which was needed further enlargement of plot size to operate the 4-row walking type transplanter in an efficient manner. Besides, 7% plots were categorized as below 250 m² in Rajshahi division which were not suitable to operate the 4-row walking type transplanter.

Table 3f Classification of plot based on size in the survey locations of Rajshahi division

District	Plot size, m²				
	<250	250-500	500-750	750-1000	>1000
	% of total sample				
Bogra	10	29	38	10	13
Chapainawabganj	21	52	13	9	5
Joypurhat	0	14	19	16	51
Naogaon	1	15	22	17	45
Natore	8	26	46	13	7
Pabna	6	33	29	9	23
Rajshahi	7	35	31	13	14
Sirajganj	6	22	22	18	32
Average	**7**	**28**	**28**	**13**	**24**

Source: Field survey, 2017

In Rangpur division, the largest share of smaller plots (<250 m²) were observed in the survey areas of Panchgarh (54%) followed by Kurigram (34%) districts (Table 3g). The largest share of plot sizes having 250-500 m² were obtained in Dinajpur (72%) followed by Kurigram (52%) districts. The distribution patterns indicated that the plot sizes more than 750 m² accounted 57-64% of total plots inthe survey locations of Rangpur and Lalmonirhat districts. On average, 44% of total plots were under the category of 500->1000 m². Those plots were suitable to operate 4-row walking type transplanter efficiently. On the other hand, 37% plots were categorized under 250-500 m² which were needed further enlargement of plot size to operate the 4-row walking type transplanter in an efficient manner. However, 19% plots were categorized as below 250 m² in Rangpur division, which were not suitable to operate the 4-row walking type transplanter.

Table 3g Classification of plot based on size in the survey locations of Rangpur division

District	Plot size, m²				
	<250	250-500	500-750	750-1000	>1000
	% of total sample				
Dinajpur	18	72	10	0	0
Gaibandha	15	32	30	14	9
Kurigram	34	52	11	2	1
Lalmonirhat	5	17	21	26	31
Panchgarh	54	35	7	3	1
Rangpur	4	18	14	26	38
Thakurgaon	4	36	22	19	19
Average	**19**	**37**	**17**	**13**	**14**

Source: Field survey 2017

The survey locations of Sylhet (19%) district dominated the largest share of smallerplots (<250m²) than the other districts of Sylhet division (Table 3h). Most of the plots in Habiganj (88%) and Sunamganj (86%) and Moulavibazar (65%) districts dominated the plot sizes more than 500 m². On an average, 71% of total plots were categorized as 500->1000 m² and those plots were suitable to operate 4-row walking type transplanter efficiently. On the other hand, 23% of total plots were categorized under 250-500 m², which were needed further enlargement of plot size to operate the 4-row walking type transplanter in an efficient manner. Besides, 6% plots were categorized as below 250 m² in Sylhet division which were not suitable to operate the 4-row walking type transplanter.

Table 3h Classification of plot based on size in the survey locations of Sylhet division

District	Plot size, m²				
	<250	250-500	500-750	750-1000	>1000
	% of total sample				
Habiganj	0	12	17	31	40
Moulavibazar	4	31	23	24	18
Sunamganj	2	12	19	22	45
Sylhet	19	37	27	13	4
Average	**6**	**23**	**22**	**23**	**27**

Source: Field survey 2017

Figure 1 shows that most of the plots (63% of total) under this study were ranged from 500-1000 m². The highest field capacity of 4-row mechanical rice transplanter will be obtained in 26% land due to larger in size (>1000 m²). Therefore, the plots sizes having more than 1000 m² do not need to enlarge further. The plot sizes of 750-1000 m² accounted 16% and offered optimum field capacity for transplanter. The plot sizes of 500-750 m² accounted 21% and offered reasonable field capacity for transplanter. There is a little burden to enlarge those plots having the sizes of 500-1000 m². The plot sizes of 250-500 m² accounted 27% land area and offered low field capacity due to frequent turning events and small space in headland operation. Emphasis has to be given to enlarge those plots having the sizes of 250-500 m² for operating 4-row walking type rice transplanter machine in an efficient manner. Only 10% land belonged to the areas below 250 m² which were not suitable to operate the 4-row walking type transplanter. Slow and fast operation of the farm machines were frequently happened during operation in the small size of plots due to more turning events. Those kind of plots incurred huge loss of time and fuel during turning which were not recommended for operating 4-row walking type rice transplanter due to more turning events and less maneuverability of machine. Those plots should be avoided to operate transplanter in commercial purpose. Emphasis has to be given to enlarge those plots to a great extent for operating the rice transplanter in an efficient manner. Islam *et al.* (2015) observed that among the transplanting plots, 15% were under <400 m² and 14% were under 450-550 m² in Bogra region. The authors also recommended the minimum plot sizes of 400 m² for operating 6-row ride on type transplanter due to requirement of more space during turning.

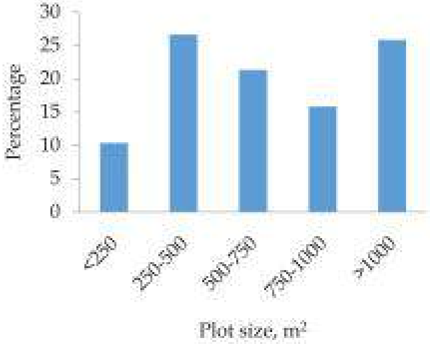


Fig. 1 Plot size in the survey locations

Distribution of plot length

Chapter IV reveals that plot length has great influence on the efficient operation of 4-row walking type transplanter. Plot length having less than 25 m increased the frequent turning events and decreased the performance of the transplanter (Fig. 6b in chapter IV).

The classification of plot based on length indicated that the plot length having less than 25 m accounted 12-37% in Barguna, Jhalokathi and Pirojpur districts in Barisal division (Table 4a). Most of the plots in the survey area of Jhalokathi (37%) district were lower than the length of 25 m. Therefore, length of those plots should be increased to more than 25 m to get the less turning events of the transplanter. Currently, 65% of total plots were under the classification of plot length 35->55 m, which were not needed to enlarge the length. On the other hand, 19% of total plots were categorized under the length of 25-35 m which may need further enlargement to get the better performance of the 4-row walking type transplanter by reducing the turning events. However, 15% of total plots were grouped as plot length below 25 m in Barisal division, which were not suitable to operate the 4-row walking type transplanter in an efficient manner. The length of those plots should be enlarged to more than 25 m to get the good machine performance.

Table 4a Classification of plot based on length in the survey locations of Barisal division

District	Plot length, m				
	<25	25-35	35-45	45-55	>55
	% of total sample				
Barguna	12	15	20	18	35
Barisal	6	21	24	10	39
Jhalokathi	37	24	20	9	10
Patuakhali	4	10	26	5	55
Pirojpur	17	27	29	14	13
Average	**15**	**19**	**24**	**11**	**30**

Source: Field survey 2017

In Chittagong division, the survey area of Chittagong (48%) and Lakshmipur (32%) districts dominated the largest share of plot length having less than 25 m (Table 4b). Therefore, length of those plots should be increased to morethan 25 m in all the districts except Chandpurto get the less turning events of the transplanter. Among all other districts in Chittagong division, Brahmanbaria and Chandpur districts indicated the largest share of plot length having more than 45 m. At present, 58% plots were under the category of plot length 35>55 m, which were not needed to enlarge. On average, 24% plots were classified under the length of 25-35 m, which may need further enlargement to get the better performance of the 4-row walking type transplanter by reducing the turning events. Besides, 17% plots were under the plot length of below 25 m in Chittagong division, which were not suitable to operate the 4-row walking type transplanter in an efficient manner. The length of those plots should be enlarged to more than 25 m to get the good machine performance.

Table 4b Classification of plot based on length in the survey locations in Chittagong division

District	Plot length, m				
	<25	25-35	35-45	45-55	>55
	% of total sample				
Brahmanbaria	2	8	22	38	30
Chandpur	0	14	44	18	24
Chittagong	48	26	15	7	4
Comilla	14	42	18	25	1
Feni	11	27	30	31	1
Lakshmipur	32	20	17	24	7
Noakhali	14	34	22	19	11
Average	**17**	**24**	**24**	**23**	**11**

Source: Field survey, 2017

Table 4c describes that the plot length having less than 25 m accounted more than 10% in the survey areas of all districts except Gazipur, Gopalganj-Kashiani, Gopalganj-Muksudpur and Madaripur districts in Dhaka division. Dhaka, Gazipur, Gopalganj -Kashiani, Gopalganj-Muksudpur and Madaripur districts accounted the largest share of plot length having more than 45m. At present, 56% plots were under the category of plot length 35->55 m which were not needed to enlarge the length. On average, 21% plots were classified under the length of 25-35 m, which may need further enlargement to get the better performance of the 4-row walking type transplanter by reducing the turning events. Besides, 15% plots were grouped as plot length below 25 m in Dhaka division, which were not suitable to operate the 4-row walking type transplanter in an efficient manner. The length of those plots should be enlarged to more than 25 m to get the good machine performance.

