SELECTIVE MECHANIZATION IN RICE CULTIVATION FOR ENHANCING PRODUCTIVITY

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Executive summary

Rice cultivation involves a number of labor intensive operations like transplanting, weed control, harvesting, threshing and winnowing. Timely operations carrying out through selective mechanization can help to reduce the burden of labor in farming operation. Selective mechanization is a new opportunity in modern rice cultivation according to the socio-economic situation of the country considering small farm land and low income of the farmer. To evaluate these technologies, field experiments were conducted in farmer's field at Pirgacha, Rangpur in *aman* season (June to November) 2015. Mechanization was applied for evaluation at four different selective levels (treatments) in six consequent operations. The mechanization systems were S_1 = Hand transplanting + Hand weeding + Harvesting by sickle; S_2 = Mechanical trasnplanting + BRRI weeder + reaper; S_3 = Mechanical transplanting + BRRI power weeder + reaper and S_4 = Mechanical transplanting + herbicide + reaper. The experiment was carried out in randomized complete block design (RCBD) with four replications. Rice variety BRRI dhan52 was used to conduct the experiment. Rice transplanter, BRRI weeder, BRRI power weeder, Vietnamese self-propelled reaper, BRRI open drum thresher and BRRI winnower were used in the respective operations. Techno-economic performances were observed and operational costs of different technologies were calculated and compared. The transplanting methods had significant effect on grain yield. Mechanical transplanting reduced 61% labor and 18% cost compared to manual transplanting. BRRI weeder, BRRI power weeder and herbicide application reduced 74, 91 and 98% labor, whereas 72, 63 and 82% cost compared to hand weeding. Herbicide application reduced the substantial amount of labor and cost in weeding operation. Mechanical harvesting also saved 96% labor and 72% cost compared to traditional method of harvesting using sickle. Selective mechanization saved 11-12% cost compared to traditional method of rice cultivation. Herbicide with mechanical transplanting and harvesting by reaper were the most cost and labor saving operation. Considering environmental issues, BRRI weeder with mechanical transplanting and harvesting by reaper might be the recommended set of selective mechanization. Appropriate scale selective mechanization ensured faster in operation, reduced burden of labor force and improved the productivity in rice cultivation.

Content

Introduction

Rice (*Oryza sativa* L.) is the major food crops covering 77% (10.71 Mha) of the total cropped areas (BBS, 2011). It ensures a sense of food security of the country. Rice production involves numerous operations among which transplanting, weeding, harvesting, threshing and winnowing are identified to affect yield and cost characteristics. Transplanting, weeding, harvesting, threshing and cleaning are the most labor intensive operations in rice cultivation. On-season labor shortage is a major problem in some paddy growing areas of the country. High labor demand during peak periods adversely affects timeliness of operation, thereby reducing the crop yield. Labor availability is scarce during peak farm operation due to shift of agricultural labor to the industrial sector. Figure 1.1 shows that the agricultural labor force followed decreasing trend (48.3% in 2012-2013 and 45.1% in 2013) whereas increased in non-agricultural sector (51.7% in 2002-2003 and 54.9% in 2013) due to shifting low productivity to high productivity sector (BBS, 2015). On the other hand, drudgery and social status of the farm operations discourage the labor to work on-farm activity. Labor force is becoming increasingly costly and scarce during peak period of farm operations. It also adds a new dimension to this problem. 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.

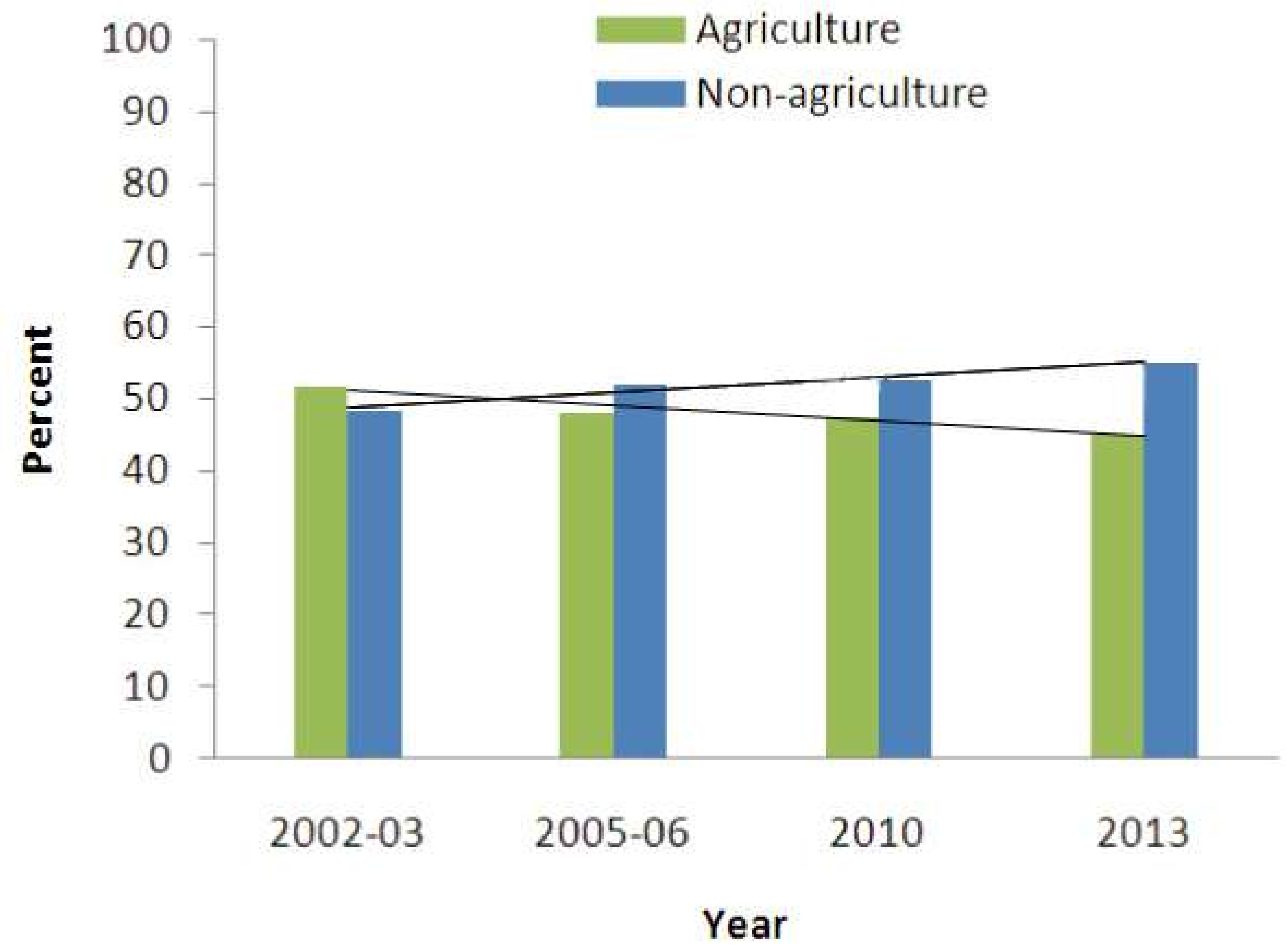


Fig. 1.1 Employment status in agriculture and non-agriculture sector

What is mechanization?

Mechanization may be defined as the process of injecting power and machinery between man and materials in a production system (Khalequzzaman and Karim, 2007). Mechanization is recognized as a central indispensable pillar for making farm operations efficient and productive in so far as it determines much of the efficiency and productivity of all the other inputs used in crop production such as labor and time (Reid, 2014).

It is widely practiced around the world, especially in rich countries where farmers have enough funds to engage in costly machinery to satisfy conditions for good yield. Besides, most of the machinery are good only in large land sizes. Farmers in the developing countries like Bangladesh have small land sizes, limited funding ability and hence depend on human laborers. Table 1.1 presents the operation wise labor requirement in manual and mechanized rice cultivation. Mechanization is the need of the hour to offset the problems of labor intensive works.

Table 1.1 Labor requirements in manual and mechanized rice cultivation

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

Importance of mechanization

Farm mechanization in crop production is very important as it helps timeliness in operations, eliminates/reduces the human drudgery and improves the productivity. Farm 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 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. Mechanization also helps better management of farm by proceeding more free time for planning and study because it contributes to timeliness in production. Much field operation can be performed within shorter period of time than that of manual operation. Mechanization also improves working condition and the performance of jobs that would otherwise be difficult or impossible by hand method. Overall cost reduction is also a highly desirable matter though in some situation the net profit may be slightly reduced because farmers prefer mechanization to avoid problems of timeliness in operation and labor management. Aurangzeb *et al.,* (2007) stated that mechanization boost up the overall productivity and production with the lowest cost.

Benefits of mechanized cultivation

Mechanization is required to

- Reduce labor requirement
- Improve land and labor productivity
- Faster operation
- Ensure timeliness operation
- Reduce turn-around time
- Increase cropping intensity
- Create job opportunity
- Increase livelihood of the rural people
- Reduce the burden of female worker

Present status of mechanization

Puddling is the most important operation in the land preparation for transplanting rice. At present, 80% land is puddled by power tiller and 18% by tractor. In some places 2% land is prepared by traditional bullock. Rice transplanting is done by manually. The mechanical transplanting of paddy has been considered as a promising option, as it saves labor, ensures timely transplanting and attains optimum plant density that contributes to high productivity. Also, row planting technology using rice transplanter prepared the way for utilization of such plant protection machines as weeder in paddy fields (Tajuddin, 2009). Mechanized transplanting is being started recently using 4-row walking type transplanter through government and public sector intervention. Seedling raising is a crucial part of mechanical transplanter. Farmers do not know how to raise seedling suitable for mechanical transplanter. Weeding operation is mostly done by hand and in some parts of the country, farmers use traditional device to control weed. Weedicide use is getting popular due to minimize weeding cost. Knapsack sprayer is widely used in crop protection. Farmers irrigate the land using shallow tubewell or deep 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) and combine harvester in the country. BRRI and private manufacturers are trying to develop combine harvester using locally available material.

Selective mechanization

The term selective mechanization can be determined after carefully considering the technical, economic and social characteristics of each situation. Selective farm mechanization is a must for increasing crop production. In Bangladesh, small-scale mechanization has proved to be appropriate for the socio-economic condition. Application of farm machinery is likely to increase land and labor productivity about 10 percent. Government has given top priority to agriculture development in order to increase operations (Kabir and Ahmed, 2005).

Human power is a critical element within the production process, both in terms of its availability and productivity (FAO and IFAD, 2003). In such situation, farmers can neither survive with age-old traditional method because of low yield and return, nor the advanced mechanical method of operation for heavy expenses. Still, remarkable improvement is obtained in yield by proper and timely transplanting, efficient control of weeds, efficient harvesting and threshing, proper post-harvest process and storage. Thus question arises, whether mechanization is suitable for us or not, and if suitable, up to which degree it should be adopted in such controversy? A possible solution is adopting mechanization at selective level considering its appropriateness based on labor requirement, operational capacity, economic feasibility and outturn facilities. By the time, a comparison of different selective mechanization for rice cultivation would be required, to decide where to take mechanization and where to drop.

The need of machinery for rice cultivation arises when seeking solutions for the problems like drudgery, high production cost, low quality, low cropping intensity and above all the labor scarcity. Various tools in appropriate forms had been used in the history of ricecultivation. From time to time the need has been changing and today the major concern is to lower the production cost, increase the quality and solve the problem of labor scarcity (Tilakaratna *et.al.*, 2004).

There is a need for development of more efficient and less costly equipment. Selective mechanization based on traditional devices can provide one cost-effective option. In the context of market economy, emphasis will have to be given to the collaborative role of public and private sectors in technology development and diffusion (MoPBD, 2015).

Justification

Studies on the performance of farm machinery were done individually in rice cultivation and post-harvest operations. But in order to get a complete picture of the difference brought by mechanization in rice cultivation, it is obvious to exercise a combine study on the major operations executed both mechanical and manual way in a rice field. Keeping this in view, this study is aimed to evaluate the impact of adopting mechanical means in five selective operations, which are transplanting, weeding, harvesting, threshing and winnowing and compare results over traditional methods.

Objectives

- To compare the cost of mechanized cultivation (transplanting, weeding, harvesting, threshing and winnowing) over traditional
- To evaluate the profitability of selective mechanization in rice cultivation

Description of the technology

Different machines for specific operations are used to obtain better accomplishment without considering single aid for multiple operations. Selective mechanization involves small machinery considering operational scale as appropriate as possible to minimize investment burden and losses due to inherent constraints (i.e. small land holding, lack of large machine travel roads) on the root farmers.

Power tiller

Power tillers (PTs) have been used for land preparation in Bangladesh since early 1960s. It is a 12-16 hp self-propelled machine specifically useful for dry and wet tillage in rice and non-rice crops (Photo 2.1). In off period, the power unit is used in pumping, threshing, cleaning and other off-farm purposes like carrying goods. The timeliness of land preparation is considered as added advantages of PTs. All power tillers were imported from China. Two models namely Sifeng and Dongfeng are widely used in Bangladesh. Its cost is approximately Tk 1.30 to 1.40 lakh. At present, 7,00,000 power tillers are in operation in the country especially for tilling and carrying of agricultural goods.

Photo 2.1 Power tiller

Mat type seedling

The plastic trays were used to raise mat-type seedlings. Seed rate depends on the thousand grain mass of the variety and germination rate. Normally, seed rate per tray for mechanical transplanting was 130-140 gm. Excessive seed rate increased the mortality of seedling and encouraged seedling in slender nature. Dry soil was filled in tray in such a way that the soil was free from any stone, stubble and grass. Sprouted seeds were spread uniformly over the tray. To protect the seeds from the birds, the mats were covered with straw. Water was sprinkled twice a day by rose cane until there was complete emergence of seedlings. The mat seedlings were ready to transplant when they had 3-4 leaves and 10-12 cm height (Photo 2.2). The seedling age, suitable for mechanical transplanting, was 12 days in warm season and more than 25 days in cold season.

Photo 2.2 Rice seedlings on plastic tray

Rice transplanter

It is a self-propelled four rows walking type rice transplanter machine driven by 3 - 4 hp petrol engine (Photo 2.3). It has a fixed row spacing of 30 cm and has provisions for adjustments of planting depth, number of seedlings per hill, floats pressure against soil, hill spacing and planting speed. It requires mat type nursery. This machine is more suitable for light textured soils. Table 2.1 presents the specification of the walking transplanter.

Photo 2.3 Mechanical rice transplanter

Table 2.1 Technical specification of walking type rice transplanter

Make and model	Daedong DP-480 (South Korea)
Width, cm	120
Row coverage	4
Weight, kg	160
Fuel tank capacity, L	3.4
Available in local market	No
Import price, Tk	4,00,000

BRRI weeder

BRRI weeder was used in the study (Photo 2.4). It has a weight of 4 kg and takes 20.93N force in each push (Chowdhury *et al.,* 2014). A minimum hill to hill distance of 20 cm is required to operate the weeder. Table 2.2 presents the specification of the BRRI weeder.

Photo 2.4 BRRI weeder

Table 2.2 Technical specification of BRRI weeder

Make and model	BRRI weeder
Width, cm	20
Row coverage	1
Weight, kg	2.5
Available in local market	Yes
Import price, Tk	600-800

BRRI power weeder

BRRI power weeder was used in this study (Photo 2.5). During operation, operator should hold tightly and control its forward speed as the tremendous rotation of spooked wheel makes the machine run along, besides uprooting the weeds. Table 2.3 presents the specification of BRRI power weeder.

Photo 2.5 BRRI power weeder

Table 2.3 Technical specification of BRRI power weeder

Make and model	BRRI power weeder
Width, cm	90
Row coverage	3
Weight, kg	160
Power, kw	1.46
Fuel tank capacity, L	3.4
Rated field capacity, ha hr^{-1}	8.1
Available in local market	No
Market price, Tk	60,000

Self-propelled reaper

The Vietnamese model self-propelled reaper is recently introduced in our country for harvesting rice and wheat (Photo 2.6). This machine is used for harvesting rice in the experimental field. Table 2.4 presents the specification of self-propelled reaper.

Table 2.4 Technical specification of self-propelled reaper

Make and model	Vietnamese self-propelled reaper
Cutting width, cm	120
Row coverage	4
Available in local market	Yes
Market price, Tk	1,75,000

Photo 2.6 Self-propelled reaper

BRRI open drum thresher

Threshing is being done by mechanical drum threshers for quite a long time. BRRI open drum thresher (ODT) is available in market (Photo 2.7). The power transmission of this machine is enabled with common V-belt. Two-three operators can perform threshing easily. Table 2.5 presents the specification of ODT.

Photo 2.7 BRRI opendrum thresher

Table 2.5 Technical specification of self-propelled reaper

Make and model	BRRI open drum thresher
Engine power, kW	3
Threshing cylinder width, m	1.8
Available in local market	Yes
Market price, Tk	30,000

BRRI winnower

BRRI winnower was used to clean the dried paddy (Photo 2.8). Electrical connection was managed from a farmer's house. It required at least two operators to constantly feed on and collect grain without spilling grains. Table 2.6 presents the specifications of BRRI winnower.

Photo 2.8 BRRI winnower

Table 2.6 Technical specification of BRRI winnower

Make and model	BRRI winnower
Motor power, kW	0.373
Available in market	Yes
Market price, Tk	15,000

Mechanization in rice cultivation brought revolutionary change by reducing labor and time requirement. Enormous studies have already been conducted on mechanized method of transplanting, weeding, harvesting, threshing and winnowing operation.

Selective mechanization

Planning Commission of Bangladesh (2015) acknowledged that, rapid expansion of mechanization is needed to compensate the shortage of draft power, farm labor and the declining interest of young people to stay in agriculture. Farm mechanization can help in improving productivity, reducing production cost, increasing input use efficiency (water, seed, fertilizer, land and labor) and achieving timeliness of crop production operations. Agricultural mechanization is also required to reduce the turn-over time.

Manandhar *et al.,* (2009) reported that selective or semi-mechanization has become a necessity of the country, as the agricultural operation is found to be completely dependent on the old and female laborers in Nepal. Large numbers of young people are migrating to Malaysia and Gulf countries due to lack of employment opportunities. Mechanization could help to complete farm operations in time. The time saved from agricultural activities could be further utilized in other income generating activities, child health care, education and recreation. Human drudgery and farm work load could be substantially reduced with quality farm operations, resulting in higher crop yields and cropping intensity. Environmental degradation could also be minimized by using selective agricultural mechanization.

Kabir *et al.* (2005) reported that around 62% work forces are engaged in agriculture. Acute agricultural labor shortage occurs during some of the vital operations like transplanting, harvesting and threshing. Selective farm mechanization is thus a must to facilitate increasing crop production. In Bangladesh, small-scale mechanization has been proven to be appropriate according to its socio-economic condition. Application of farm machinery is likely to increase about 10% of the land and labor productivity. Also, the government has indexed agricultural development at top priority to increase production and quality.

Aderoba (1987) have demonstrated that because of the small land holdings, farmers in developing countries like Nigeria, required a system of selective mechanization due to many inherent constraints (i.e. low capital and poor technological environment) in the traditional system of agriculture.

Mechanical transplanting

Islam *et al.* (2015a) reported that, mechanically transplanted plot showed significantly higher grain yield (9-14%) than hand transplanted method due to use of infant seedlings and better planting efficiency. Also, mechanical transplanter reduced 1.8% input cost over traditional transplanting.

Munnaf (2014) conducted an experiment to observe the performance of Kukje self-propelled rice transplanter. The field efficiency and planting efficiency of the transplanter were 83% and 95%, respectively. Percent damaged (3.33%) and missing (5.33%) hills were higher in mechanical transplanting method and percent floating (4.33%) hill was higher in case of manual transplanting method. The average labor input in mechanical transplanting was 1.4 man-day ha^{-1} where 25 man-day ha^{-1} was in case of manual transplanting. The total production costs were Tk 53,612 ha^{-1} and Tk 49,304 ha^{-1} for manual and mechanical transplanting methods, respectively. Crop established with mechanical transplanting method using tender aged seedling resulted in 14% higher grain yield than manual transplanting. The net return of manual and mechanical transplanting method swas Tk 42,310 and 61,080 ha^{-1}, respectively. The benefit cost ratio (BCR) of mechanical and manual transplanting were 2.24 and 1.78, respectively. Kukje self-propelled rice transplanter should have break-even area coverage more than 10 ha yr^{-1} for economic transplanting.

GBK (2012) explained that the manual transplanting is labor intensive, time consuming, expansive and required large number of workers. About 25-40 man-days ha^{-1} are required to transplant with manual transplanting method where an operator with the help of an assistant can do the same work with self-propelled rice transplanter and it is possible to transplant more than 2 ha 8 hr^{-1}.

Singh *et al.* (2011) reported that yield from traditional method and self-propelled paddy transplanting method was 4.83 and 5.70 t ha^{-1}, respectively.

Alizadeh *et al.* (2011) reported that around 30% increase in yield was found in mechanical transplanting compared to the manual transplanting method. Average labor input in rice transplanter was 30 man-hr ha^{-1} compared to 126 man-hr ha^{-1} in hand transplanting.

The transplanters are classified on the basis of nursery used i.e. machine using wash root seedling and machine using mat type seedlings. Mat type seedlings are raised on a polythene sheet with the help of frames. Twenty to 30-days-old seedlings were found most suitable for transplanting. The mat thickness for best results should be about 2 cm. Transplanting mat type seedlings is becoming more popular due to its superior performance and reduced labor requirement (50 man-hr ha^{-1}). The 6-row manually operated machine was found to be the most economical (AnoopDixxit, 2007).

Manjunatha *et al.* (2009) reported that mechanized transplanting cost was Rs 789 ha^{-1} as compared to Rs 1,625 ha^{-1} in case of manual transplanting. Usually rice transplanter machines are used for their maximum usage of 90 ha yr^{-1}.

Aslam *et al.* (2008) noted that the availability of labor become scarce and increasing the wages of labor, manual transplanting found laborious and costly leading to reduce profits to the farmers.

Chaudhary *et al.* (2005) further reported that, the payback period for investment on the transplanter was 10.23 and one year against area coverage of 20 and 80 ha, respectively. The break-even area coverage by transplanter should be more than 13.14 ha yr^{-1} to make the machine transplanting profitable in comparison to the manual transplanting.

Baruah *et al.* (2001) reported that the cost of machine transplanting was found to be only Rs. 1,310 ha^{-1} in comparison to Rs 2,463 ha^{-1} for manual transplanting. The cost of growing mat type nursery for mechanical transplanting was about 40 % whereas the cost for raising conventional nursery was only 25% of the transplanting cost.

Weeding

Islam *et al.* (2015c) reported that, power and mechanical weeders reduced production cost, were faster in weed control and improve labor efficiency without sacrificing grain yield. Also, power and mechanical weeder appeared as environment-friendly weed control technology than chemical control in low land rice cultivation. The authors recommended that weed control efficiency of weeder should be compared with the use of herbicides.

Alizadeh (2011) reported that, among different types of weeder, the highest weeding efficiency and effective field capacity were achieved by the power weeder. The operation time in single row conical weeder, two rows conical weeder, rotary weeder and power weeder was decreased by 57, 78, 63 and 90% compared to hand weeding method, respectively. Weeding cost in single row conical weeder, two rows conical weeder, rotary weeder and power weeder was reduced by 16, 39, 22 and 49%, respectively compared to hand weeding method.

Chauhan and Johnson (2010) stated that the risks of crop yield loss due to competition from weeds in direct seeded rice was greater than in transplanted rice, because the weeds and rice emerge together and farmers are not usually able to use standing water to suppress weeds at the early growth stages of rice. Dry weight of grasses (6.18 and 8.77 g m^{-2}), sedges (3.32 and 4.97 g m^{-2}), broad-leaved weeds (1.85 and 2.74 gm^{-2}) at 45 and 60 DAS, the N-P-K uptake of 4.09-1.53-4.49 kg ha^{-1} by weeds at 60 DAS were minimum and the weed control efficiency was maximum (67%) in drum seeding method than wet and dry seeding (Singh and Singh, 2010).

Veeraputhiran and Balasubramanian (2010) observed that maintaining weed free condition till maturity produced the grain yield of 7139 kg ha^{-1} of transplanted rice. The overall effect of crop weed competition is the reduction in the economics as well as biological yield of rice.

Reddy (2010) reported that direct planting system recorded less total weed dry weight (1062 kg ha^{-1}) and nutrient removal by weeds (31:16:52 kg NPK ha^{-1}) over drum seeding. However, weed control efficiency was similar for both the establishment methods.

Pal *et al.*, (2009) opined that hand weeding on 20 and 40 DAT recorded the highest grain yield of 5.08 t ha^{-1} in Gangetic alluvial soil because it gave very little scope to weeds to flourish and to compete with the crop preferably at the critical stage of crop weed competition.

Mrunalini and Ganesh (2008) opined that the implements like conoweeder that helped to save labor, time and reduced man-days required for weeding from 30 to 10 as they become more experienced in handling the cono weeder implement.

Weedy environment throughout the crop growth caused yield reduction to the tune of 57-61% in case of transplanted rice and 64-66% in case of wet seeded rice in comparison to season long weed free situation (Mukherjee *et al.,* 2008). The unit increase in intensity of monocots, dicots and weed dry weight causes decrease in Pusa Basmati 1 rice grain yield by 2.18, 1.64 and 2.85 q ha^{-1}, respectively during wet season (Singh *et al.*, 2008).

Francis (2007) found higher weed population (6.58 m^{-2}) and weed biomass (12.9 kg ha^{-1}) in SRI than conventional transplanted rice, which can be attributed to more inter space area and less population.

Hasanuzzaman *et al.,* (2007) mentioned that hand weeding incurred the highest control cost (two hand weeding at 30 and 45 DAT) and the lowest in chemical weed management.

Puniya *et al.* (2007) noticed that the highest loss of nutrients (N 42.07, P 10.00 and K 21.80 kg ha^{-1}) occurred with unweeded control due to more density and dry weight of weeds in transplanted rice during kharif in silt loam soil of Pantnagar.

Crop yield losses due to weeds mainly depend upon their intensity as well as on type of weed flora. There is a linear correlation between yield loss and population of weeds, however, above certain population limits, yield reductions becomes nearly constant due to self-competition among weed plants. The greatest loss caused by the weeds resulted from their competition with crop for growth factors viz., nutrients, soil moisture, light, space etc (Walia, 2006).

Cono weeding alone was found to contribute 17.43 % for grain yield when the average grain yield under the cono weeding treatments 3,376 kg ha^{-1} was compared against the average grain yield under hand weeding treatments 2,875 kg ha^{-1} (Sridevi, 2006). The impact of cono weeding in increasing the ammoniacal and nitrate nitrogen content of the rhizosphere soils was evident only at harvest (37.9 ppm) and grain filling stages (49.6 ppm), respectively while at the rest of the stages cono weeding had not set any notable impact on the nitrogen fractions of the rhizospheresoil (Sudhalakshmi *et. al.*, 2005).

Depending upon the weed species, different weed management options are given keeping in view their susceptibility when growing in a crop (Walia, 2006). The dominant grass weed species were *Echinochloa crusgalli and Echinochloa colona,* sedges were *Cyperusiria, C. rotundus* and *Fimbristylis miliacea* and broad-leaved weed species were *Ammania baccifera, Marsilia quadrifolia* and *Potamogeton distinctus* under puddled condition of sandy clay loam soil during rainy season. The broad leaved constituted 34.1 %, grasses 42.2 % and sedges 23.6 % of the total weed population under weedy conditions (Singh *et al.*, 2007). The wet seeded rice was infested with composite weed flora comprising of 52% grasses, 30% sedges and 17.5% broad-leaved weeds (Ravisankar *et. al.*, 2008).