Table 4c Classification of plot based on length in the survey locations in Dhaka division

District	Plot length, m				
	<25	25-35	35-45	45-55	>55
	% of total sample				
Dhaka	16	12	14	14	44
Faridpur	43	25	9	4	19
Gazipur	1	15	22	17	45
Gopalganj-Kashiani	5	21	20	23	31
Gopalganj-Muksudpur	8	15	19	17	41
Kishoreganj	52	33	7	4	4
Madaripur	0	11	39	27	23
Rajbari	17	31	25	7	20
Tangail- Dhanbari	19	26	26	11	18
Tangail- Ghatail	68	13	10	7	2
Average	**24**	**21**	**19**	**13**	**24**

Source: Field survey, 2017

Table 4d states thatthe classification of plot based on length in the survey areas of Khulna division. The survey areas of Chuadanga (31%), Bagerhat (28%), Kushtia (24%), Jhenaidah (23), Khulna (21%), Meherpur (20%), Magura (17%) and Satkhira (16%) districts dominated the largest share of plot length having less than 25 m. Very few plots having the length more than 45 m were observed in Khulna, Kushtia and Magura districts. At present, 47% plots are under the category of plot length 35->55 m, which were not needed to enlarge the length. On average, 33% plots were classified under the length of 25-35 m which may need further enlargement to get the better performance of the 4-row walking type transplanter by reducing the turning events. However, 20% plots were grouped as plot length below 25 m in Khulna division, which were not suitable to operate the 4-row walking type transplanter in an efficient manner. The length of those plots should be enlarged to more than 25 m to get the good machine performance.

Table 4d Classification of plot based on length in the survey locations in Khulna division

District	Plot length, m				
	<25	25-35	35-45	45-55	>55
	% of total sample				
Bagerhat	28	24	34	14	0
Chuadanga	31	27	22	12	8
Jessore	2	27	27	25	19
Jhenaidah	23	38	15	12	12
Khulna	21	42	22	6	9
Kushtia	24	45	15	5	11
Magura	17	33	16	8	26
Meherpur	20	14	24	22	20
Satkhira	16	28	14	21	21
Average	**20**	**33**	**21**	**13**	**13**

Source: Field survey 2017

Table 4e shows that the survey locations of Mymensingh (43%), Jamalpur, (39%), Netrakona (38%) and Sherpur (27%) dominated the largest share of plot length having less than 25 m in Mymensingh division. The plot length having more than 45 m accounted 13-23% in all the survey areas of Mymensingh division. At present, 31% plots were under the category of plot length 35- > 55 m which were not needed to enlarge the length. On the other hand, 32% plots were classified under the length of 25-35 m which may need further enlargement to get the better performance of the 4-row walking type transplanter by reducing the turning events. On average, 37% plots were grouped as plot length of below 25 m in Mymensinghdivision which were not suitable to operate the 4-row walking type transplanter in an efficient manner. The length of those plots should be enlarged to more than 25 m to get the good machine performance.

Table 4e Classification of plot based on length in the survey locations in Mymensingh division

District	Plot length, m				
	<25	25-35	35-45	45-55	>55
	% of total sample				
Mymensingh	43	25	11	8	13
Sherpur	27	36	14	11	12
Jamalpur	39	28	20	7	6
Netrakona	38	38	11	8	5
Average	**37**	**32**	**14**	**8**	**9**

Source: Field survey 2017

In Rajshahi division, the survey areas of Chapainawabganj (50%), Bogra (33%), Natore (26%) and Rajshahi (21%) districts were accounted for the largest share of plot length having less than 25 m (Table 4f). Most of the plots in Rajshahi division belonged to the length having 25-35 m. At present, 41% of total plots were under the category of plot length 35->55 m which are not needed to enlarge. On the other hand, 38% of total plots were classified under the length of 25-35 m, which may need further enlargement to get the better performance of the 4-row walking type transplanter by reducing the turning events. On average, 21% plots were grouped as plot length of below 25 m in Rajshahi division, which was not suitable to operate the 4-row walking type transplanter in an efficient manner. The length of those plots should be enlarged to more than 25 m to get good machine performance.

Table 4f Classification of plot based on length in the survey locations in Rajshahi division

District	Plot length, m				
	<25	25-35	35-45	45-55	>55
	% of total sample				
Bogra	33	48	15	1	3
Chapainawabganj	50	32	3	15	0
Joypurhat	2	34	30	16	18
Naogaon	10	27	28	20	15
Natore	26	47	22	4	1
Pabna	10	36	20	15	19
Rajshahi	21	50	23	5	1
Sirajganj	16	28	26	15	15
Average	**21**	**38**	**21**	**11**	**9**

Source: Field survey2017

The distribution pattern on plot length indicates that the survey areas of Dinajpur (76%), Panchagarh (56%), Gaibandha (37%) and Thakurgaon (34%) districts under Rangpur division dominated the largest share of plot length having less than 25 m (Table 4g). The plot length having more than 45m was accounted 39 and 30% in Rangpur and Lalmonirhat districts. At present, 31% plots are under the category of plot length 35->55 m, which are not needed to enlarge. On the other hand, 29% of total plots were classified under the length of 25-35 m which may need further enlargement to get the better performance of the 4-row walking type transplanter by reducing the turning events. On average, 40% plots were grouped as plot length of below 25 m in Rangpur division, which was not suitable to operate the 4-row walking type transplanter in an efficient manner. Plot length should be increased to more than 25 m in all the districts under Rangpur division to get the less turning events of the transplanter.

Table 4g Classification of plot based on length in the survey locations in Rangpur division

District	Plot length, m				
	<25	25-35	35-45	45-55	>55
	% of total sample				
Rangpur	10	22	29	21	18
Lalmonirhat	12	23	35	11	19
Dinajpur	76	24	0	0	0
Thakurgaon	34	39	17	6	4
Panchgarh	56	35	3	4	2
Gaibandha	37	33	20	10	0
Kurigram	52	30	10	4	4
Average	**40**	**29**	**16**	**8**	**7**

Source: Field survey 2017

Table 4h states that the survey areas of Sylhet (37%) and Moulavibazar (16%) districts under Sylhet division dominated the largest share of plot length having less than 25 m. Plot length should be increased to more than 25 m in all the districts except Habiganj to get the less turning events of the transplanter. The plot length having 25-35 m was accounted 20-41% in the survey areas of Sylhet division. Moderate field performance of transplanter was obtained in those areas. The plot length having more than 55 m was accounted 31 and 14% in Sunamganj and Habiganj districts. At present, 45% plots were under the category of plot length 35->55 m which are not needed to enlarge. On the other hand, 31% plots were classified under the length of 25-35 m, which may need further enlargement to get the better performance of the 4-row walking type transplanter by reducing the turning events. On average, 15% plots were grouped as plot length of below 25 m in Sylhet division, which was not suitable to operate the 4-row walking type transplanter in an efficient manner. The length of those plots should be enlarged to more than 25 m to get the good machine performance.

Table 4h Classification of plot based on length in the survey locations in Sylhet division

District	Plot length, m				
	<25	25-35	35-45	45-55	>55
	% of total sample				
Sylhet	37	31	22	10	0
Sunamganj	5	20	28	16	31
Moulavibazar	16	31	28	19	6
Habiganj	1	41	32	12	14
Average	**15**	**31**	**28**	**14**	**13**

Source: Field survey 2017

Turning events and maneuverability depended on the length of the plot. Plots having larger lengths substantially reduced the time loss, hence increased the field capacity of the farm machine. The length of plots available in the study areas was mostly (49%) between 35 to more than 55 m (Fig.2). On average, 28% plots were classified under the length of 25-35 m. Little emphasis should be given to enlarge those plots to get the better performance of the 4-row walking type transplanter by reducing the turning events. The plot length having less than 25 m accounted 23% are not suitable for operating farm machinery especially 4-row mechanical rice transplanter due to frequent turning events. Plot length should be increased to more than 25 m in all the districts to get the less turning events of the transplanter.

During turning, press the left/right clutch depending on the turning direction, make position and start transplanting operation. Extra time, energy and fuelwere needed to perform those tasks. More turning events increased the turning loss. The length of plot can be enlarged through mutual cooperation of the land owner by keeping the plot sizes same.

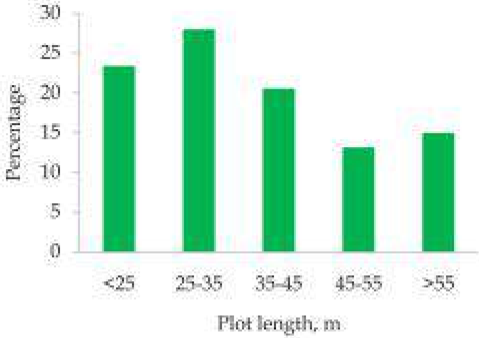


Fig. 2 Plot length in the survey locations

Distribution of plot shape

Machine performance depended on the shape of the plots. Plot shape has great influence on the efficient operation of 4-row walking type transplanter. The irregular shape of plot decreased the performance of the transplanter (Fig. 9 in Chapter IV). Irregular shape of plots influenced the intervention of manual labor in transplanting. Shape characteristics of the agricultural plots were divided into four categories depending on the percent uniformity of plot shape which was measured by eye estimation. The categories were as irregular (>4%), moderately irregular (2-4%), moderately regular (1-2%) and regular (<1%).The classification of plot shape is described in the following section.

Table 5a shows the classification on the uniformity of plot shape in the survey areas of Barisal division. Most of the plots were found in regular and moderately regular shape in Barisal division. The plots having moderately irregular and irregular shape accounted 25 and 13% plot areasin Jhalokathi and Barguna districts compared to other districts in Barisal division. On average, 11% of the total plot areas were categorized as moderately irregular and irregular shape in Barisal division where transplanter was inaccessible and initiated manual labor to transplant seedlings. Those portions of land should be reshaped to ensure the accessibility of transplanter machine.

Table 5a Classification of plot based on uniformity in the survey locations of Barisal division

District	Regular	Moderately regular	Moderately irregular	Irregular
	% of total sample			
Barguna	56	31	11	2
Barisal	65	29	6	0
Jhalokathi	35	40	22	3
Patuakhali	77	21	2	0
Pirojpur	50	46	4	0
Average	**59**	**30**	**10**	**1**

Source: Field survey 2017

The highest portions of regular shape of plots were observed in the survey areas of Brahmanbaria (91%), Chandpur (88%) and Feni (73%) districts compared to other districts in Chittagong divisions (Table 5b). Chittagong (24%), Lakshmipur (15%) and Comilla (12%) districts possessed the largest portions of moderately irregular shape of plots. On average, 10% of plot areas were categorized as moderately irregular and irregular shape in Chittagong division where transplanter was inaccessible and initiated manual labor to transplant seedlings. Those portions of land should be reshaped to ensure the accessibility of transplanter machine.

Table 5b Classification of plot based on uniformity in the survey locations of Chittagong division

District	Regular	Moderately regular	Moderately irregular	Irregular
	% of total sample			
Brahmanbaria	91	8	1	0
Chandpur	88	11	1	0
Chittagong	25	45	24	6
Comilla	56	32	12	0
Feni	73	23	4	0
Lakshmipur	49	35	15	1
Noakhali	60	35	4	1
Average	**63**	**27**	**9**	**1**

Source: Field survey 2017

The survey areas of Dhaka (95%), Tangail-Ghatail (87%), Gazipur (76%), Madaripur (71%) and Tangail- Dhanbari (51%) districts dominated the largest portion of regular shape of plots compared to the other districts in Dhaka division (Table 5c). Very few portions of plots were observed as regular in shape in Faridpur district (3%). Most of the plots in the survey areas especially Faridpur (75%) and Gopalganj-Muksudpur (43%) possessed the largest share of irregular and moderately irregular shape of plots.In the survey areas of Dhaka division, 23% of total plot areas were observed as moderately irregular and irregular shape whereas the rests of the plots were regular and moderately regular in shape in different magnitude. The transplanter was inaccessible in 23% plot areas and initiated manual labor to transplant seedlings. Those portions of plots should be reshaped to ensure the accessibility of transplanter machine.

Table 5c Classification of plots based on uniformity in the survey locations of Dhaka division

District	Regular	Moderately regular	Moderately irregular	Irregular
	% of total sample			
Dhaka	95	4	1	0
Faridpur	3	22	42	33
Gazipur	76	21	3	0
Gopalganj-Kashiani	26	60	9	5
Gopalganj-Muksudpur	17	40	24	19
Kishoreganj	38	32	20	10
Madaripur	71	24	4	1
Rajbari	22	40	30	8
Tangail-Dhanbari	51	26	18	5
Tangail- Ghatail	87	6	5	2
Average	**51**	**26**	**15**	**8**

Source: Field survey 2017

In the survey areas of Khulna division, Satkhira (99%), Bagerhat (98%), Jhenaidah (96%), Jessore (82%), Meherpur (74%), Magura (68%), Kushtia (56%) and Chuadanga (58%) districts dominated the largest portion of the regular and moderately regular shape of plots (Table 5d). The distribution pattern also indicated that Chuadanga and Khulna districts dominated the largest share of irregular shape of plots compared to other districts in Khulna division. However, 28% plot areas were categorized as irregular and moderately irregular shape in Khulna division, where transplanter was inaccessible and initiated manual labor to transplant seedlings. Those portions of land should be reshaped to ensure the accessibility of transplanter machine.

Table 5d Classification of plot based on uniformity in the survey locations of Khulna division

District	Regular	Moderately regular	Moderately irregular	Irregular
	% of total sample			
Bagerhat	82	16	2	0
Chuadanga	20	38	17	25
Jessore	35	47	14	4
Jhenaidah	21	48	26	5
Khulna	4	27	44	25
Kushtia	16	40	35	9
Magura	28	38	30	4
Meherpur	34	40	22	4
Satkhira	79	20	1	0
Average	**36**	**36**	**22**	**6**

Source: Field survey 2017

Table 5e describes the classification on the uniformity of plot shape in the survey areas of Mymensingh division. It was observed that 66-85% of total plot areas in each plot were categorized as regular and moderately regular in shape whereas rests of the plots were irregular in shape in different magnitude. In Mymensingh division, 3-7% areas were grouped as irregular shape. At present, 15% of total plot areas were categorized as irregular and moderately irregular shape in Mymensingh division where transplanter was inaccessible and initiated manual labor to transplant seedlings. Those portions of land should be reshaped to ensure the accessibility of transplanter machine.

Table 5e Classification of plot based on uniformity in the survey locations of Mymensingh division

District	Regular	Moderately regular	Moderately irregular	Irregular
	% of total sample			
Jamalpur	38	28	27	7
Mymensingh	55	30	12	3
Netrakona	47	29	18	6
Sherpur	56	24	14	6
Average	**55**	**30**	**12**	**3**

Source: Field survey 2017

In Rajshahi division, the distribution pattern on the uniformity of plot shape indicated that very few portions of plots having regular in shape were observed in the survey areas of Chapainawabganj (5%) and Natore (13%) districts (Table 5f). Most of the portion of plots in the survey areas of Chapainawabganj (48%), Rajshahi (41%), Natore (33%) and Naogaon (21%) districts possessed the irregular and moderately irregular in shape. On average, 25% areas were categorized as irregular and moderately irregular shape in Rajshahidivision where transplanter was inaccessible and initiated manual labor to transplant seedlings. Those portions of land should be reshaped to ensure the accessibility of transplanter machine.

Table 5f Classification of plot based on uniformity in the survey locations of Rajshahi division

District	Regular	Moderately regular	Moderately irregular	Irregular
	% of total sample			
Bogra	42	33	20	5
Chapainawabganj	5	47	36	12
Joypurhat	64	34	2	0
Naogaon	25	54	16	5
Natore	13	54	30	3
Pabna	40	42	18	0
Rajshahi	16	43	36	5
Sirajganj	45	40	10	5
Average	**32**	**43**	**20**	**5**

Source: Field survey 2017

In Rangpur division, most of the plots in the survey areas of Lalmonirhat (93%), Rangpur (84%), Gaibandha (78%), Kurigram (78%), Dinajpur (77%), Thakurgaon (74%) and Panchgarh (74%) districts possessed the regular and moderately regular shape (Table 5g). The highest portion of plots having moderately irregular and irregular shape was observed in the survey area of Thakurgaon (26%), Panchgarh (26%), Dinajpur (23%) and Kurigram (22%) districts compared to other districts in Rangpur division which influenced the manual transplanting. The least amount of irregular shape (4-8%) of plots was observed in Rangpur, Dinajpur and Thakurgaon districts. Currently, 19% areas were categorized as irregular and moderately irregular shape in Rangpur division where transplanter was inaccessible and initiated manual labor to transplant seedlings. Those portions of land should be reshaped to ensure the accessibility of transplanter machine.

Table 5g Classification of plot based on uniformity in the survey location of Rangpur division

District	Regular	Moderately regular	Moderately irregular	Irregular
	% of total sample			
Dinajpur	43	34	17	6
Gaibandha	52	35	9	4
Kurigram	48	30	16	6
Lalmonirhat	79	14	7	0
Panchgarh	53	21	18	8
Rangpur	50	34	10	6
Thakurgaon	42	32	20	6
Average	**53**	**28**	**14**	**5**

Source: Field survey 2017

Table 5h stated the distribution pattern on the uniformity of plot shape in the survey areas of Sylhet division. In the survey areas of Habiganj (99%), Moulavibazar (89%), Sunamganj (87%) and Sylhet (71%) districts dominated the largest share of regular and moderately regular shape of plots whereas rests of the portion were irregular in shape in different magnitude (Table 5h). The highest portion of moderately irregular and irregular shape of plots was observed in the survey area of Sylhet district (29%). On average, 11% of total plot areas were categorized as irregular and moderately irregular shape in Sylhet division where transplanter was inaccessible and initiated manual labor to transplant seedlings. Those portions of land should be reshaped to ensure the accessibility of transplanter machine.

Table 5h Classification of plot based on uniformity in the survey location of Sylhet division

District	Regular	Moderately regular	Moderately irregular	Irregular
	% of total sample			
Sylhet	25	46	26	3
Sunamganj	79	18	3	0
Moulavibazar	48	41	11	0
Habiganj	79	20	1	0
Average	**58**	**31**	**10**	**1**

Source: Field survey 2017

The shape characteristics of the plots showed noticeable share of irregular portion. Irregular shape of plots caused extra travel, offered low transplanting capacity and high cost. Machines are unable to transplant in the pocket area due to inaccessibility, which influenced the manual transplanting (Islam *et al.*, 2015). The shape of the plots should be converted to regular shape to harness the benefit of mechanized transplanting by escaping the burden of manual transplanting. On average, 5% areas were categorized as irregular shape where transplanter was inaccessible and initiated manual labor to transplant seedlings (Fig. 3). Those portions of lands should be reshaped to ensure the accessibility of transplanter machine. On the other hand, 15% plots were categorized as moderately irregular shape and little efforts were needed to reshape those lands in order to access the transplanter machine for transplanting rice seedlings.