Prasad *et al.*, (2001) stated that transplanting recorded the lowest weed population (63.5 m^{-2}) and weed dry weight (24.1 g m^{-2}), which was followed by sowing of sprouted seeds in puddled condition and dry drilling of seeds. Transplanted rice recorded the lowest weed count of 3.19 m^{-2} and weed dry weight of 2.44 g m^{-2} resulting in the highest grain yield of 3105 kg ha^{-1} (Singh *et. al.*, 2007). Further, they reported that the weed intensity and weed dry weight increased with the increase in fertility level and was maximum with application of 120: 60: 60 kg NPK ha^{-1}.

Weeds are self-grown and appear simultaneously with crop plant creating severe competition for nutrient, space, moisture and solar energy resulting in low yield of crop. Grassy weeds were heavy competitors with rice crop and were followed by sedges and broad leaved weeds (Umapathy and Sivakumar, 2000).

Herbicide

Reddy (2010) reported that preemergence application of pretilachlor + safener@0.45 kg ha^{-1} on 3 DAS + cono weeding on 45 DAS recorded the gross return of RS 65,961 ha^{-1}, net return of RS 46,793 ha^{-1} and B: C ratio of 3.4 and was comparable with pretilachlor + safener @ 0.45 kg ha^{-1} on 3 DAS + motorized weeding on 45 DAS during wet season.

Nargis *et al.*, (2009) found that cost of insecticide and herbicide per hectare for the farmers was Tk 208 respectively, which was 0.55 % of total costs. Kabir *et al.*, (2008) reported that economic feasibility of herbicide application as well as environmental implications of continuous and longer term use of herbicides in rice fields should be addressed properly in future research programs.

Hossain (2006) reported that chemical weed control has been gaining popularity in Bangladesh in recent years leading to high growth rate in herbicide use in rice cultivation. Islam (2001) reported that phytotoxicity by herbicides led to lower yield production.

Herbicides can reduce the labor requirement tremendously, but there was inconsistency in their performance. The inconsistency included the cost of herbicides relative to labor, farmers' lack of knowledge about the rate, time and application method. Also, unavailability of herbicides and sprayers are some of the major factors that restrict the use of herbicides by small scale farmers. These limitations make mechanical method of controlling weeds preferable to the use of herbicides (Singh, *et al.*, 1981).

Harvesting

Zami *et al.*, (2014) reported that, the BRRI reaper made a reduction of about 68% in harvesting cost whereas the labor saving was 72%. On the other hand, about 20% of labor and 18% of harvesting cost were saved by BRRI reaper over the Chinese reaper. For economic justification of machine application, the yearly field capacity of machine must not be less than 3 and 5 ha for BRRI and Chinese reaper, respectively.

Rahman (2004) modified the Chinese brand self-propelled reaper named SUFALA and tested for field performance and economic evaluation in harvesting wheat and rice. Petrol engine of SUFALA was replaced by 3 kW diesel engine. Cutting and lugbelt speed ratio was maintained at 1.5:1. Mechanical functions of cutting and throwing were found satisfactory. The effective field capacity and field efficiency were higher for wheat harvesting 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 were 19 and 21 man-hr ha^{-1}, respectively. The harvesting costs by reaper were Tk 390 ha^{-1} and Tk 405 ha^{-1} for wheat and rice, respectively. The modified self-propelled reaper has a break-even area of 3.50 and 7.00 ha for wheat and rice, respectively.

Rahman *et al.* (2004) conducted modification of power transmission system of a Chinese reaper. The effective field capacity, field efficiency and fuel consumption were 0.22 ha hr^{-1}, 81.58% and 0.47 L hr^{-1}, respectively. At forward speed of 2 km hr^{-1} and the cutting width of the reaper 1.2 m, the total loss of crop was 3.12%. The requirement for mechanical harvesting was 10 man-hr ha^{-1} against for manual harvesting which was 200 man-hr ha^{-1}. Mechanical harvesting saved 95% labor requirement of manual harvesting. The harvesting cost by reaper was Tk 286 ha^{-1}. On the other hand manual harvesting cost was Tk 1980 ha^{-1}. Harvesting cost of rice with reaper was 89% of manual harvesting. The reaper has a breakeven point 10 ha yr^{-1}.

Hossain (2003) fabricated self-propelled reaper by using locally available materials. The manufacturing cost of the reaper was about Tk 30,000. The reaper was tested under different conditions for operational performance evaluation for rice harvesting, the average effective field capacity and efficiency were 0.26 ha hr^{-1} and 78% respectively for rice and forward speed of 2.76 km hr^{-1}, the cutting width of reaper and fuel consumption were 1.2 m and 0.49 L hr^{-1}, respectively. The total loss of crop was 3.38% for rice. The authors recommended that the performance test should be done for longer period under variable conditions.

Hossain and Faruque (2003) conducted field performance and improvement of cereal reaper made by Janata Machine Tools Limited. The effective field capacity, field efficiency and fuel consumption were 0.21 ha hr^{-1}, 80.76% and 0.45 L hr^{-1} respectively. At forward speed 2.15 km hr^{-1} and the cutting width of the reaper 1.2 m, the total loss of crop was 3%. The requirement for mechanical harvesting was 15 man-hr ha^{-1} against for manual harvesting was 139 man-hr ha^{-1}. Mechanical harvesting saved 89% labor requirement of manual harvesting. The harvesting cost by the reaper was Tk 626 ha^{-1}. On the other hand manual harvesting cost was Tk. 2100 ha^{-1}. Harvesting cost of rice with reaper was 70% of manual harvesting. The reaper has a breakeven point 11 ha yr^{-1}.

Threshing

Tamanna (2012) reported that threshing of paddy was found mostly mechanized in the study areas (88%). The study unveiled that 59% of the respondents were using closed drum threshers followed by 15% open drum thresher and 14% pedal thresher. Rest 8% was still using traditional hand beating methods. Among the power threshers 73% were operated by diesel engine and only 1% operated by electricity

Ferdous (2007) reported that profitability of open drum thresher was higher than pedal thresher and close drum thresher requires a substantial amount of money to invest. Zaman (2006) reported that the open drum thresher was operated by the farmers in 42 homesteads in 10 villages. Maximum threshing output was 792 kg hr^{-1} and the average labor requirement was 40 man-hr ha^{-1}.

Alam *et al.* (2007) reported that through put and threshing capacity of BRRI open drum thresher found to be 734 and 338 kg hr^{-1}, respectively. The cylinder loss, spilled grain loss and gross threshing loss for BRRI open drum thresher were 1.81, 0.35 and 2.16 %, respectively. Labor requirement was 16.71 man-hr t^{-1}. Operating and threshing cost were 294 and 445 Tk t^{-1}, respectively.

Kathrivel *et al.* (2003) reported that engine equipped paddy thresher was low cost and user friendly. Small and medium farmers can make use of these technologies for production and preservation of quality rice. Thus, it would enhance the productivity of farm workers. It also safeguards the availability of rice as a measure of food security and additional income generation for the farm workers.

Al-Amin (2001) obtained much lower threshing outputs of 169 kg hr^{-1}. 338 kg hr^{-1} 339 $kghr^{-1}$ and 359 kg hr^{-1} from MAWTS, BRRI, Boby and Farida models of open drum threshers, respectively; the effective drum lengths of the MAWTS thresher was 72 cm and of other threshers 151 cm. These variations in threshing outputs were due to differences in crop variety, yield, moisture content, straw length, straw-grain ratio, and thresher drum length and drum rpm.

Alam and Rahman (2001) mentioned that timely threshing of paddy is very crucial. High moisture content of harvested grain makes it perishable if not threshed in time. Therefore, farmers threshed their harvest in the same day to maintain its quality intact. Regarding profitability, the sample farmers expressed that open drum thresher could make an average margin of Tk 1,900 per season over traditional hand beating and animal treading. Moreover, a farmer can make an extra income of Tk 1,500 to 2,000 per season, if thresher is rented out of its extra capacity. Custom hire service of the thresher could be a profitable proposition and it can make an income of Tk 4,000 per season. However, the custom hire service of the thresher is not common in the region. The farmers explain the situation as carrying and installing the machine is laborious and difficult, especially the installing of the thresher. The lighter weight threshers caused much vibration during operations especially when the engine is coupled directly with the thresher frame. It requires proper tide up with the bamboo pegs deeply installed in the soil to prevent vibration. There are some open drum threshers, which are compact and engine is installed with the thresher frame, and do not have the difficulty of vibration. However, these threshers are costly and cannot compete in the market.

The cracked grain losses of BRRI open drum thresher, TH8, TH7 and CCK thresher were 0.0, 0.16, 0.10 and 0.15 percent, respectively and were statistically similar. However, all these were significantly lower than that of the BRRI thresher about 0.39 percent (Zami, 2000).

Al-Amin and Rahman (2000) performed a study in four different types of threshing method e.g. traditional threshing, pedal threshing, open drum threshing and power threshing. Gross Margin of traditional threshing (Tk 63 hr^{-1}) was found significantly greater and followed by power threshing (Tk 36 hr^{-1}), open drum threshing (Tk 36 hr^{-1}) and pedal threshing (Tk 15 hr^{-1}). Whereas, net margin of open drum threshing (Tk 28 hr^{-1}) was found the highest and traditional threshing (Tk 2.13 hr^{-1}) was the lowest. Considering various costs ratios and financial indicators along with present socio-economic status and facilities available to farmers, open drum threshing and power threshing may have been considered as most promising threshing method for farmers of Bangladesh.

Winnowing

Muhammad *et al.* (2013) reported that the cleaning efficiency of the machine indicated negative correlation with feed rate for the crops tested.

Tamanna (2012) reported that winnowing was still performed manually (80%) and usually done by kula, while 12% respondents used PT operated fan and 2% used electric fan for winnowing operation in Bangladesh. Regarding power use, 86% used manual power, 12% used mechanical means of power, i.e. fan with diesel engine operated PT and 2% used electricity.

Rahman *et al.* (2012) reported that winnowing capacity, fuel consumption and labor requirement of the modified winnower was found same as motor operated winnower. Moreover, farmers could use this modified winnower in rural areas where electricity was not available. The winnower was modified to improve the performance. A 4 hp diesel engine was replaced by electric motor. The winnowing capacity of the modified winnower was 550-600 kg hr^{-1} (paddy), which was higher than the previous BRRI winnower.

Satter *et al.*, (2005) reported that the average capacity of pedal and power winnower was 406 and 808 kg hr^{-1}, respectively. The average cleaning efficiency for pedal and power winnower is 97 and 93%, respectively. The operating cost of pedal and power winnower are Tk 22 and 15 hr^{-1}, respectively. Loss is one percent in winnower compared to six percent that of traditional system.

Mazed (2004) reported that grain winnower can be made in small workshop with locally available iron materials and suitable for seed production farm. Two operators can clean about 750 kg paddy hr^{-1}, reduce human drudgery for manual winnowing. This winnower can serve farms with electricity facilities. All parts are made of sheet metal, metal screen and mild steel.

Ahiduzzaman *et al.*, (2000) reported that cleaning efficiency by *Kula* was found 96% whereas by BRRI winnower was 95.3% at single pass. Cleaning efficiency increased to 98.5 and 99.15% by double and triple pass respectively. The machine winnowing capacity was 423 kg hr^{-1} (0.6 man-day t^{-1}) at single pass over manual winnowing capacity of 47 kg hr^{-1} (2.66 man-day t^{-1}). Winnowing capacities were found to be 256 kg hr^{-1} and 188 kg hr^{-1} at double and triple pass, respectively. The authors also reported that, manual winnowing cost was found Tk 146 t^{-1}; whereas mechanical winnowing cost was Tk 41, 62 and 92 t^{-1} at single, double and triple passes, respectively.

This chapter discusses various materials and methods followed for the experimental work. The experiment was conducted for studying the profitability of selective mechanization in rice cultivation over traditional method in *aman* season 2015.

Experimental location

This experiment was conducted in the farmers' field (25º32-25º46' N and 89º18'-89 º30' E with 12 m altitude from mean sea level), Purbaparul, Pirgacha, Rangpur (Fig. 4.1). Pirgacha upazila lies under the Tista Meander Floodplain (AEZ 3). This AEZ 3 holds most of the Rangpur, eastern part of Panchagarh and Dinajpur; northern Bogra and part of Jaipurhat, Noagaon and Rajshahi districts covering area of 9,468 sq. km (BBS, 2012).