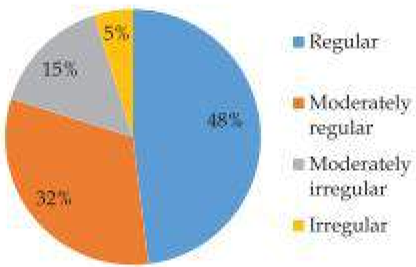


Fig. 3 Plot shape in the survey locations

Distribution of plot length-width ratio

The plot L/W ratio has great influence on the performance of farm machinery. Length wise operation of farm machinery is preferable to minimize the turning events. Plot length should be increased by keeping the same plot size.

Table 6a describes the classification of plot length-width (L/W) ratio in the survey areas of Barisal division. The plot L/W ratio of 1-1.5 was accounted 20-22% in Barisal, Barguna and Patuakhali districts and 34-44% in Pirojpur and Jhalokathi districts. The distribution pattern also shows that more than 60% plots of Barisal, Barguna and Patuakhali districts were observed as greater than the L/W ratio of 2. On average, L/W ratio of 1-1.5, 1.6-2.0 and >2 accounted 24, 19 and 57% land, respectively in Barisal division.

Table 6a Classification of plot based on plot length-width ratio in the survey locations of Barisal division

District	Plot length-width ratio		
	1-1.5	1.6-2.0	>2
	% of total sample		
Barisal	20	17	63
Barguna	22	16	62
Patuakhali	21	17	62
Jhalokathi	34	27	39
Pirojpur	44	29	27
Average	**24**	**19**	**57**

Source: Field survey 2017

Table 6b shows that L/W ratio of 1-1.5 was observed in the largest portion of lands (43-47%) in the survey areas of Chandpur, Chittagong, Comilla and Feni districts under Chittagong division. The L/W ratio of 2 was observed in more than 30% plots in all the districts except Comilla district in Chittagong division. On average, L/W ratio of 1-1.5, 1.6-2.0 and >2 accounted 39, 24 and 37% land, respectively in Chittagong division.

Table 6b Classification of plot based on plot length-width ratio in the survey locations of Chittagong division

District	Plot length-width ratio		
	1-1.5	1.6-2.0	>2
	% of total sample		
Brahmanbaria	23	24	53
Chandpur	46	18	36
Chittagong	43	23	34
Comilla	47	24	29
Feni	43	25	32
Lakshmipur	36	29	35
Noakhali	38	23	39
Average	**39**	**24**	**37**

Source: Field survey 2017

In Dhaka division, the classification on L/W ratio showed that very few portion of plots (7%) were categorized as L/W ratio of 1-1.5 in the survey areas of Gazipur district (Table 6c). Among the districts in Dhaka division, the plots in Kishorganj district accounted (71%) the largest portion of land under L/W ratio of 1-1.5. More than 50% plots belonged to the category of L/W ratio of >2 in Gazipur, Dhaka, Gopalganj-Muksudpur districts. On average L/W ratio of 1-1.5, 1.6-2.0 and >2 accounted 40, 32 and 27% land, respectively in Dhaka division.

Table 6c Classification of plot based on plot length-width ratio in the survey locations in Dhaka division

District	Plot length-width ratio		
	1-1.5	1.6-2.0	>2
	% of total sample		
Dhaka	19	13	68
Faridpur	36	26	38
Gazipur	7	15	78
Gopalganj-Kashiani	47	28	25
Gopalganj-Muksudpur	29	10	61
Kishoreganj	71	18	11
Madaripur	41	24	35
Rajbari	31	16	53
Tangail-Dhanbari	28	28	44
Tangail-Ghatail	17	44	39
Average	**33**	**23**	**44**

Source: Field survey2017

It was observed that L/W ratio of 1-1.5 accounted 30-42% plots in the survey areas of most of the districts in Khulna division (Table 6d). In Meherpur district, the lowest portion of land (12%) was found under the group of L/W ratio of 1-1.5. The L/W ratio of >2 were prevailed in 40-78% land in all the districts except Bagerhat and Kushtia districts. On average, L/W ratio of 1-1.5, 1.6-2.0 and >2 accounted 43, 25 and 32% land, respectively in Khulna division.

Table 6d Classification of plot based on plot length-width ratio in the survey locations of Khulna division

District	Plot length-width ratio		
	1-1.5	1.6-2.0	>2
	% of total sample		
Bagerhat	36	31	33
Chuadanga	30	25	45
Jessore	32	20	48
Jhenaidah	31	23	46
Khulna	25	18	57
Kushtia	42	26	32
Magura	41	18	41
Meherpur	12	10	78
Satkhira	28	32	40
Average	**33**	**24**	**43**

Source: Field survey2017

The survey results showed that L/W of 1-1.5 accounted 35-58% land in the survey areas of Mymensingh division (Table 6e). In Netrakona district, the highest portion of land (58%) was categorized as L/W ratio of 1-1.15. On average, L/W ratio of 1-1.5, 1.6-2.0 and >2 accounted 40, 32 and 27% land, respectively in Mymensingh division.

Table 6e Classification of plots based on plot length-width ratio in the survey locations in Mymensingh division

District	Plot length-width ratio		
	1-1.5	1.6-2.0	>2
	% of total sample		
Jamalpur	35	27	38
Mymensingh	46	20	34
Netrakona	58	29	13
Sherpur	44	39	17
Average	**40**	**32**	**27**

Source: Field survey 2017

In Rajshahi division, the distribution of plot L/W ratio revealed that more than 40% plots were found under the category of L/W ratio of 1-1.5 in the survey areas of Bogra, Natore, Joypurhat, Rajshahi and Chapainawabganj districts (Table 6f). Pabna district (63%) accounted the highest portion of land under L/W ratio of >2 and the lowest in Bogra district (9%). On average, L/W ratio of 1-1.5, 1.6-2.0 and >2 accounted 43, 25 and 32% land, respectively in Rajshahi division.

Table 6f Classification of plot based on plot length-width ratio in the survey locations of Rajshahi division

District	Plot length-width ratio		
	1-1.5	1.6-2.0	>2
	% of total sample		
Bogra	61	30	9
Chapainawabganj	43	24	33
Joypurhat	48	15	37
Naogaon	39	33	28
Natore	51	27	22
Pabna	16	21	63
Rajshahi	47	24	29
Sirajganj	38	19	43
Average	**43**	**25**	**32**

Source: Field survey 2017

Table 6g shows that L/W ratio of 1-1.5 was found the highest in Dinajpur followed by Thakurgaon district under Rangpur division. Plot L/W ratio of 1-1.5 was obtained as 24-45% in survey areas of other districts in Rangpur division. Turning events of farm machinery will be much higher in those areas of Dinajpur and Thakurgaon districts than other districts in Rangpur division. Turning events will be less in those areas where L/W ratio of greater than 2 in the survey areas of Kurigram, Lalmonirhat and Panchgarh districts. On average, L/W ratio of 1-1.5, 1.6-2.0 and>2 accounted 43, 29 and 28% land, respectively in Rangpur division.

Table 6g Classification of plot based on plot length-width ratio in the survey locations of Rangpur division

District	Plot length-width ratio		
	1-1.5	1.6-2.0	>2
	% of total sample		
Dinajpur	74	25	1
Gaibandha	45	31	24
Kurigram	30	23	47
Lalmonirhat	35	23	42
Panchgarh	31	25	44
Rangpur	24	51	25
Thakurgaon	63	27	10
Average	**43**	**29**	**28**

Source: Field survey 2017

In the survey areas of Sylhet division, the largest share of plot L/W ratio of 1-1.5 was observed in Habiganj followed by Sunamganj, Sylhet and Moulavibazar districts (Table 6h). On the other hand, the largest share of plot L/W ratio of greater than 2 was obtained in Sunamganj followed by Moulavibazar, Sylhet and Habiganj district. On average L/W ratio of 1-1.5, 1.6-2.0 and >2 accounted 35, 28 and 37% land, respectively in Sylhet division.

Table 6h Classification of plot based on plot length-width ratio in the survey locations of Sylhet division

District	Plot length-width ratio		
	1-1.5	1.6-2.0	>2
	% of total sample		
Sylhet	35	27	38
Sunamganj	36	22	42
Moulavibazar	24	35	41
Habiganj	45	28	27
Average	**35**	**28**	**37**

Source: Field survey 2017

In short, the plot L/W ratio of 1-1.5 was accounted 37% in the survey areas of Bangladesh (Fig. 4). Turning events of farm machinery will be much higher in those areas. The plot L/W ratio of greater than two was observed in 38% land and turning events will be less in those areas. Moderate turning events will be obtained in 25% plot having the plot L/W ratio of 1.6-2.0. Turning events increase the loss of time, fuel and decrease the field capacity. Taniyama (1975) stated that the operation efficiency of machine generally become higher in proportion to the size of field plots and the L/W ratio of plots. The efficiency of transplanter will be increased with the increase in L/W ratio.