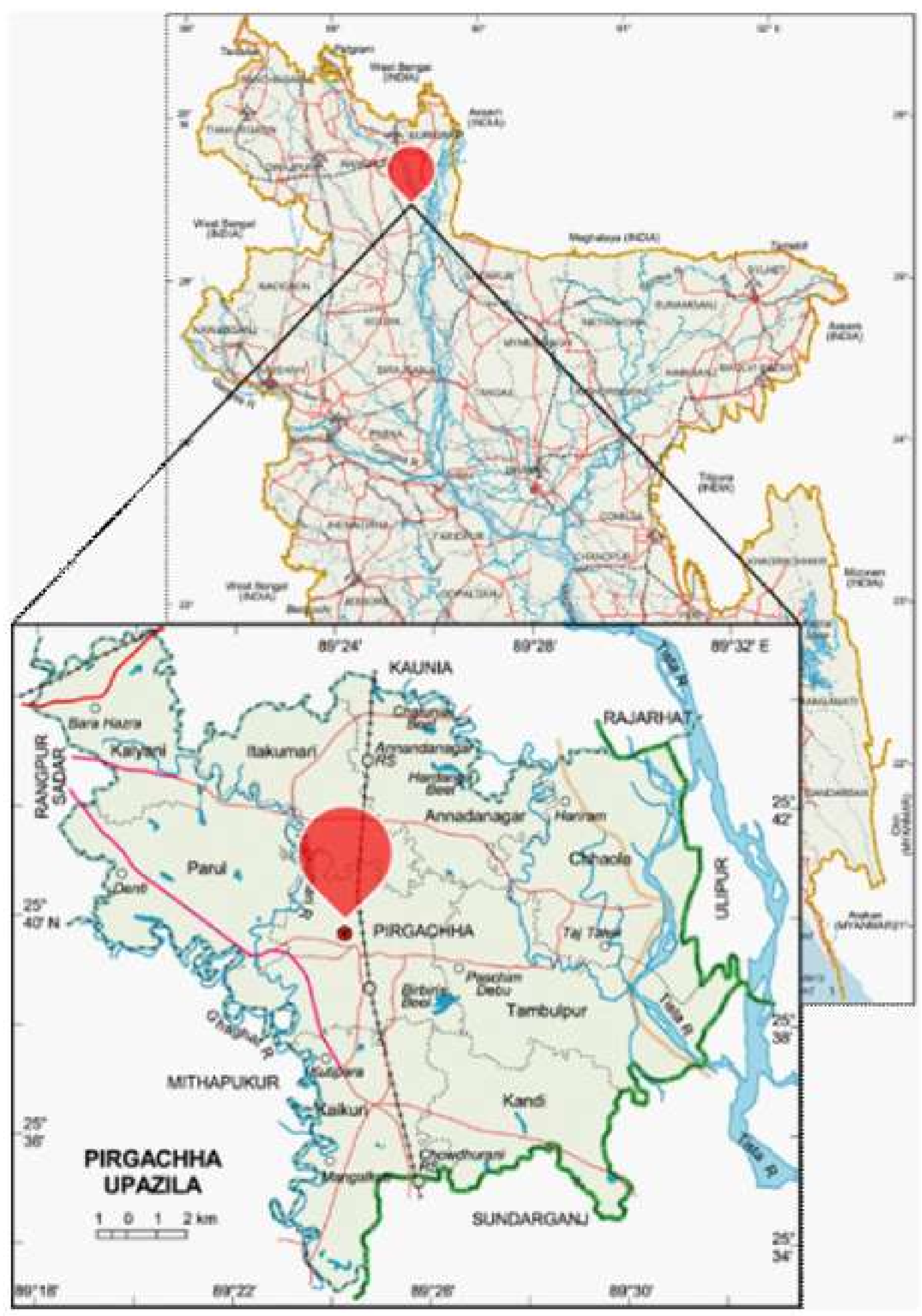


Fig. 4.1 Location of the study

Soil composition of study area was alluvial soil (80% of total area) of the Teesta River basin, belonged to Non-calcareous Grey Floodplain (non-saline) category (UNDP-FAO, 1988). Soil pH ranges from 5.4 to 6.5, having limitations like doughtiness in dry season, rapid to moderate permeability and low water holding capacity. The climate of the experimental region is tropical wet and dry. The annual rainfall averages to 2,931 mm and annual temperature ranges from 11 to 32ºC (Fig. 4.2). Rainfall is generally heavy during July and August (BBS, 2009).

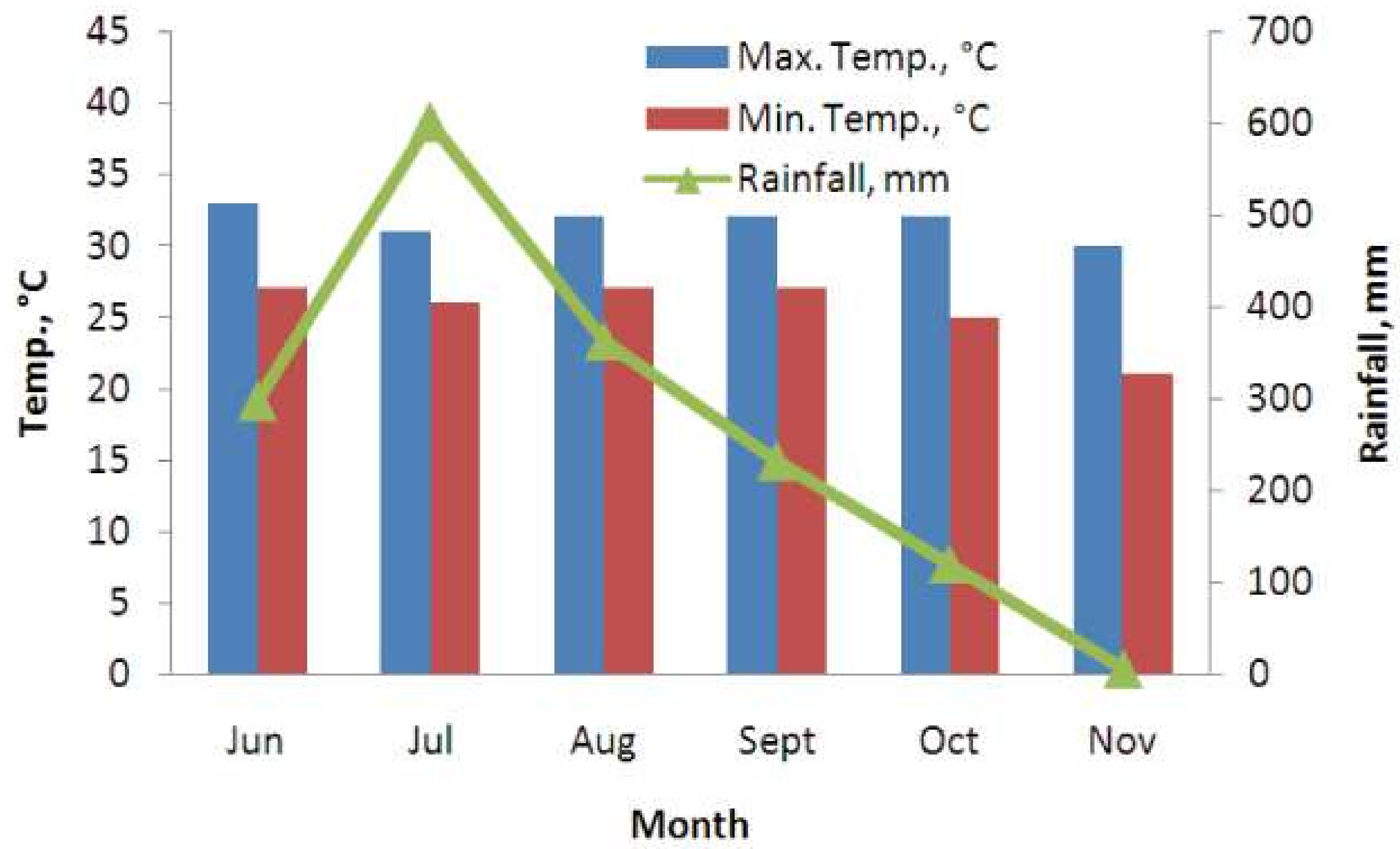


Fig. 4.2 Temperature and rainfall distribution during experimental period

Experimental design

Four mechanization systems were designed to conduct the experiments (Table 4.1). Mechanical options were changed in transplanting, weeding and harvesting operation. Two methods were used in transplanting i.e. hand transplanting (HT) using traditional seedling (S_1) and mechanical transplanting (MT) using special seedling (S_2, S_3 and S_4). Four weed control methods were used namely hand weeding (HW), BRRI weeder (BW), BRRI power weeder (BPW) and herbicide control (HC). Two harvesting methods were used namely manual harvesting by using sickle in S_1 and mechanical harvesting using self-propelled reaper in S_2, S_3 and S_4. Fertilizer, pesticide, threshing and cleaning operations were done by the same methods in all the experimental plots. Fertilizer and pesticide were applied by hand broadcasting and knapsack sprayer, respectively. Crops were threshed and cleaned by BRRI open drum thresher (ODT) and BRRI winnower, respectively. The experiment was laid out in a randomized block design with four replications. Each of the replication represented a block in the experiment.

Table 4.1 Four different mechanization systems in this experiment

Mechanization system	Land preparation	Transplanting	Weeding	Fertilizer application	Pesticide application	Harvesting	Threshing	Cleaning
S_1	PT	HT	HW	HB	Sprayer	Sickle	ODT	Winnower
S_2	PT	MT	BW	HB	Sprayer	Reaper	ODT	Winnower
S_3	PT	MT	BPW	HB	Sprayer	Reaper	ODT	Winnower
S_4	PT	MT	HC	HB	Sprayer	Reaper	ODT	Winnower

PT = Power tiller; HT = Hand transplanting, MT = Mechanical transplanting, HW = Hand weeding, BW = BRRI weeder, BPW = BRRI power weeder, HC = Herbicide control, ODT = Open drum thresher

Seed sprouting

Healthy seeds were selected by specific gravity method. Seeds were then immersed in water in bucket for 24 hrs and then seeds were taken out of water and kept thickly in gunny bags. The seeds started sprouting after 48 hrs and sown after 72 hrs.

Preparation of seedling nursery

High yielding rice variety BRRI dhan52 was used in all the plots to conduct the experiment. A piece of high land was selected for seedling raising. The land was puddled well with country plough, cleaned and leveled with ladder on 14 June 2015. The whole seedbed was then divided into four equal parts for sowing sprouting seeds. The sprouted seeds (dry seed @ 23 kg ha^{-1}) were sown in the nursery bed on 16 June 2015. Proper care was taken to raise the seedlings in the seedbed. Weeds were removed from the seedbed. Manure and fertilizer was not applied whereas, water and pest management practices were followed in order to raise healthy seedlings (Photo 4.1).

Photo 4.1 Conventional seedlings

Seedling uprooting

Nursery beds were made wet by water application both in the morning and evening on the previous day before uprooting the seedlings. Without causing any major injury to the roots, the seedlings were uprooted and kept on soft mud in shade before they were transplanted in the main field. Seedlings were uprooted from seedbed on 22 July 2015 (Photo 4.2). The age of the seedlings was 36 days.

Photo 4.2 Uprooting of the rice seedlings

Tray preparation for mechanical rice transplanter

Bavistin powder was mixed with water. Bavistin powder is generally used to protect the seeds from the seed borne diseases. Seeds were immersed in treated water toprotect from the seed borne diseases. Seeds were kept into soaking for 24 hours. Seeds were taken out from water then kept in gunny bags to create warm environment for seed sprouting. Generally it takes minimum 24 hours for sprouting. Collected dry soil free from debris, hard metal, roots and other foreign materials and normal soil like sandy clay loam was collected for the experiment, which was generally collected in the dry season, then sieve was used for removing any kind of stone, from soil. For mechanical transplanting, seedlings were grown in a tray of 58 × 28 × 2.5 cm size. The plastic trays are used to raise mat-type seedlings. Dry soil was filled in the trays upto 2/3rd of the tray height. Sprouted seeds spread uniformly over the tray. Leveler was used to level the soil. Again dry soils were poured on the sprouted rice seeds upto the height of the trays. Sufficient amount of water was applied to keep the soil moist. Water was sprayed on the tray by sprayer (Photo 4.3). Mat formation was good in *aman* season. Seedlings were carried as making roll from farmers' home to transplanting field by labor (Photo 4.4).

(a) Tray in germination stage

(b) Seedling in tray

Photo 4.3 Rice seedlings on plastic tray

Photo 4.4 Seedling mat transportation to the field

Land preparation

The experimental land was prepared by power tiller (Photo 4.5). The land was well prepared to puddled condition according to the layout on 20 July 2015. All weeds and stubbles were decomposed. Standing water was drained out before transplanting.

Photo 4.5 Land preparationby power tiller

Manual transplanting

Thirty-eight-day-old seedlings were transplanted manually on 23 July 2015. Two to three seedlings were transplanted in each hill (Photo 4.6). Farmers were advised to maintain a spacing of 20 x 20 cm. However, they did not maintained proper line spacing.

Photo 4.6 Manual transplanting

Mechanical transplanting

Thirteen-day-old seedlings were transplanted by mechanical rice transplanter during 23 July 2015 (Photo 4.7). Before starting the transplanter, seedling mat was rolled and fed to the transplanter and all the required adjustments such as hill spacing, number of plant per hill and planting depth were done based on the machine operator's manual. In mechanical transplanter, line to line distance was fixed at 30 cm and plant to plant spacing can be varied and set at 17 cm.

Photo 4.7 Transplanting by mechanical transplanter

Field efficiency of farm machines

Theoretical field capacity

The theoretical field capacity of a machine is the rate of field coverage that would be obtained if the machine performs its function 100% of the time at the rated forward speed and always covers 100% of its rated width. Therefore,

$$C_0 = \frac{W \times S}{T} \qquad (1)$$

Where,

C_0 = Theoretical field capacity, ha hr^{-1}
w = Operating width of the weeder, m
S = Transplanting speed, km hr^{-1}
C = Constant, 10

Actual field capacity

It is the ratio of actual average rate of field coverage by the machine to the total time during operation. Therefore,

$$C = \frac{A}{T} \tag{2}$$

Where,

C= Actual field capacity, ha hr^{-1}
A= Total transplanted area, ha
T= Total operating time required for transplanting, hr

Field efficiency

It is the ratio of effective field capacity to the theoretical field capacity of a machine under field conditions and the theoretical maximum productivity and it can be calculated by the following equation:

$$Eff = \frac{C}{C_o} \times 100 \tag{3}$$

Where,

Eff = Field efficiency, %
C = Actual field capacity, ha hr^{-1}
C_o= Theoretical field capacity, ha hr^{-1}

Fuel consumption

Fuel consumption of transplanter, power weeder, reaper and thresher was measured by filling the fuel tank twice, before and after each operation. Re-filled volume was the actual fuel consumption according to the following equation:

$$Fc = \frac{Fr}{t} \tag{4}$$

Where,

Fc = fuel consumption, l hr^{-1}
Fr = re-filled volume of fuel, l
t = operating time, hr

Fertilizer application

The entire amount of phosphorus, potassium, sulphur and zinc fertilizer in the form of triple super phosphate, muriate of potash, gypsum and zinc sulphate at the rate of 52, 82, 58 and 7.5 kg ha^{-1}, respectively were broadcast and incorporated into the soil at final land preparation. Cow dung was used at the rate of 10 t ha^{-1} at the time of final land preparation. Urea at the rate of 180 kg ha^{-1} was top dressed in three installments, at 15 (60 kg ha^{-1}), 45 (70 kg ha^{-1}) and 55 (50 kg ha^{-1}) day after transplanting.