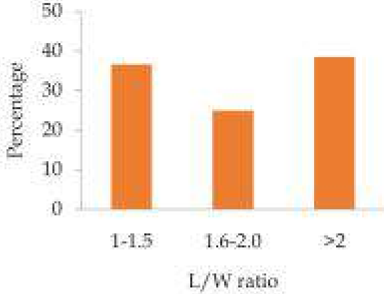


Fig. 4 Plot length-width ratio in the survey locations

Land improvement

Perhaps, fragmentation of agricultural land is not a natural calamity, but human caused problem, which could be consolidated by raising awareness and encouraging farm landowners to get into combine scheme for better production and reducing cost. Bringing uniformity in land shape and combining lands to upgrade to larger land sizes would additionally solve following problems;

- Low operation capacity
- Inaccessibility of farm machine
- Remove pocket areas
- Frequent turning events and
- Large irrigation and drainage channel area

The total reformation process is thus performable through three distinct steps;

- Reshaping (developing uniformity in shape)
- Enlargement of plot size (Consolidation of scattered plots)
- Construction of farm road for machine accessibility

Assumption

Area coverage under *aman* rice cultivation during 2014-15 was 55,30,000 ha (BBS, 2015) in which 30% area is assumed to have inaccessibility of machine and direct seeded rice cultivation (Islam, 2016) i.e. 3,871,000 hectare areasare considered as transplanting service and used in the calculation of land reformation process.

Reshaping

Keeping the plot area same,the reshaping of the existing plots can be done in two ways namely rectangularization and enlargement of plot length.

Rectangularization

Plot shape with unparalleled boundaries caused difficulties to transplant seedlings by mechanical transplanter in non-uniform portion of land and offered low field capacity (Fig. 5). This situation compelled the farmer/entrepreneur for manual transplanting in the same field having pocket area due to inaccessibility of mechanical rice transplanter. Depending on the irregularity in shape, pocket area filling by manual labor required 7-13 man-hr ha^{-1} and consumed additional 4-6 trays ha^{-1} to transplant seedlings. On the other hand, plots with parallel boundaries offered higher field capacity ($ha\ hr^{-1}$), and least or no gap for manual transplanting. Straightening of agricultural plots is thus an obvious need for mechanization in Bangladesh. The irregularity in plot shape can be eliminated by mutual cooperation among the land owners.

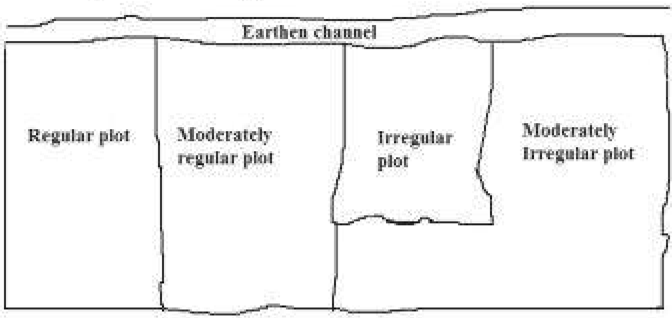


Fig. 5a Existing land condition

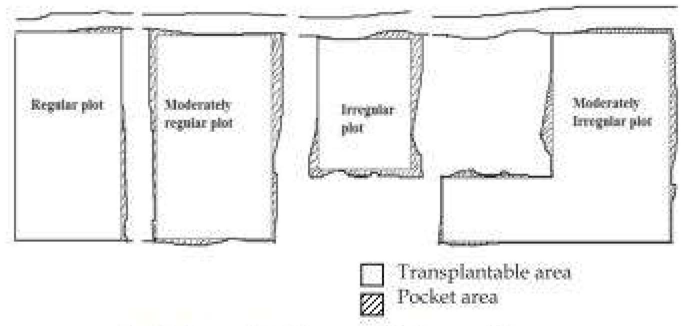


Fig. 5b Transplanter inaccessibility in pocket areas

Enlargement of plot length

The performance of the transplanter depended on the length of the plot. For the same plot area, length wise operation reduced the turning loss (Fig. 10a). Field capacity depended on the turning loss of the plot, which inturn depended on the number of turning events in each plot (Fig. 10b). In order to minimize the turning events, the length of each plot should be enlarged as much as possible. The plot length can be increased in four steps (Table 7). In the first step, change the plot length having less 25 m to 25-35 m would save few amounts of fuel, labor and cost of transplanting. At the second phase, enlarge the plot length to 35-45 m would save 8% fuel, 10% labor (operator) and 11% cost in transplanting. In the third step, enlarge the plot length to 45-55 m would save 10% fuel, 15% labor (operator) and 12% cost in transplanting. At the final step, changing the plots length more than 55 mwould save 11% fuel, 19% labor (operator) and 15% cost in transplanting. From socio-economic perspective of the farmer, it is very difficult, sometimes impossible to reshape the plot in lengthwise. However, mechanization point of view, emphasis should be given to increase the plot length in order to reduce the turning events of the transplanter. Enlarging plot length to more than 55 m would save transplanting cost of Tk 538 million per year.

Table 7 Effect of plot length enlargement on fuel and labor cost

	Length, m	Area, %	Area, ha	Fuel, million L	Labor, million man-hr	Cost, million Tk
Present form	<25	23	890,330	5.10	8.09	945
	25-35	28	1,083,880	6.17	9.03	1,097
	35-45	21	812,910	3.93	5.81	702
	45-55	13	503,230	2.39	3.35	416
	>55	15	580,650	2.72	3.63	463
	Total			**20.32 (100%)**	**29.92 (100%)**	**3,624 (100%)**
Step 1	<25	0	-	-	-	-
	25-35	51	1,974,210	11.233	16.45	1,998
	35-45	21	812,910	3.93	5.81	702
	45-55	13	503,230	2.39	3.35	416
	>55	15	580,650	2.72	3.63	463
	Total			**20.28 (99.82%)**	**26.92 (98%)**	**3,580 (99%)**
Step 2	<25	0	-	-	-	-
	25-35	0	-	-	-	-
	35-45	72	2,787,120	13.49	19.91	2,409
	45-55	13	503,230	2.39	3.35	416
	>55	15	580,650	2.72	3.63	463
	Total			**18.60 (92%)**	**26.89 (90%)**	**3,288 (91%)**
Step 3	<25	0	-	-	-	-
	25-35	0	-	-	-	-
	35-45	0	-	-	-	-
	45-55	85	3,290,350	15.63	21.94	2,723
	>55	15	580,650	2.72	3.63	463
	Total			**18.35 (90%)**	**25.56 (85%)**	**3,186 (88%)**
Step 4	<25	0	-	-	-	-
	25-35	0	-	-	-	-
	35-45	0	-	-	-	-
	45-55	0	-	-	-	-
	>55	100	3,871,000	18.15	24.19	3,086
	Total			**18.15 (89%)**	**24.19 (81%)**	**3,086 (85%)**

Enlargement of plot size

Size of farm machines and their performances are greatly influenced by the plot size. The present form of plot size distribution in Bangladesh is mostly fragmented (74% below 1000 m^2) (Fig. 1). At the present condition, the operation cost of 4-row mechanical transplanter is estimated as Tk 9,251 million. There is a great scope to save transplanting cost by enlarging small plots. Small and medium size plots could be reduced easily by combining plots that belong to same owner. Table 8 presents the effects of plot size enlargement on fuel, labor and cost. Enlarging very small lands (<250 m^2) to small lands (250-500 m^2) could save 1% fuel, labor and cost in transplanting. Further enlarging plots from 250-500 m^2 to 500-700 m^2 could save 6% fuel, 7% labor and 7% cost in transplanting. At third attempt, enlarging plots from 500-750 m^2 to 750-1000 m^2 could save 7% fuel, 11% labor and 9% cost in transplanting. At final stage, enlarging plots from 750-1000 m^2 to >1000 m^2 would save 8% fuel, 85% labor and 11% cost in transplanting. Grouping of scattered field plots or land consolidation is a complicated issue in Bangladesh. Like Japan and Srilanka, land consolidation program may not be applicable here. The farmers will not give consent to exchange their plots due to social security. Difference of the scattered holdings interms of land quality, accessibility and mentality will hamper the land consolidation. The enlargement process is not an easy task. It will jeopardize the social systems. However, from mechanization point of view, enlargement of small plots are very much important to attain the maximum benefit of mechanization. Step by step procedure can be followed to enlarge the plot size. The fragmentation of agricultural lands can be eliminated by mutual cooperation among the land owners, local government and policy makers. Enlarging fragmented land to bigger size (>1000 m^2) would save transplanting cost of Tk 400 million per year.

Table 8 Effect of plot size enlargement on fuel and labor cost

	Plot size, m^2	Area, %	Area, ha	Fuel, million L	Labor, million man-hr	Total cost, million Tk
Present form	<250	10	387,100	2.22	3.52	411
	250-500	27	1,045,170	5.95	8.71	1,058
	500-750	21	812,910	3.93	5.81	702
	750-1000	16	619,360	2.94	4.13	513
	>1000	26	1,006,460	4.72	6.29	802
				19.76 (100%)	**28.45 (100%)**	**3,486 (100%)**
Step 1	<250	0	-	-	-	-
	250-500	37	1,432,270	8.15	11.94	1,450
	500-750	21	812,910	3.93	5.81	702
	750-1000	16	619,360	2.94	4.13	513
	>1000	26	1,006,460	4.72	6.29	802
	Total			**19.75 (99.92%)**	**28.16 (99%)**	**3,467 (99%)**
Step 2	<250	0	-	-	-	-
	250-500	0	-	-	-	-
	500-750	58	2,245,180	10.87	16.04	1,940
	750-1000	16	619,360	2.94	4.13	513
	>1000	26	1,006,460	4.72	6.29	802
	Total			**18.33 (94%)**	**25.39 (93%)**	**3,173 (93%)**
Step 3	<250	0	-	-	-	-
	250-500	0	-	-	-	-
	500-750	0	-	-	-	-
	750-1000	74	2,864,540	13.61	19.10	2,370
	>1000	26	1,006,460	4.72	6.29	802
	Total			**18.33 (93%)**	**25.39 (89%)**	**3,173 (91%)**
Step 4	<250	0	-	-	-	-
	250-500	0	-	-	-	-
	500-750	0	-	-	-	-
	750-1000	0	-	-	-	-
	>1000	100	3,871,000	18.15	24.19	3,086
	Total			**18.15 (92%)**	**24.19 (85%)**	**3,086 (89%)**

Optimum length and size of plot for paddy cultivation

What would be the optimum plot length and size for paddy cultivation where water management can be done efficiently? This is a burning question. Upland farming does not need perfect land leveling to maintain water height in the field. Drainage system should be ensured in upland farming. In case of low land farming, especially paddy cultivation, the land should be sufficiently leveled to maintain uniform water height during transplanting and continuous stagnant water for crop establishment. It is very difficult to maintain constant water height in large size of plot. Smaller sizes of plots are preferable for good water management. On the other hand, machine does not perform well in small size of plot. There must be compromise between machinery performance and water management. The machine performance appeared good in plots having L/W more than 2 and plot length greater than 40 m. Hence, the plot size having 45 × 20 m may be recommended for paddy cultivation. Taniyama (1975) mentioned that Japan standardized the plot size as 100 x 30 meters depending on the convenience of machine turning, length of long and short side. The proposed plot size was lower than that of Japan. We need to consider the present land tenure system, socio-economic condition and mentality of the farmer to reshape and resize the plots. From our country's perspective, we may think to reshapeirregular plots.

Importance of farm road

Type and size of the machinery depended on the accessibility of farm machinery in the plots. Land fragmentation and smaller plot size having irregular shape restricted the movement and smooth operation of the farm machine. Absence of farm road, damaged or earthen road, water logging, irrigation canal, inundation in low lying area, undulated plot hampered the entrance of the farm machines in the plot to perform certain task. Moreover, different types of crops are grown at the same time in each area. For example, during transplanting of *boro* crops, the harvesting of potato is going on in the same locality. Therefore, as the transplanting/seeding time is different consequently harvesting time will be different. Crops are matured in different days and unable to move the machine in the middle of the plots to harvest and start to transplant rice seedlings using mechanical transplanter due to lack of farm road. Sometimes crops were damaged in the neighboring farmer's plot due to movement of farm machinery. Elevation of the rural road is higher than the farm land and difficult to unload/move the machine in the plot. The slop of the road lost the balance of the farm machines and possibility to trip over the machine. Farm road facilitated to transport harvested crops and other agricultural inputs to the nearer of the crop field. Consequently reduced the transportation time and cost. Government intervention and mutual co-operation among the land owners can facilitate the construction of farm road in planned way.

It is important for the machinery operator to know the existing land condtion and the effect on farm machinery operation. It is also necessary to optimize the plot size and shape in terms of efficient machinery and operation and water management in the rice field, which will reduce the time, fuel and energy. Small and fragmented land resulted in low efficiency of transplanter. Sizes of the plots should be more than 250 m^2 to increase the operational efficiency of transplanter. Step by step approach should be followed through government intervention and land owner has to enlarge the dispersed small plots, plot rectangularization, reshaping the plot, land leveling, construction of farm road, improvement of irrigation and drainage facility. Large size of farm machinery even small machines would be spread successfully if land improvement works is undertaken. However, land reshaping or enlargement of plot size may not be possible in the current situation. In such situation, Islam (2015) emphasized the scheduling of machinery operation i.e. plots under commercial operation should be clustered to increase the operational efficiency of farm machine. Mandal (2017) called it as 'operational consolidation' of holdings, which was effective in custom hire service of farm machine. Each country has unique system in wide spread adoption of mechanization. Considering the mechanization system of other country, we should formulate the mechanization system to suit in our country context. Modification and improvement is needed on the imported machinery to suit our present land system. This step will enable the policy makers/ farmers to adopt relevant measures.

CHAPTER VIII

MECHANICAL RICE HARVESTING

Introduction

Rice harvesting is one of the most expensive field activity among all other activities of crop production in Bangladesh. Farmers use sickle for reaping cereal crops, which is quite tedious and labor intensive operation involving human drudgery. Harvesting of paddy using sickle required about 120 to 200 man-hr ha^{-1} and caused a peak labor demand during the harvesting season (Pandey and Devnani, 1981; Haque *et. al.*, 1989). Farmers are compelled to practice delayed harvesting due to shortage of labor, which results in yield loss; sometimes incurred total loss of field crops due to natural disaster. Iqbal *et al*. (1980) found that harvesting losses increased linearly with time, ranging from 3 per cent in the first week to 7 per cent in the third week after maturity of crop. Timely harvesting of the crop is very much important to get the desired yield. Therefore, it is essential to introduce mechanical harvester for rice harvesting in time to reduce the postharvest losses. An efficient harvest depends greatly on pre-harvest management—evenness of field level, variety selection, crop maturity, accessibility of machine into the field, water and nutrient management.

China developed a small harvester machine, which is similar to lawn mower for cutting grass and other cereal crops such as rice, wheat, corn, feed grasses, and shrubs by changing with appropriate cutter attachment (Boshima, 2007). The design feature of this machine was simple, light weight, inexpensive, easy to assemble and disassemble, and very easy to operate. Lawn mower was modified with a light engine (1.5-1.88 kW), high rpm (<4,500) in cutting blade and attachment of swing arm. The circular blade was made detachable and removable. It is expected that low cost small scale hand reaper may be suitable to the socio-economic condition of our farmers. Handaka and Joko Pitoyo (2011) modified commercial lawn mower into a rice harvester machine. Modifications were made on (1) replacing the cutter blade with a rotary blade; (2) changing the dynamic balance of the harvest machine into a mower type; (3) adding a guider and a propeller; and (4) adding an operator belt. . It had a working width ranging from 75 to 100 cm. The test result showed that modified machine had a working capacity of 0.05-0.06 ha hr^{-1}, fuel consumption of 15.0 l ha^{-1}, work efficiency of 95%, and weighing of about 10 kg. The authors also mentioned that the minimum blade rpm was 4,500 for paddy reaping. ACI Motors Ltd., Dhaka and Alim industries Ltd. Sylhet imported hand reaper from China, which was powered by 1.25 kW petrol engine.

Power tiller mounted and self-propelled reaper were introduced in our country to harvest rice and wheat crops. Research organization developed rice-wheat reaper and disseminated throughout the country. Rahman *et al.* (2004) modified a self propelled reaper named SUFALA and tested for field performance and economic evaluation in harvesting wheat and rice. The effective field capacity and field efficiency were higher for wheat than rice harvesting. Harvesting loss was found 2.81 and 3.47% for wheat and rice, respectively. The labor requirement for mechanical harvesting of wheat and rice was 19 and 21 man-hr ha^{-1}, respectively. Zami *et al.*, (2014) reported that, the BRRI reaper made a reduction of about 68% in harvesting cost whereas the labor saving was 72%. BRRI reaper saved 20 and 18% labor and harvesting cost over the Chinese reaper. Alam *et al.* (2014) studied the field performance of Korean self-propelled reaper (KSR), China self-propelled reaper (CSR) and BRRI power tiller mounted reaper (BPR) in Mithapukur, Rangpur district during *aman* 2013 season. The effective field capacity of KSR, CSR and BPR was observed 0.18, 0.18 and 0.15 ha hr^{-1} with field efficiency of 66.0, 86.0 and 66.7%, respectively. The field capacity varied from one plot to another due to varying in plot size and operator's skill. The fuel consumption of KSR, CSR and BPR was obtained 0.76, 0.48 and 1.25 l hr^{-1}, respectively. The break-even area of KSR, CSR and BPR was 9.15, 7.82 and 8.43 ha yr^{-1} of, respectively. Public and private organization were trying to promote local and imported reaper (self propelled or power tiller mounted) through the creation of local service provider. ACI motors

Ltd., Dhaka; The Metal (Pvt) Limited, Dhaka; Janata Engineering Workshop, Chuadanga and other companies imported different models of self-propelled reaper from China, Korea and Vietnam. Those reapers were sold to the farmers under the country wide subsidy program. In some places, entrepreneur purchased the reaper for use in rental service. Due to limitation, this technology is not getting popular throughout the country.