Water management

Experimental plots were irrigated as and when needed. Excess water was drained out of the plots before 15 days of harvest to enhance maturity of the crop.

Pesticide and insecticide application

Severe pests were infested in the plant during the Aman season. However, the pests were controlled by a single application of Virtaco 40 WG (Clorantanipole+thiomythoxam @ 300 g ha^{-1}), Differ 300 EC (difeconazole+propiconazole @ 750 ml ha^{-1}) and Nativo 75 WG (trifloxystrobin+tebuconazole @ 300 g ha^{-1}) at the vegetative growth stage. From planting to harvesting the crops were kept under constant observations.

Weeding

Weeding was done manually by hand twice at 18 DAT and 55 DAT and machine weeding once at 20 DAT (Photo 4.8). After that no other weeding operation was done up to harvest. During weeding, different weed species grown in the experimental plot were identified and counted species-wise.

Herbicide application

Rifit (pretilachlore) @ 100 ml ha^{-1} was applied at 5 DAT in moist soil by hand broadcasting mixing with urea fertilizer in the plots.

Performance of weeder

Weeding efficiency

To determine the weeding efficiency in three places of each plot bamboo frame of 1×1 m was thrown in the field randomly and the number of weeds was counted. The weeding efficiency was computed by using the following equation:

$$\text{Weeding efficiency, } \Sigma = \frac{W_1 - W_2}{W_1} \times 100 \qquad (5)$$

Where,

W_1 = number of weeds before weeding
W_2 = number of weeds after weeding
Σ = weeding efficiency

Tiller damaged

In order to determine the damaged plant, as a quality of work done (Tewari *et al.*, 1993) in three places of each plot, bamboo frame of 0.50 × 0.50 m was thrown in the field randomly and the number of damaged plants in the frame were counted. The percent of breakage of rice tiller was computed by using the following equation:

$$DP = \frac{Q_1}{Q_2} \times 100 \qquad (6)$$

Where,

DP = Damaged tillers, %

Q_1 = Number of tillers broken in the row after weeding operation

Q_2 = Total number of plants in the row

a. Manual weeding

b. BRRI weeder

c. BRRI Power weeder

d. Herbicide application

Photo 4.8 Weeding operation

Weed species

Data on weed density were collected from each plot at vegetative growth stage of the rice plants by using 0.5 × 0.5m quadrate as per method described by Cruz *et al.* (1986). The quadrate was placed in three spots at random outside 1 m^2 central areas, kept for taking yield data (Photo 4.9). The weeds within the quadrate were counted species-wise and converted to number m^{-2} multiplying by four.

Photo 4.9 Data collection on weed counts

Performance of thresher

Threshing capacity

The weight of grains (whole and damaged) threshed per unit time is called threshing capacity. At the end of each test, total threshed grain was collected and the capacity was calculated from the following expression:

$$TC = \frac{WG}{T} \times 60 \qquad (7)$$

Where,

TC = threshing capacity, kg hr^{-1}
WG = weight of total output grain, kg
T= recorded time, hr

Separating loss

The loosed grain collected from threshed straw is called separating loss. The separating loss was calculated as follows:

$$SL = \frac{WSG}{WG + WSG + WPG} \times 100 \qquad (8)$$

Where,

SL = separating loss, %
WG = weight of output grain, kg
WSG = weight of separating loss grain, kg
WPG = weight of spilled grain, kg

Spilled grain loss

During threshing, the threshed straws were deposited at a distance in front of the thresher. After collecting the threshed grain as net output, the grains still scattered at a certain distance from the thresher was termed as spilled grain. The spilled grain loss was calculated in respect to total grain as:

$$PL = \frac{WPG}{WG + WSG + WPG} \times 100 \quad (9)$$

Where,

PL = Spilled grain loss, %
WG = weight of output grain, kg
WSG = weight of separating loss grain, kg
WPG = weight of spilled grain, kg

Gross threshing loss

Gross threshing loss included cylinder loss, separating loss and scattered grain loss. After threshing, the weights of un-threshed, scattered and threshed grains un-separated from straw were obtained and the loss was calculated as follows:

$$GL = \frac{WSG + WPG}{WG + WSG + WPG} \times 100 \quad (10)$$

Where,

GL = Gross threshing loss, %
WG = weight of output grain, kg
WSG = weight of separating loss grain, kg
WPG = weight of spilled grain, kg

Threshing efficiency

The threshing efficiency was calculated from the following expression:

$$TW = \frac{WG}{WG + WSG + WPG} \times 100 \quad (11)$$

Where,

TE = Threshing efficiency, %
WG = weight of output grain, kg
WSG = weight of separating loss grain, kg
WPG = weight of spilled grain, kg

Performance of winnower

The test involves taking a pair of samples, which were at the grain outlet and the non-grain (unwanted material) outlet. The weights of grain and other material in each sample were recorded. The procedure was repeated for each throughput. The amount of debris in clean grain outlet samples determined the cleanliness (cleaning efficiency) while the amount of grain found in non-grain outlet samples determines the grain loss. The cleaning efficiency and grain loss were calculated as follows:

$$EC = \frac{WG}{WTG} \times 100 \quad (12)$$

$$GL = \frac{WGN}{WG + WGN} \times 100 \quad (13)$$

Where,

EC= Cleaning efficiency, %
GL = Grain loss, %
WG= Weight of grain material in clean-grain sample, kg
WTG = Weight of total material in clean-grain sample, kg
WGN = Weight of grain material in non-grain sample, kg

Yield and yield contributing characters

Two sample area of around 10 m^2 were selected randomly in each plots and harvested to obtain grain yield. Wet grain weight was adjusted to 14%(wb) moisture content. Twelve hills were selected randomly in each plot to measure plant height and panicle length (Photo 4.10). Plant height was measured from the base to tip of the longest panicle. Panicle length was taken by measuring distance from the basal node to apex (Photo 4.11). Each of the panicles having no grains is considered as non-effective tiller and at least one grain was counted as effective tiller. Number of panicles in each hill were counted and recorded to determine panicle number m^{-2} (Photo 4.12).

a. Measuring sample area

b. Harvesting sample area

4.10 Measuring yield contributing characters

4.11 Measuring the plant height and panicle length

4.12 Counting effective and total tillers per hill

Photo 4.13 Crop condition at 100 DAT

Harvesting, threshing and cleaning

When about 85-90% of the grains become golden yellow, the crop was thought to be matured. Manually transplanted plots matured earlier as the seedling age was 36 days and harvested on 17 November 2015. Transplanted seedling of 13 days were matured later and harvested on 23 November 2015 (Photo 4.14). The harvested crop of each plot was bundled separately, tagged properly and brought to the clean threshing floor (Photo 4.15). The bundles were dried in open sunshine, threshed and seeds were cleaned (Photo 4.16).

a. Manual harvesting **b. Mechanical harvesting**

Photo 4.14 Harvesting operations

c. Crop binding — d. Carrying from field

Photo 4.15 Harvested crops are bundled and carrying to the farm yard

e. Mechanical threshing — f. Mechanical winnowing

Photo 4.16 Threshing and cleaning operations

Economic analysis

In order to estimate the production cost, the data on working speed, total time and labor and material inputs to complete the operations were recorded. Rental charge of the machines was also included in the cost estimation.Table 4.2 presents detailed view of rental charge and fuel costs. Among these machines, mechanical weeder was an exception with no fuel cost.

Table 4.2 Machine-wise rental charge and fuel costs

Machine	Rental charge Tk ha^{-1}	Fuel cost Tk ha^{-1}	Total Tk ha^{-1}
Transplanter	2310	620	2930
BRRI Weeder	76	NA	76
BRRI Power Weeder	373	1012	1385
Reaper	658	357	1014
Opendrum thresher	387	633	1020
Winnower	83	150*	233

*Electricity and cable hiring cost

Land value and interest on investment was considered to calculate the total input cost. Price of the produce was collected from the local markets to compute total production cost, gross return, gross margin and benefit-cost ratio. The benefit-cost ratio (BCR) was computed as follows:

$$BCR = \frac{\text{Gross Return}}{\text{Production Cost}} \qquad (14)$$

Statistical analysis

Statistical analysis was done by using software IRRI STAR 2.0.1. Least significant difference was used to compare the means.

Results and Discussions

The results obtained in this study have been presented and interpreted in this chapter under relevant headings and sub-headings

Machine performance

Table 5.1 presents the performance parameters of farm machines used in the study. Field capacity of DP480 model rice transplanter was lower than Kukje model as reported by Munnaf (2013) due to smaller sizes of plots. The field capacity of BRRI weeder was higher as mentioned in Islam *et al.* (2015c) due to less weed infestation and soft soil. Weeding was performed on a contractual basis rather than daily labor, and lead them to work faster. Field capacity of BRRI power weeder was slightly higher than the other model as reported by Alizadeh *et al.* (2011), because soil of the study location was softer than that in Iran. The field capacity and fuel consumption of the Vietnamese self-propelled reaper was found similar to BRRI self-propelled reaper as reported by Zami *et al.,* (2014). Threshing capacity of open drum thresher was found similar to 359 kg hr^{-1}, though gross threshing loss was lower compared to 2.16 for BRRI open drum thresher as reported by Alam *et al.* (2007). The cleaning efficiency of BRRI winnower found satisfactory in a single pass operation because of improved design. There was noticeable grain loss and winnowing capacity was lower compared to 550-600 kg hr^{-1} because of lack in operator's skill.

Table 5.1 General performance characteristics of farm machines

<table>
<tr><th>Machine</th><th>Forward speed, km hr^{-1}</th><th>Field capacity, ha hr^{-1}</th><th colspan="2">Field efficiency, %</th><th>Fuel consumption, L hr^{-1}</th></tr>
<tr><td>Transplanter</td><td>1.80</td><td>0.14</td><td colspan="2">57.09</td><td>0.71</td></tr>
<tr><td>BW</td><td>2.64</td><td>0.06</td><td colspan="2">-</td><td>-</td></tr>
<tr><td>BPW</td><td>2.44</td><td>0.11</td><td colspan="2">51.86</td><td>0.65</td></tr>
<tr><td>Reaper</td><td>3.67</td><td>0.24</td><td colspan="2">53.90</td><td>0.84</td></tr>
<tr><td rowspan="3">ODT</td><td rowspan="2">Threshing capacity, kg ha^{-1}</td><td colspan="3">Loss, %</td><td rowspan="2"></td></tr>
<tr><td>Cleaning</td><td>Spilled</td><td>Gross</td></tr>
<tr><td>353</td><td>1.30</td><td>0.34</td><td>1.64</td><td>0.60</td></tr>
<tr><td></td><td>Capacity, kg ha^{-1}</td><td>Cleaning efficiency, %</td><td colspan="2">Grain Loss, %</td><td>Electricity consumption, kW hr^{-1}</td></tr>
<tr><td>Winnower</td><td>359</td><td>99.81</td><td colspan="2">1.77</td><td>0.373</td></tr>
</table>

Seedling tray requirement

Number of seedling tray used during transplanting was directly related to space setting. Average tray requirement ranged from 160-170 ha^{-1} during *aman* season. Transplanter should be calibrated on seedling density, space and depth setting depending on the seedling density, vigor and land condition before start the transplanting operation.

Plant spacing

Figure 5.1 presents the histogram of plant spacing. The line to line spacing was taken 30 cm for mechanized transplanting keeping 17 cm plant to plant spacing though it was found impossible to keep consistency in plant to plant spacing. The reason behind this inconsistency was skidding and slipping of lug wheel in puddled field.

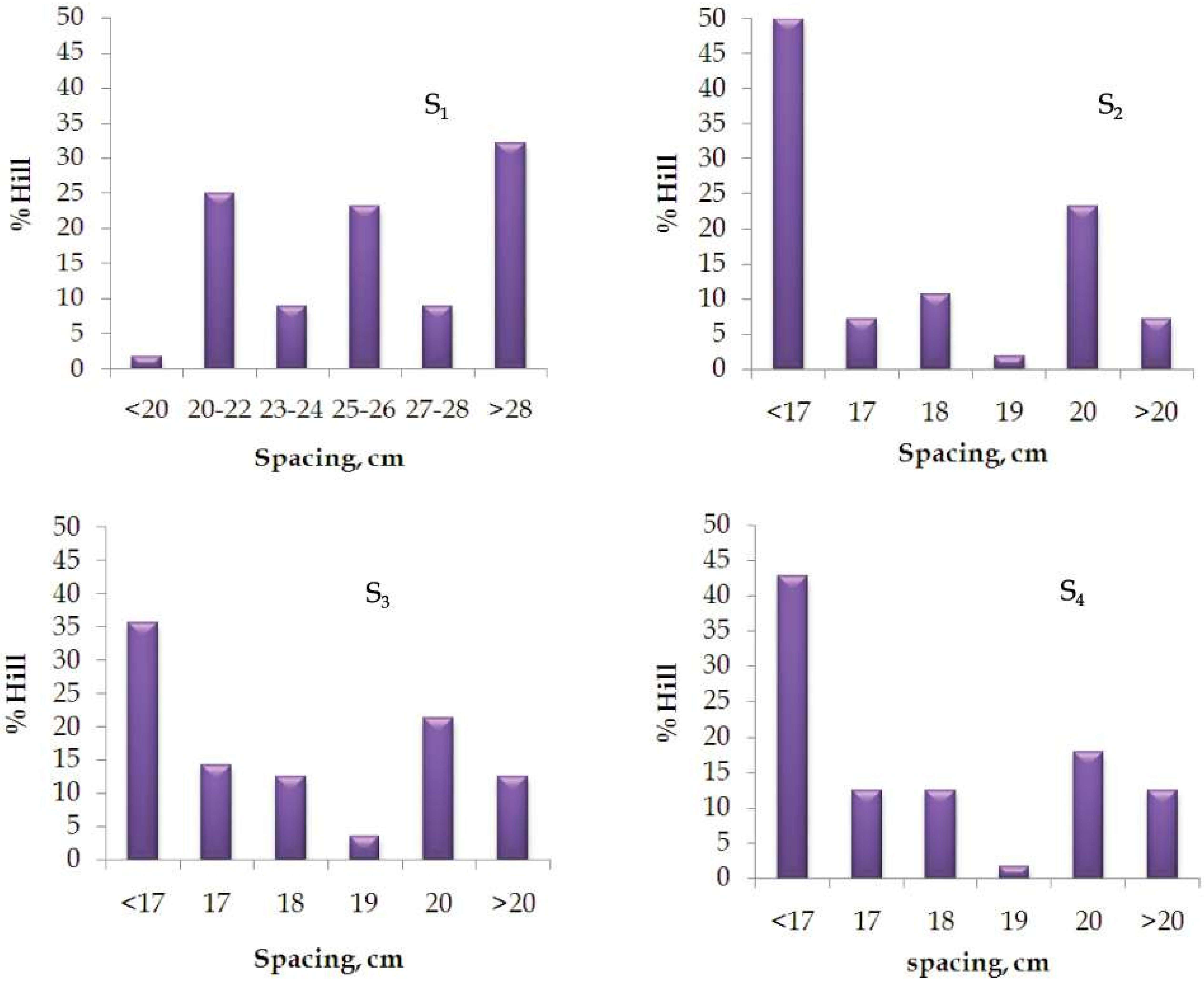


Fig. 5.1 Histogram of plant spacing

Hill density

Plant population is directly related to hill density in any experimental field. Figure 5.2 presents the treatment-wise hill density. Hill density was lower in T_1 than the other three mechanized treatments due to higher plant to plant spacing.