Combine harvester was recently introduced in our country to harvest rice and wheat. Whole and head-feed type combine harvesters having different capacities are now available in the market. Combine harvester performs all basic functions esp. gathering, threshing, separating, cleaning, bagging of grain, etc in a complete integrated engineering forms where mechanical, electrical and electronics, hydraulics and agricultural engineering have been applied in most advanced and proven technology. Head feed combine harvester is considered as most promising machine for harvesting rice as the straw remains long after harvesting. The price of the machine was beyond the purchasing power of the ordinary farmers. This bigger size of machine with higher field capacity needs to be investigated thoroughly to know the constraints and business viability.

Several attempts were taken to popularize different kinds of harvester (hand reaper, self-propelled reaper, combine harvester, etc.) at farm level since 1995s. Those harvesters are not yet been popularized due to some inherent problem such as operator's comfortability, high cost, limited annual use, lack of versatility, unavailability of spare parts etc. It is expected that cereal production will be boost up after the introduction of harvester in order to reduce postharvest loss and ensure the quality production. The data on the performance of harvesting equipment in commercial purposes were not available in our country. This study finds the performance of harvesting equipment namely hand reaper, self-propelled reaper and combine harvester in our land tenure system.

Hand reaper

Honda hand reaper model: UKM-435, sometimes called hand held reaper. Hand reaper was especially designed for cutting wheat, rice, soybean, maize and grass, etc. The hand reaper consisted of one petrol engine, operating arm with shoulder carry belt and circular cutting blade (Photo 1). Table 1 presents the specification of the hand reaper. Islam *et al.*(2014) conducted the field performance of hand reaper in the farmer's field, Dirasharm, Gazipur City Corporation, Gazipur in *boro* season 2014.

Photo 1 Hand reaper

Table 1 Specification of hand reaper

Model no.	UKM-435
Cutting blade diameter	25.4cm
Circular blade teeth/inch	10 no
Total teeth	150 no
Blade manufacturing metal	SS Steel
Weight of reaper	9 kg
Length of Machine with engine	1.94 m
Length of handle	1.64 m
Type of engine	Petrol
Engine power (Hp)	0.5
Fuel tank capacity	0.650 liter
RPM of cutting blade (Medium Speed)	4300
Operation direction	Right to left

Operating system shoulder carries with hand SWAP (Hanging by belt)

Description of hand reaper

Hand reaper means one kind of tools for harvesting paddy, wheat, maize, bushes, etc. The reaped grain stalks are gathered into *sheaves* (bunches), tied with string or with a twist of straw. Hand reaper is now rarely seen in the industrialized countries. However, this machine can be used in areas where accessibility for reaper or combine harvester is limited (such as on narrow terraces).

Cutting blade

The cutting blade was the most important part of hand reaper. The metal of cutting blade depended on the type of crops to be harvested and the life of the machine. Different types and shape of blades were available in the market. Blade of 20 cm diameter having heat treated edges was purchased from the market. Another blade of 25 cm diameter was manufactured in local blacksmith shop. The teeth of the blade was similar to the teeth of sickle. Both types of blades were used in harvesting rice.

Photo 2 Field operation of hand reaper

Field performance

The theoretical width of cutting was observed 75-100 cm (4-5 lines), however actual width of cutting was 85 cm (average 3-4 lines). Field capacity of hand reaper was obtained 0.026 ha hr^{-1} at a speed of 0.30 km hr^{-1}. Harvesting efficiency of hand reaper was observed low in wet than dry field. The fuel consumption of hand reaper was found 0.7~0.8 L hr^{-1}. One operator was required to operate the hand reaper. However, one standby operator was needed to operate alternatively after half an hour of operation. One labor was engaged in refueling, tightening the machine with body and to bundle the harvested paddy at the time of harvesting. The operator could swap the reaper about 23 times per min and cut four adjacent hills in each swap. The shattering loss by hand reaper and sickle was 1.11 and 0.98%, respectively. There was a negligible difference on shattering loss (0.13%) was observed between two systems. The harvesting cost by using hand reaper and the manual operation was Tk 9,340 and 14,940 ha^{-1}, respectively. Hand reaper saved 37% cost over traditional method of manual harvesting. The hand reaper machine should be operated at least 1.74 ha yr^{-1} to get break-even outcome with neither loss nor profit.

Problems of harvesting

Operator's safety and fatigue are the important consideration for selecting a machine. It was observed that operator felt exhaustion and difficulty to swap the reaper due to excessive weight (9 kg) of the hand reaper. Operator also felt discomfort to hold the two handlesdue to wider space between the handles. Operator became tired after 25~30 minute of harvesting. Long hours of operation created weakness of the operator. It was also difficult to move with hand reaper in the muddy field. Professionally trained operator was needed to operate the hand reaper. More time was needed during binding of the harvested crops as it felt down scatteredly. Hand reaper was unable to cut the lodged crop. The crops were also dropped down in overlap condition due to less width of cut. Harvested crops were fallen haphazardly when guide and propeller was not used in the hand reaper. Cutting blade having 20 cm diameter provided less contact area of cutting, which was not suitable for hand reaper.

Precondition

The crops should be in upright position and straw should be greenish (at 80% maturity of paddy) during harvesting time. Hand reaper is unable to cut the overdried straw. The space between the handles should be reduced to grip easily by the ordinary people and make sure to balance the machine during operation. As the harvested crops were fallen haphazardly, it was advisable to thresh the crop in close drum thresher without binding. Harvested crops may be threshed in the field inorder to avoid binding and carrying loss. The diameter of the cutting blade should be 25 cm with at least four number of teeth per running centimeter (periphery) to increase the contact area of cutting. High speed carbon with properly heat treated metal should be used to manufacture cutting blade. It will increase the life of the blade. Guide should be used to facilitate the line falling of harvested paddy. Both hands always needed to be kept on the control handles for proper balancing of the machine and safety concern. Accident becomes obvious if the reaper is operated by one hand.

The performance of the hand reaper was depended on the operator's skill. The field capacity, field efficiency, fuel consumption, shattering loss and harvesting cost were found satisfactory. This machine can be used for cutting and windrowing stems of rice, maize, grass, and other cereals. The price of the hand reaper was within the purchasing power of the farmers. They can harvest their own crop as well as provide service to the other farmers on rental basis. However, from the operator's point of view, it caused fatigue to the operator after half-an-hour operation. The operator felt discomfort due to release exhaust gas nearer to the operator, creation of noise and vibration during harvesting crops. This machine was not ergonomically fit to harvest cereal crops. Farmers showed unhappiness as harvested crops were fallen haphazardly.

Self-propelled rice-wheat reaper

Islam *et al*. (2016c) commercially operated the self-propelled reaper in the farmer's field at Bamonkanda, Bhanga, Faridpur and Satashia, Muksudpur, Gopalganj district to identify the constraints and business viability of self-propelled reaper. Table 2 shows the specifications of self-propelled reaper. Single *boro* rice was cultivated in the region as rest of the time occupied by tidal water. Crop harvesting was often harmed by strong northwester storm, flood and heavy rain. It was crucially important for the farmers to collect grain quickly and timely.

Table 2 Specifications of self-propelled reaper

Parameter	Reaper
Model	AR 120
Overall dimension	200 x 135 x 110
Engine hp	4.5 – 6.5 @ 3600 rpm
Weight	135
Fuel type	Gasoline
Fuel consumption, L ha^{-1}	4
Width of cut, m	1.2
Available in local market	Yes
Market price, BDT	180,000

Photo 3 Harvesting by reaper

Effect of crop inclination on field capacity

Field capacity of reaper varied on the inclination of crop in field besides plot size, shape and operator skill. Field capacity decreased with the increase in inclination of crop (Fig. 1). It was observed that self-propelled reaper was unable to cut the crops when crop inclination was more than 50°.

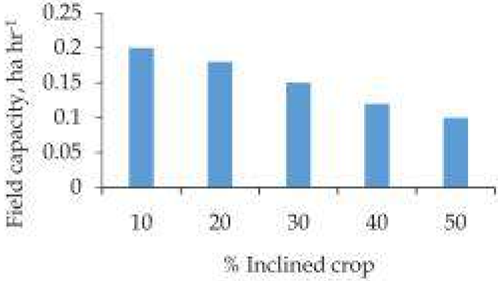


Fig. 1 Field capacity in relation to crop leaning/inclination

Labor distribution

The pre-requisite on the operation of self-propelled reaper was to cut the corner crop by sickle to facilitate the movement of reaper. Figure 2 presents the labor requirement for side cutting harvesting, declogging and carrying. Sometimes straws were clogged in the star wheel due to improper operation. Clogging depended on the synchronization between density of the crop and speed of the reaper. Higher speed of the reaper in densely populated field created clogging in the star wheel. The pressure ring unable to press the bulk volume of straw and slow down the delivery of cut crop through the conveyor belt.

The speed of the harvester should be low incase of densely populated field. The speed of the harvester should be optimized depending on the crop density, which minimize the labor requirement in declogging. It was mandatory to cut the crop in four corners in each plot to start harvesting operation of the reaper. Labor requirement depended on the number of plots to be harvested in each day and independent on the plot size. Selection of larger size of plots will minimize the labor requirement of side cutting.