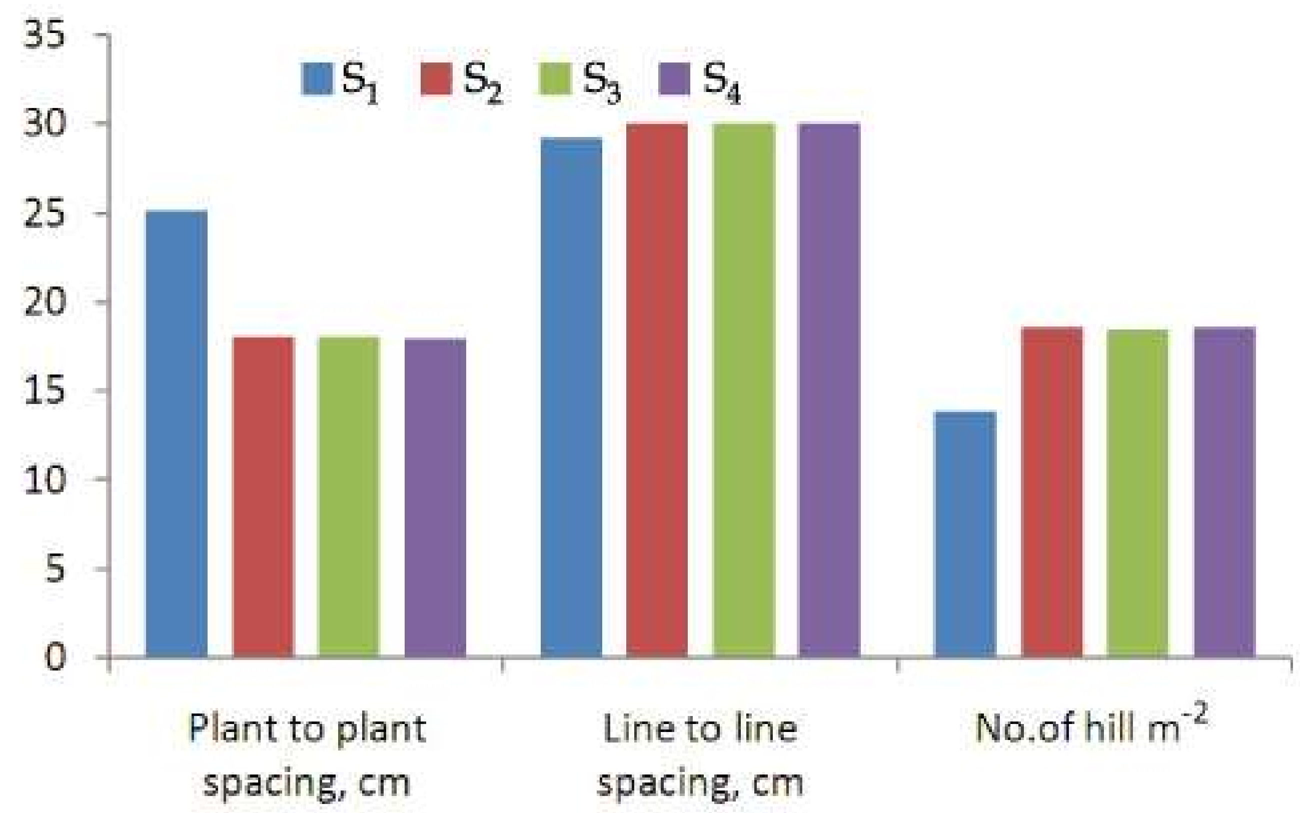


Fig. 5.2 Hill density of mechanical and manual transplanted field

Weed species

Twelve weed species were found during weed sampling (Table 5.2). Among those Khudey shama *(Echinochloa colona* L.;Beauv), Keshuti *(Eclipta prostrata),* Goicha *(Paspalum comersoni),* Kanainala *(Murdania nudiflora),* and Kakri *(Cucumismelo* var. *utilissimus*) showed significant presence. Most of the weeds were found annualandperennial belonging to grass, broad leaf and sedge category. The broad leaved constituted 13.32%, grasses 83.42% and sedges 3.26% of the total weed population. Khudeshama *(Echinochloa colonum* L.*)* was found with the highest infestation in experimental plots.

Table 5.2 Growth of weed species in the experimental plots

Local name	English name	Scientific name	Family name	Life cycle	Type	Population (%)
Khudeshama	Jungle rice	*Echinochloa colona L.*;Beauv	Gramineae	Annual	Grass	77.81
Keshuti	White eclipta	*Eclipta prostrata*	Compositae	Annual	Broadleaf	7.84
Goicha	Paspalum grass	*Paspalum comersoni*	Poaceae	Perennial	Grass	4.13
Kanainala	Kanai nala	*Murdania nudiflora*	Commelinaceae	Annual	Broadleaf	4.03
Kakri	Long melon	*Cucumismelo var.* utilissimus	Cucurbitaceae	Perennial	Sedge	2.06
Jhilmorich	Jhilmorich	*Sphenoclea zeylanica* Gaertn.	Sphenocleaceae	Annual	Broadleaf	1.14
Kalmilata	Water Spinach	*Ipomoea aquatica* Forssk.	Conovolvulaceae	Annual	Broadleaf	0.10
Durba	Bermuda Grass	*Cynodonda ctylon L.*; pers	Gramineae	Perennial	Grass	0.83
Chesra	Bog bulrush	*Scripus juncoides*	Cyperaceae	Perennial	Sedge	0.68
Kochuripana	Water hyacinth	*Eichhomia crassipes*	Pontederiaceae	Perennial	Sedge	0.52
Anguli	Scrab grass	*Digitaria sanguinalis L.; Scop*	Gramineae	Annual	Grass	0.65
Panikachu	Big water colocasia	*Monochoria hastata*	Pontederiaceae	Annual	Broadleaf	0.21

Weeding efficiency

Figure 5.3 shows the weed control efficiency of different weed management methods. Apparently, HW and HC controlled weed successfully, however weeds were seen to regain in the HW field just after few days. This was happened because the weeds were temporarily suppressed and not uprooted permanently, which necessitated second hand weeding whereas, herbicide controlled weed successfully. The efficacy of herbicide depends on the application time and dose. Among the mechanical weed management options, BPW showed the highest weed control efficiency than BW. The reason behind higher efficiency in BPW was the active rotor mechanism of power weeder providing tremendous shuffling force, which results in much better displacement action against weeds not only on surface but also from root level. Weeding efficiency of BPW observed in the present study is similar to the finding of Islam *et al.* (2015c).

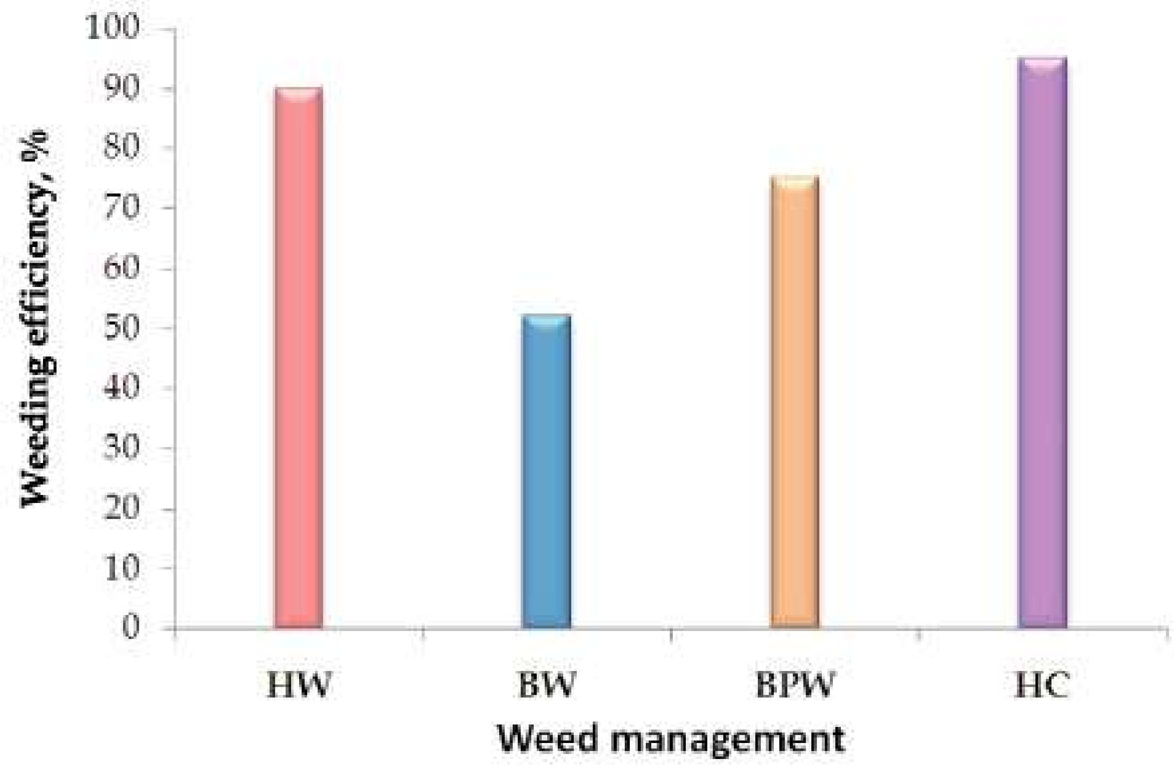


Fig. 5.3 Weeding efficiency

Tiller damaged

Damaged tiller ratio is a reflection of quantity of crops damaged during weed control operation by mechanical means and depends on uniformity of plant to plant spacing in the experimental fields. Exact plant spacing is prerequisite of mechanized weeding which depends on skilled labor. As the plots belonging to BW and BPW were transplanted using rice transplanter, plant spacing was mostly uniform and did not enhance tiller damage so much. But the inclination of plants over inter-plant spaces caused obstruction in movement of weeder and resulted in consequent crop damage. Figure 5.4 presents a comparison of damage plants in experimental plots across treatments. Between two treatments, BPW incurred the highest tiller damage (14%) because of high forward speed and blade rotation. On the other hand, low percentage of tiller damage was obtained in BW (8%), which was operated at slower speed than BPW. The data also revealed that between two weeding method, the percentage of damaged tiller in BPW was as much as double than that in BW. Tiller damage in BW was close to the findings of Islam *et al.,* (2015c) whereas higher in BPW due to lack of operator's skill and faster in machine speed.

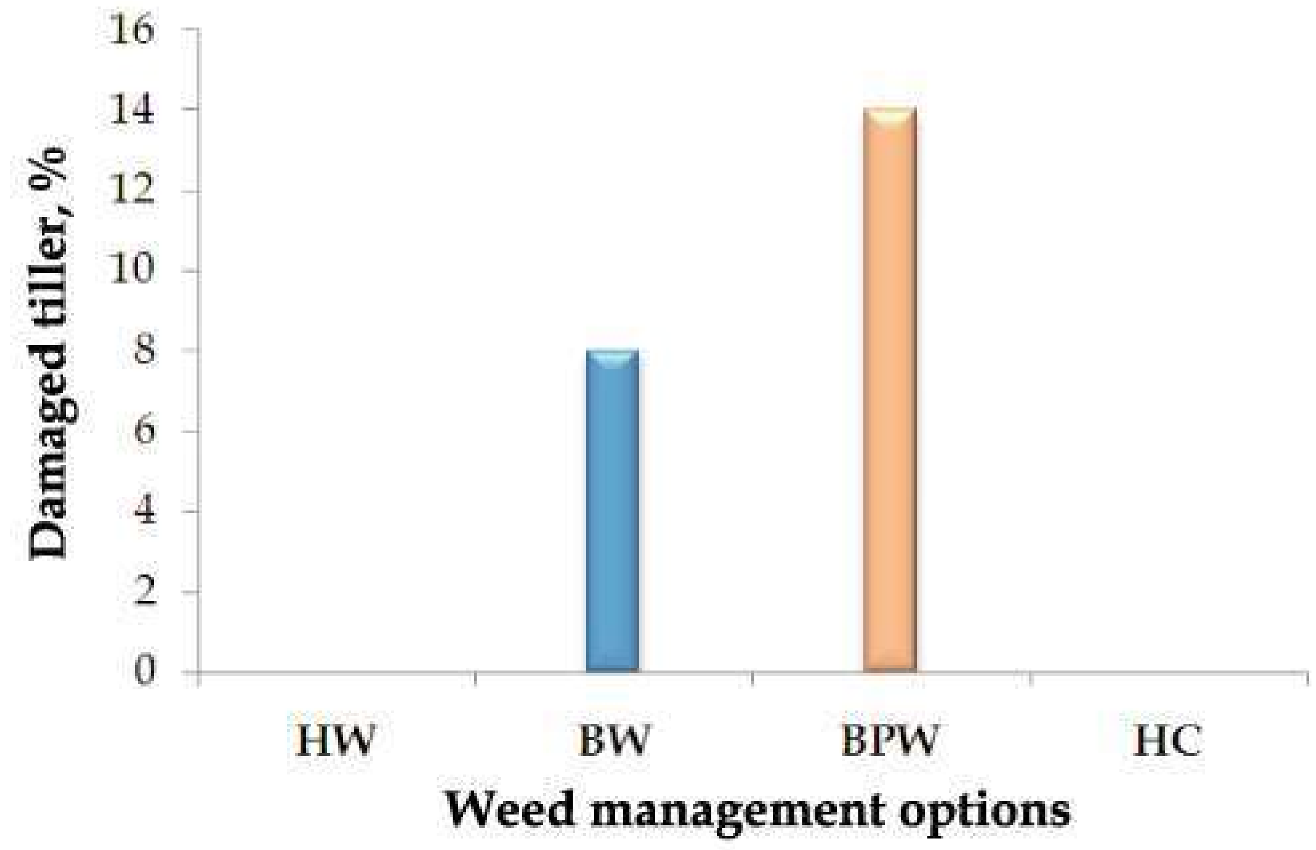


Fig. 5.4 Tiller damaged during weeding operation

Plant height

Plant height in S_1 was primarily observed to be higher than the other three treatments from 20 to 60 DAT, but in maturity stage it became similar for all (Fig. 5.5). This reveals that S_1 attained greater height because seedlings were older than that of other three treatments.

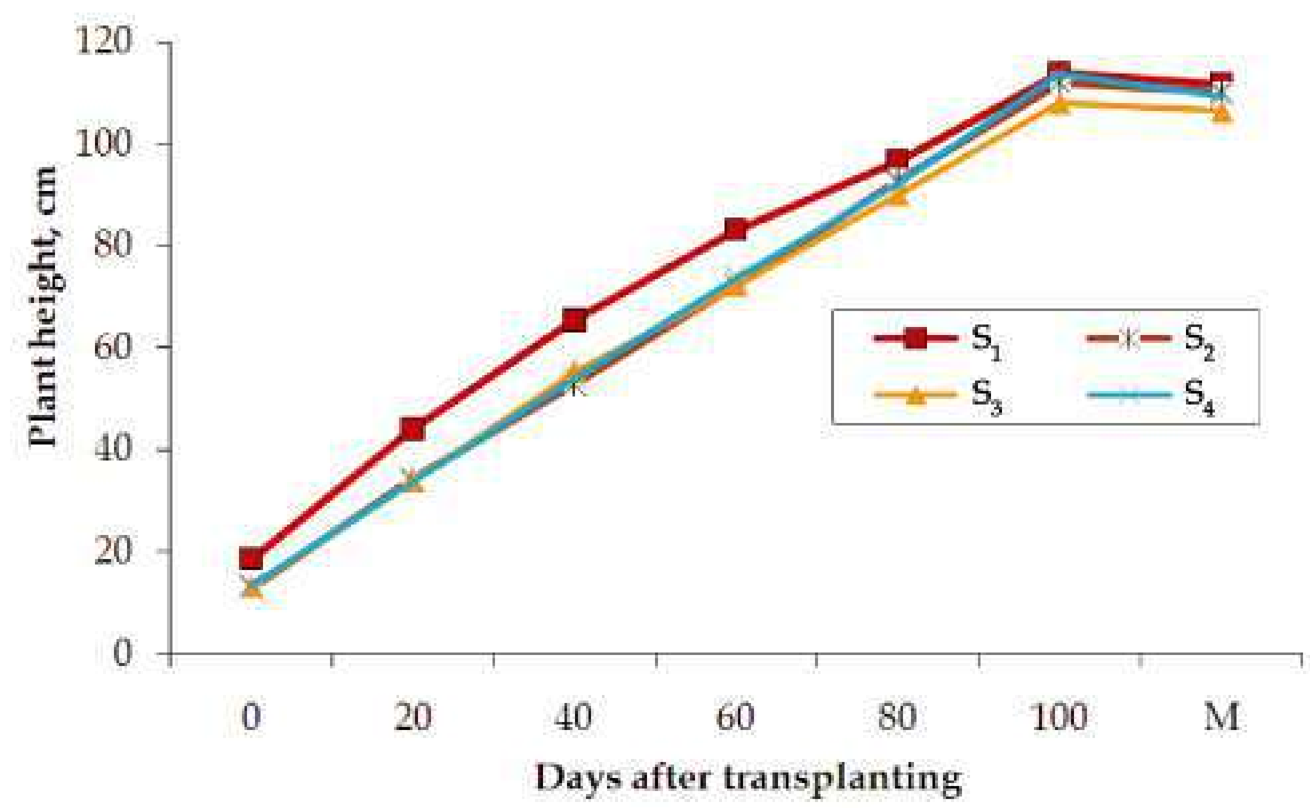


Fig. 5.5 Plant height in the experimental plot

Tillering pattern

At different DAT

Tillering pattern followed similar trend from 0 to 20 DAT in all the treatments (Fig. 5.6). Crops were submerged in water for eight days from 20 DAT (12-08-2015), which hindered growth of tillers at its maximum tillering stage. After submergence (from 40 DAT), the tillering ability in manually transplanted fields always lag behind the mechanically transplanted field, which might be due to use of older age seedling. Among four treatments, seedlings in S_1 were older than the others resulting in lower tiller production. This was happened because of older seedlings were weak in food competition than the younger ones. Final attainment in number of tillers was not as much as expected. During operation of weeder, damaged tiller was observed higher in BPW than BW and plants were revived later due to compensating behavior of rice plants and followed the similar trend of herbicide control field. S_4 showed the highest tiller survival and the lowest in S_1.

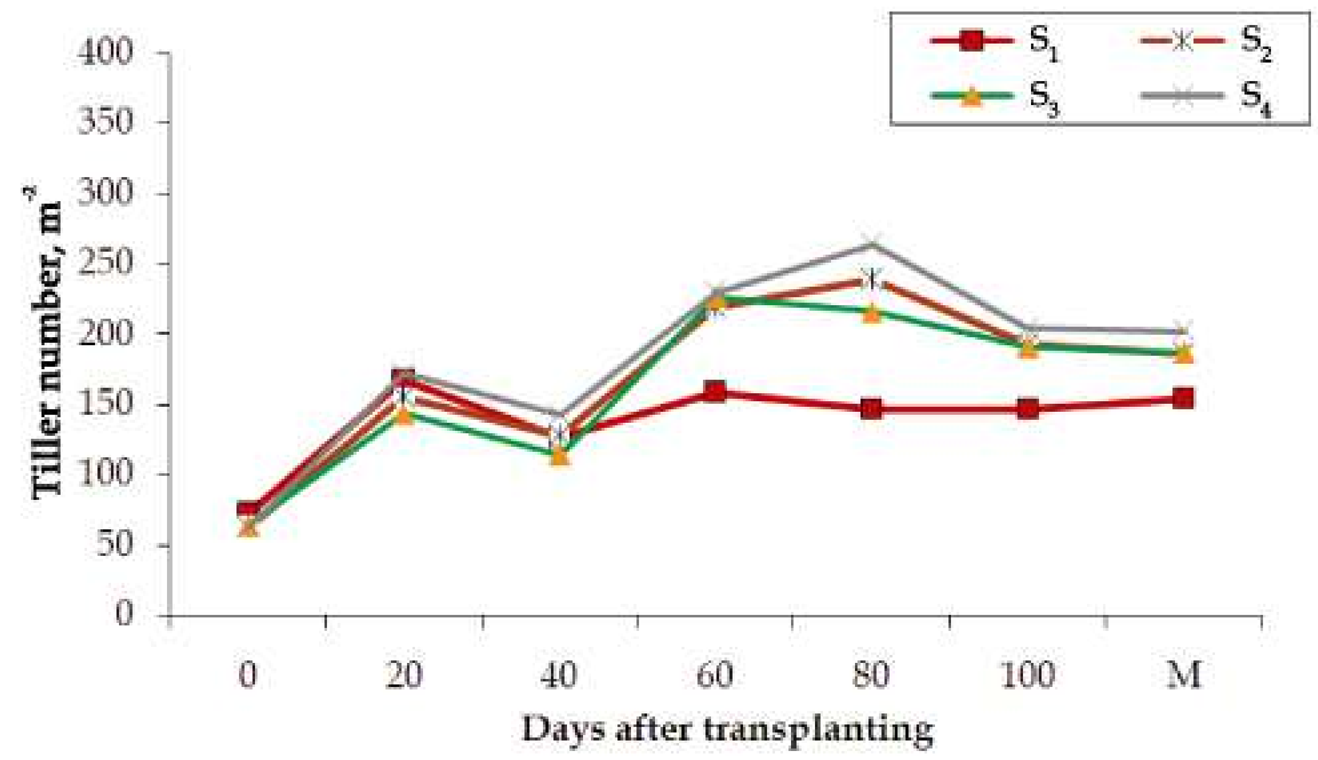


Fig. 5.6 Tiller number at different DAT

Stage-wise

Numbers of tillers were counted and recorded throughout the study period. Figure 5.8 present the tiller count in different growing stages. At active tillering stage, plant population was almost similar in manually and mechanically transplanted field. Much difference was observed at maximum tillering, where mechanically transplanted field produced the highest tiller than manually transplanted plots and remains higher upto maturity stage. Among the mechanically transplanted plot, weed control by BW and BPW field produced the lowest number of tillers than the herbicide control field at maximum tillering stage, which might be due to tiller damage during weeding operation. At flowering and maturity stage, some tillers were aborted and the plant populations were almost similar among the mechanically transplanted field due to leaf senescence.

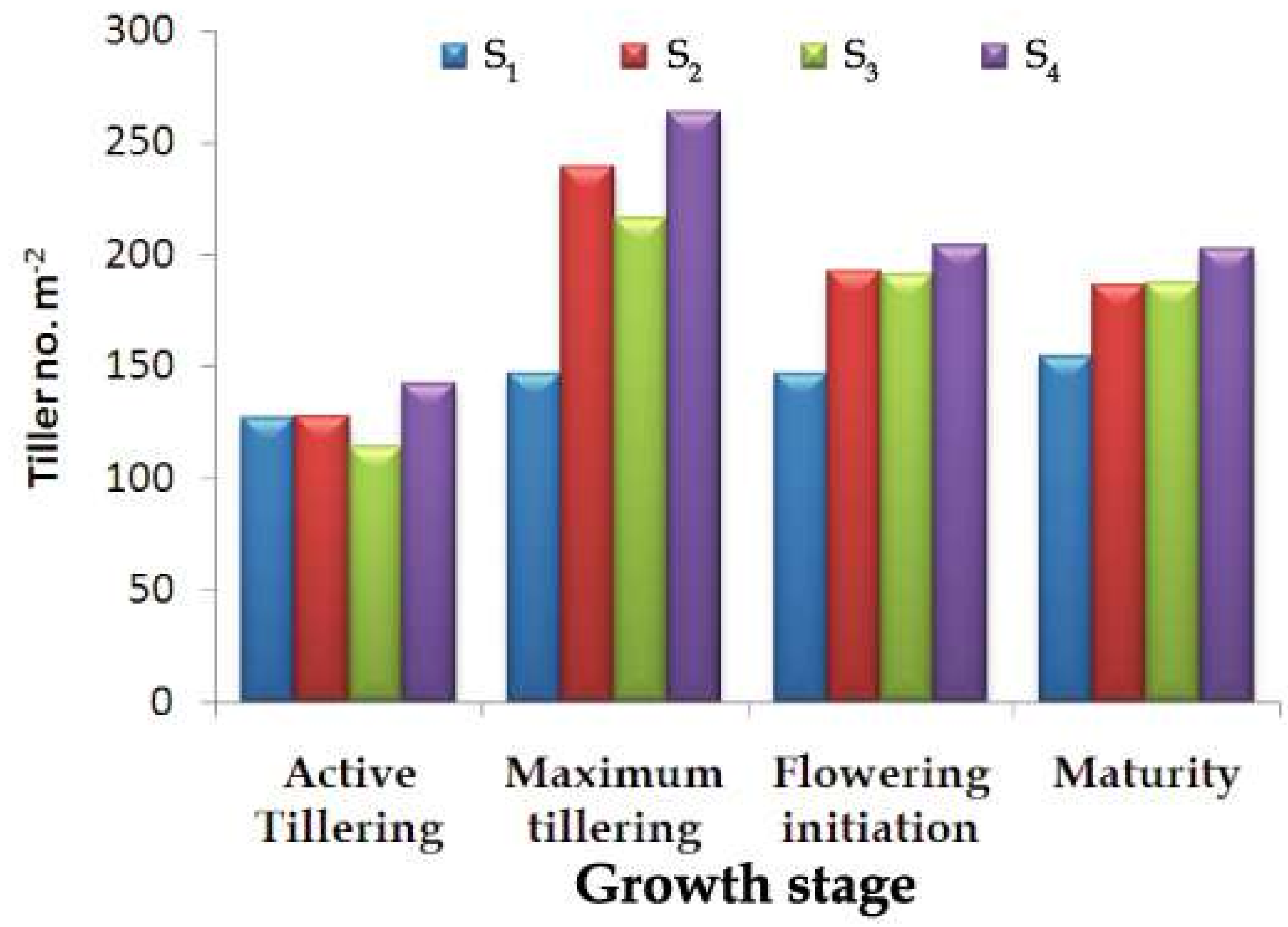


Fig. 5.7 Tiller number at different growth stage

Grain yield

Figure 5.8 presents the yield, which was statistically analyzed. Grain yield was significantly higher (9-11%) in mechanically than manually transplanted field. Regular field monitoring was done to observe the crop condition. In the whole period of experiment, the field was nicely green ensuring the normal growth. Insect pest and disease were observed severe and control measures were taken by applying insecticide and pesticide. Lodging of any plants were not observed and yield was not reduced due to lodging.