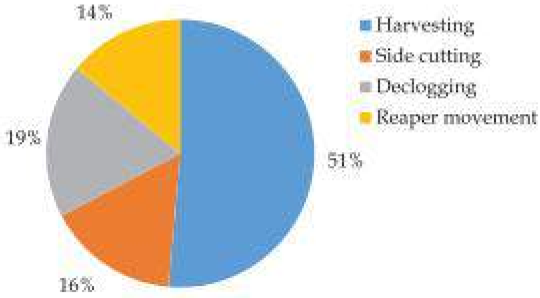


Fig. 2 Labor distribution in harvesting

Time distribution

Machine was kept idle during preparation of field by side cutting. Most of the time was spent as idle while the side was cut by sickle. Frequent clogging was noticed besides occasional engine overheating. Due to the movement pattern of reaper, almost one-third of the operation time was spent in turning (Fig. 3). Engine showed overloaded symptom when operated in the excessive muddy field and required extra time to operate in the field. Nuts and bolts were loosened during operation of the reaper and it took time to trouble shoot the problem. Idle time was meant here as the plots were not ready for the operation of the reaper. Fuel stock has to be maintained nearer to the field, which will reduce the idle time. Careful planning may reduce the idle time. Reduction of idle, plot to plot movement and trouble shooting time will increase the area coverage in each day of operation.

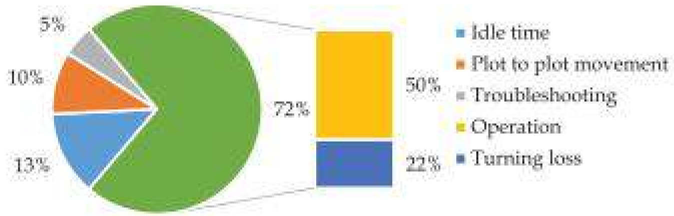


Fig. 3 Time distribution in harvesting by reaper

Cost analysis

Table 3 presents the cost scenario of mechanical and manual harvesting of rice. The cutting cost was saved by 43% when harvested by reaper in comparison to traditional harvesting. Mechanical intervention in harvesting to threshing reduced cost by 11% of the total harvest and postharvest operation.

Table 3 Harvesting and threshing cost

Activity	Cost, Tk ha^{-1}	
	Traditional	Reaper
Harvesting	7,000	3,705
Binding	5,000	5,000
Carrying (Field to threshing yard)	7,200	7,200
Threshing	5,415	5,415
Winnowing and bagging	2,000	2,000
Carrying (threshing yard to farmer house)	2,250	2,250
Total	**28,865 (100%)**	**25,570 (88%)**

The field performance of reaper was related to the time required to move from one plot to another, speed of the machine, traveling time across the field, the width of cut, loss time, field efficiency and operators' skill. Field capacity decreased with the increase in inclination of crop. The labor requirement and time loss during harvesting should be considered to formulate business plan of the self-propelled reaper. Reaper can be operated in small and fragmented land. The price of the reaper seems to be affordable to the small holder farmers.

Combine harvester

Islam (2014) studied the performance of combine harvester and operated commercially in nine villages under Dhamrai upazila of Dhaka district to harvest rice in *boro* 2014 season. Table 4 presents the technical specification of the combine harvester.

Table 4 Specifications of head feed combine harvester

Machine name	DAEDONG DSC 48
Model	4A200T-C
Type	Vertical 4 cylinder water cooling diesel engine
Engine hp	50
Weight	2180 kg
Engine rpm	2800
Thresher rpm	503
Forward speed	0.98 m s^{-1}
Cutting width	1.45 m
Fuel capacity of the tank	50 litre

Fuel consumption

Fuel consumption of the combine harvester depended on the distance from machine shelter to working place, plot to plot movement, plot size and shape, crop density, lodged crop, width of cut, speed of operation and it was 40 L ha^{-1}. Machine should be operated at slow speed in densely cropped area. Cutting of lodged crop took more time than standing crop. Fuel consumption increased in the small plot due to the requirement of more turning time. The irregular shape of the plots also affected the fuel consumption due to the requirement of more time to complete harvesting in the pocket areas.

Field capacity

Figure 4a shows the land size in the study area. Plot sizes were varied from 162-2,752 m^2. About 17% plots belonged to the size <500 m^2. Field capacity increased progressively with the increase in plot size due to less turning events as well as less loss time (Fig. 4b). Field capacity of the plots having 750-1,000 m^2 attained 83% more than the plot sizes <500 m^2. Field capacity of combine harvester was low in the plots having the sizes less than 500 m^2. Therefore, the plot sizes less than 500 m^2 were not recommended to operate combine harvester in an efficient manner. The field capacity of the combine harvester was obtained 0.18 ha hr^{-1}. Field capacity of the combine harvester was decreased in the irregular shape of plots due to requirement of more time to complete harvesting. Combine harvester was unable to enter into the pocket areas due to limited entry facilities and compelled the farmer for manual harvesting. Plot enlargement and reshaping are urgently needed to get the optimum performance of the head feed combine harvester.

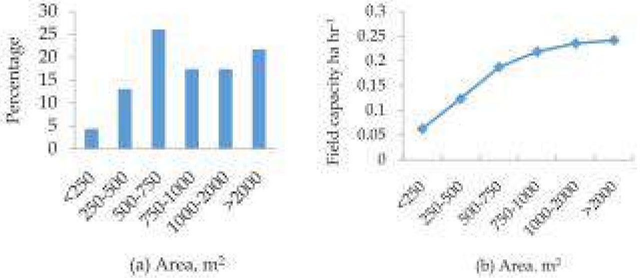


Fig. 4 Field capacity of combine harvester with respect to land size

Harvester movement

The operators faced difficulty to move the machine in sloppy surface as the height of road from the field surface was observed more than 2 m. It caused damage of the machine and required extra care. Ladder was used to move the harvester in the sloppy surface. It was mandatory to construct farm road to promote the accessibility of farm machine. Care should be taken to load and unload combine harvester from the trucks.In some cases, combine harvester was bogged down as the low soil bearing capacity due to excessive wetness. According to Taniyama (1975), the layout of farm roads should be readjusted to facilitate the movement of farm machines to each field plot without causing damage to machines, to levees and to irrigation channels. The author also recommended the height of farm roads should be 50 cm (height from field surface) of main farm roads and 30 cm for branch farm roads (height from field surface). Some plots were very far and damaged the irrigation channel and levees due to the machine movement.

Operation cost

Figure 5 presents the cost distribution of harvesting operation. Operation cost was categorized as transport, fuel, supervisor, operator, labor and other charges. Among the cost items, operator, labor and other charges were higher, which needed careful attention to reduce the cost. Transport cost may be minimized to operate harvester in adjacent plots. Fuel consumption may be decreased by avoiding small sizes of plots. The operation cost may also be reduced through careful selection of plots having larger in size and regular in shape.

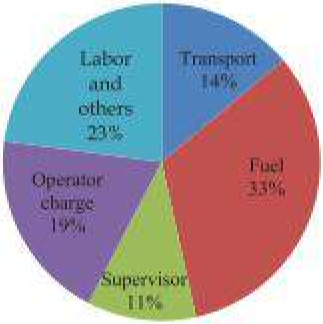


Fig. 5 Cost distribution in operation of combine harvester

Turning loss

The total number of turns depended on the plot size and shape. Number of turning events reduced with the increase of plot size (Fig. 6a). The loss time during turning depended on the frequency of turning, which was affected by the plot size. Turning loss was reduced with the increase in plot size (Fig. 6b). The turning loss was observed more for the plot size < 500 m^2. The turning loss was observed double for the plot size of < 250 m^2 than the 250-500 m^2. Turning time was also depended on the operator's skill and shape of turning point. The turning loss could be minimized if the plot size was larger than 500 m^2 and the operators had good skill.

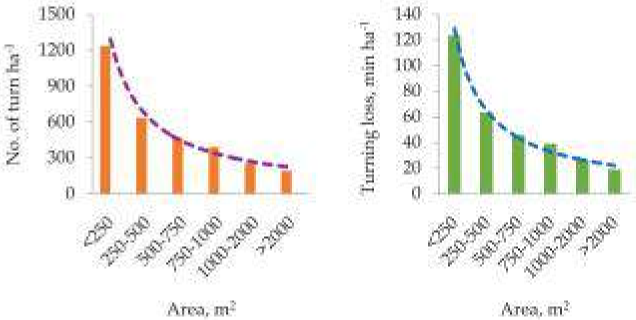


Fig. 6 (a) Effect of plot size on turning events (b) Effect of plot size on turning loss

Problem identification

It was very difficult to move the machine from one place to another due to lack of farm road. Plot elevation also affected the movement of the machine. Sometimes straw was clogged in the conveyer belt. Fuel and air filter were also clogged due to dust and chaff. More time was required to move in the muddy field and harvesting lodged crop.

Field capacity increased with the increase in plot size due to reduction of turning loss. Combine harvester reduced the time required in harvesting, cost of harvesting and drudgery of the farmers. The seasonal use of combine harvester was observed 16 days in one locality. Rental service of combine harvester appeared as business viable model. The unique advantage of these combination is its ability to perform in wet and uneven field condition, keeping straws in full length with binding facilities, ability to take up lodged crop and easy maneuvering. Moreover, it is also able to operate in fragmented land condition. Thus, it is very suitable for Bangladesh land tenure system.The head feed combine harvester is an efficient, economical, labor and time saving machine but its initial cost is quite high. The price of the harvester should be affordable to the farmers.

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