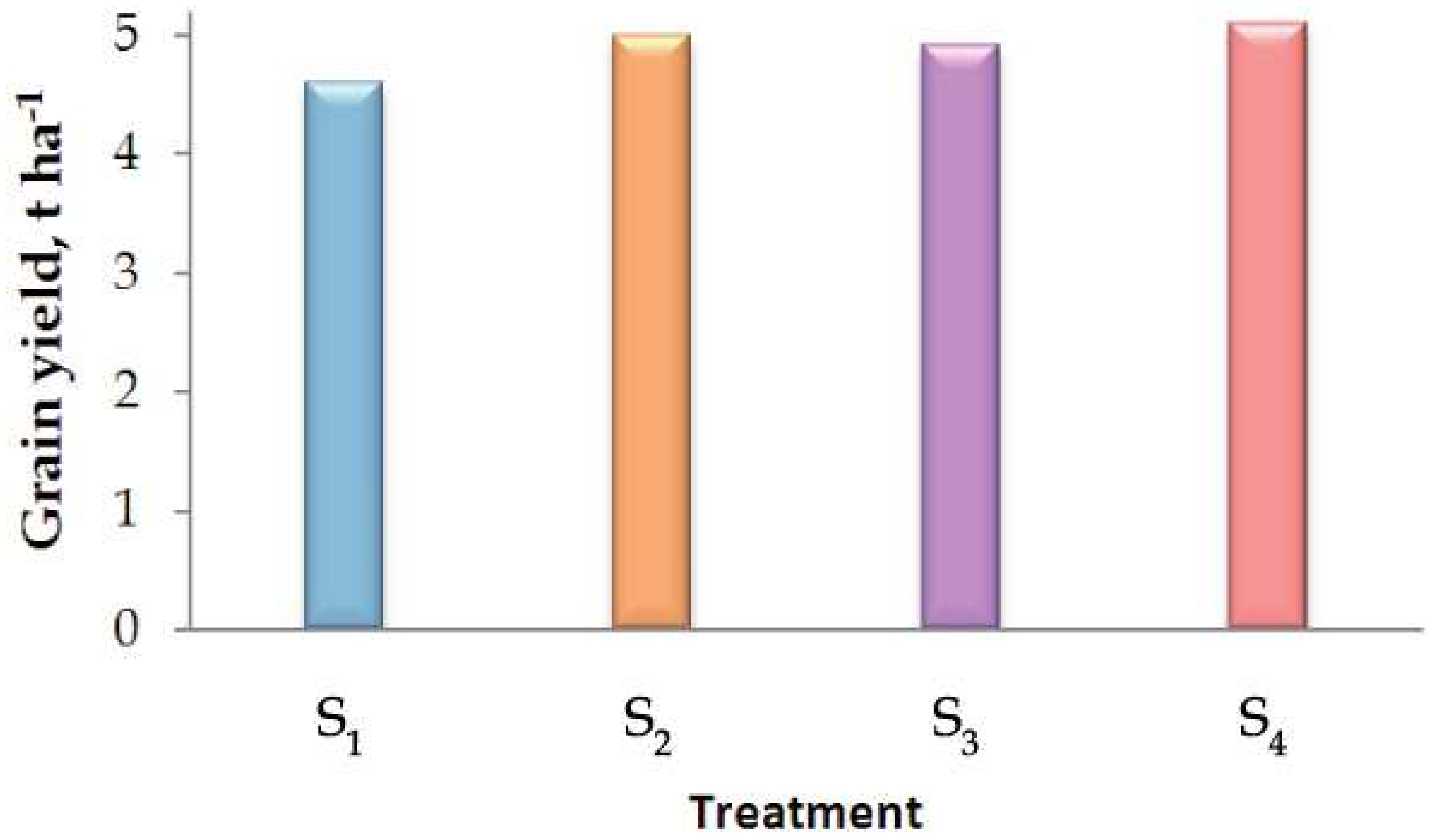


Fig. 5.8 Effect of selective mechanization on grain yield

Labor requirement in rice production

Transplanting

Labor requirement in seedling tray preparation for mechanical transplanter (61.15 man-hr ha^{-1}) was observed 49% higher than that in traditional method of seedbed preparation (31.25 man-hr ha^{-1}) due to higher time required in soil sieving and irrigating the trays (Fig. 5.9). On the other hand, manual transplanting (150 man-hr ha^{-1}) required 17 times more labor than mechanical transplanting (9 man-hr ha^{-1}). The present findings coincided with the result mentioned in Islam *et al*. (2015a). It was observed that 61% less time was required from seedling raising to transplanting in mechanical (181.45 man-hr ha^{-1}) than manual transplanting (70 man-hr ha^{-1}) in Aman season. Islam *et al*., (2015a) also reported that labor requirement in seedling raising in Boro season was 71-77 man-hr ha^{-1}, which was higher than the present findings of 61 man-hr ha^{-1} due to less age of seedlings as well as less nursery time required in *aman* season than that in *boro* season.

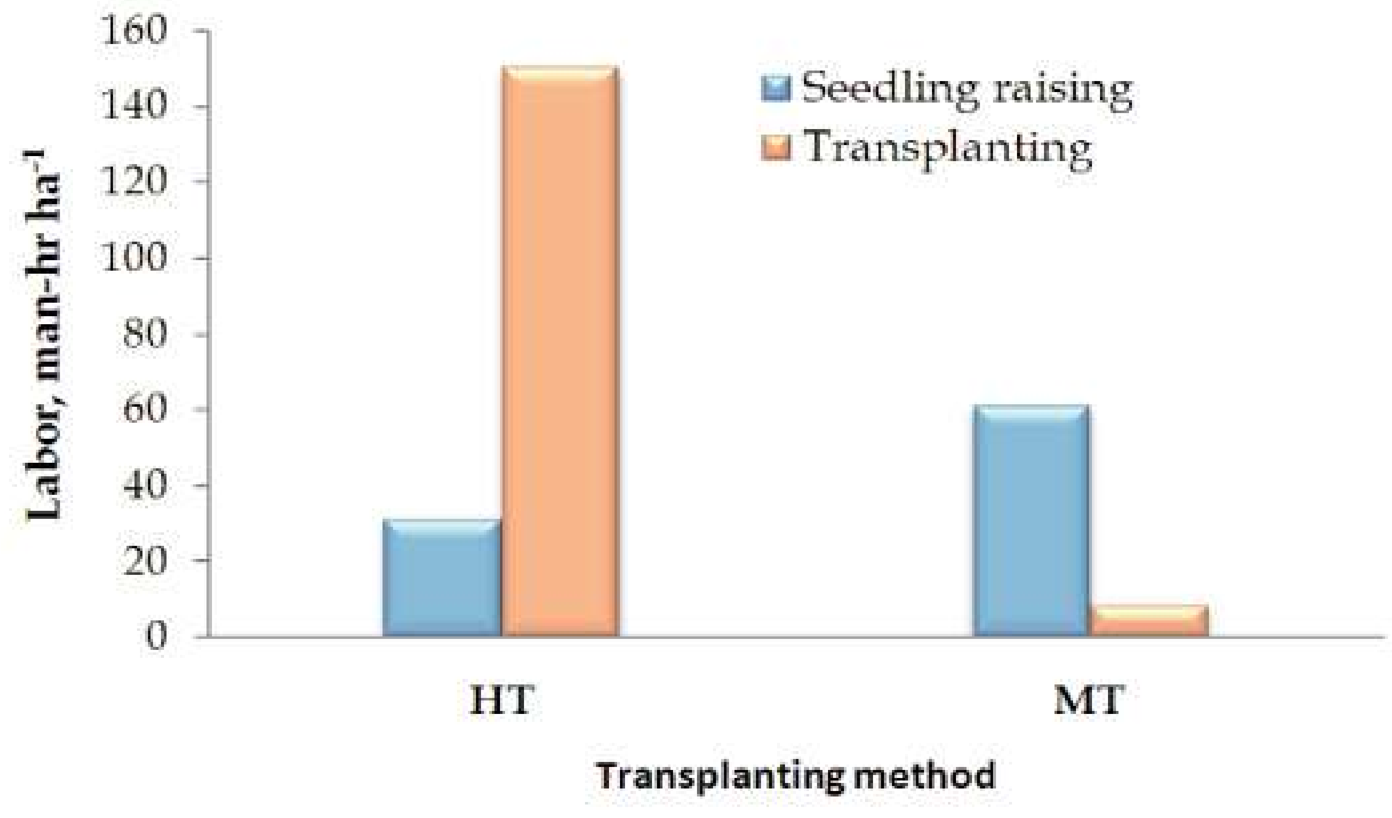


Fig. 5.9 Labor requirement in transplanting

Weeding

Method of weed management had a substantial effect on labor requirement. The highest labor was involved in HW and lowest in HC. Hand weeding reflected the most labor intensive operation in rice production (Fig. 5.10). BW (26 man-hr ha^{-1}), BPW (9 man-hr ha^{-1}) and HC (2 man-hr ha^{-1}) saved 74, 91 and 98% labor requirement in weeding operation compared to HW. The present results supported the findings as reported by Islam *et al*. (2015c).

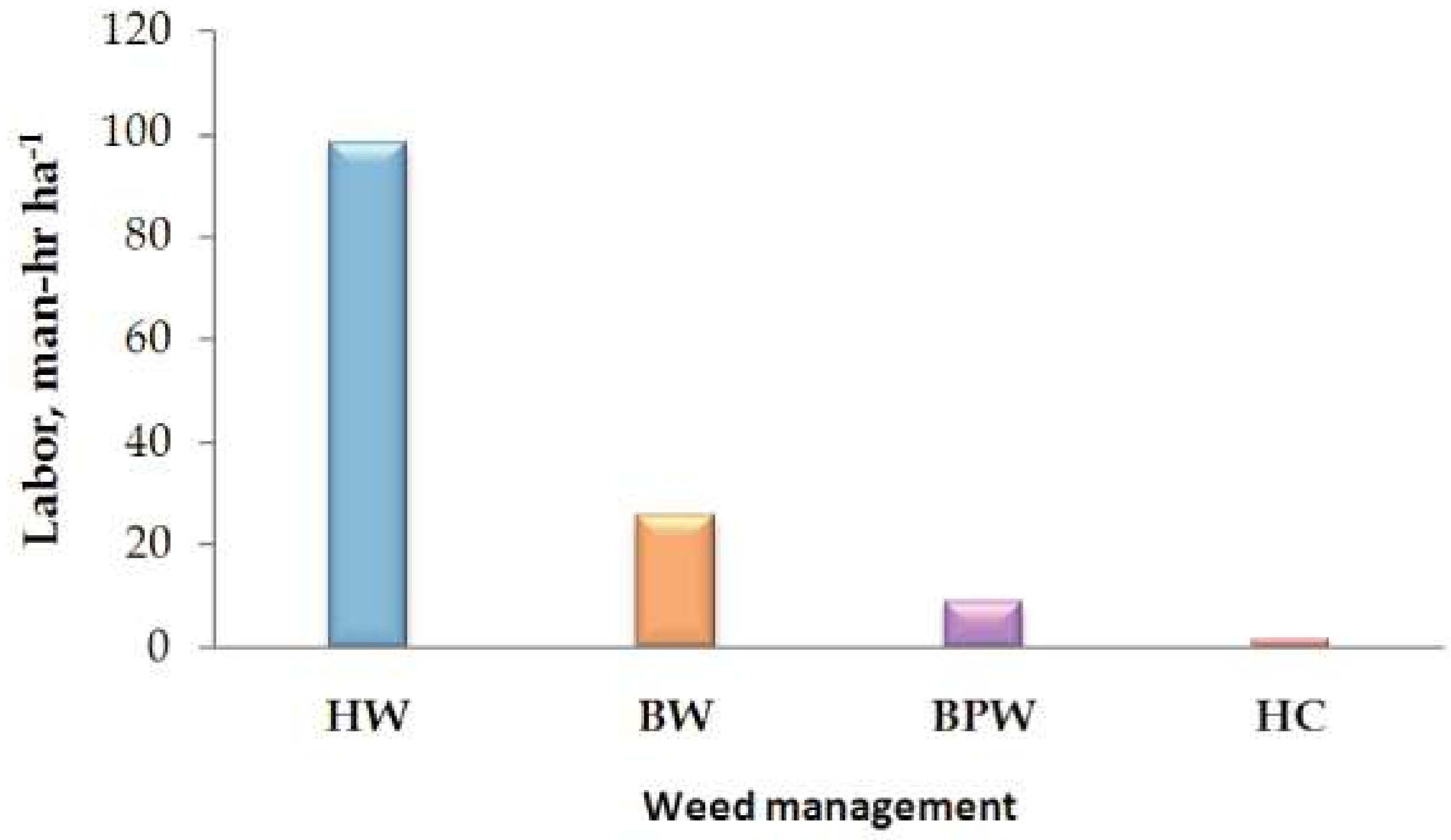


Fig. 5.10 Labor requirement in weeding operation

Harvesting

There was distinct difference of labor requirement observed in harvesting rice by manual and reaper. The Vietnamese reaper (103 man-hr ha^{-1}) saved 96% labor over traditional method (4.30 man-hr ha^{-1}) (Fig. 5.11). Alam *et al.,* (2014) mentioned that the manual harvesting took the highest labor (80-84 man-hr ha^{-1}) than the harvesting reaper (9-10 man-hr ha^{-1}).

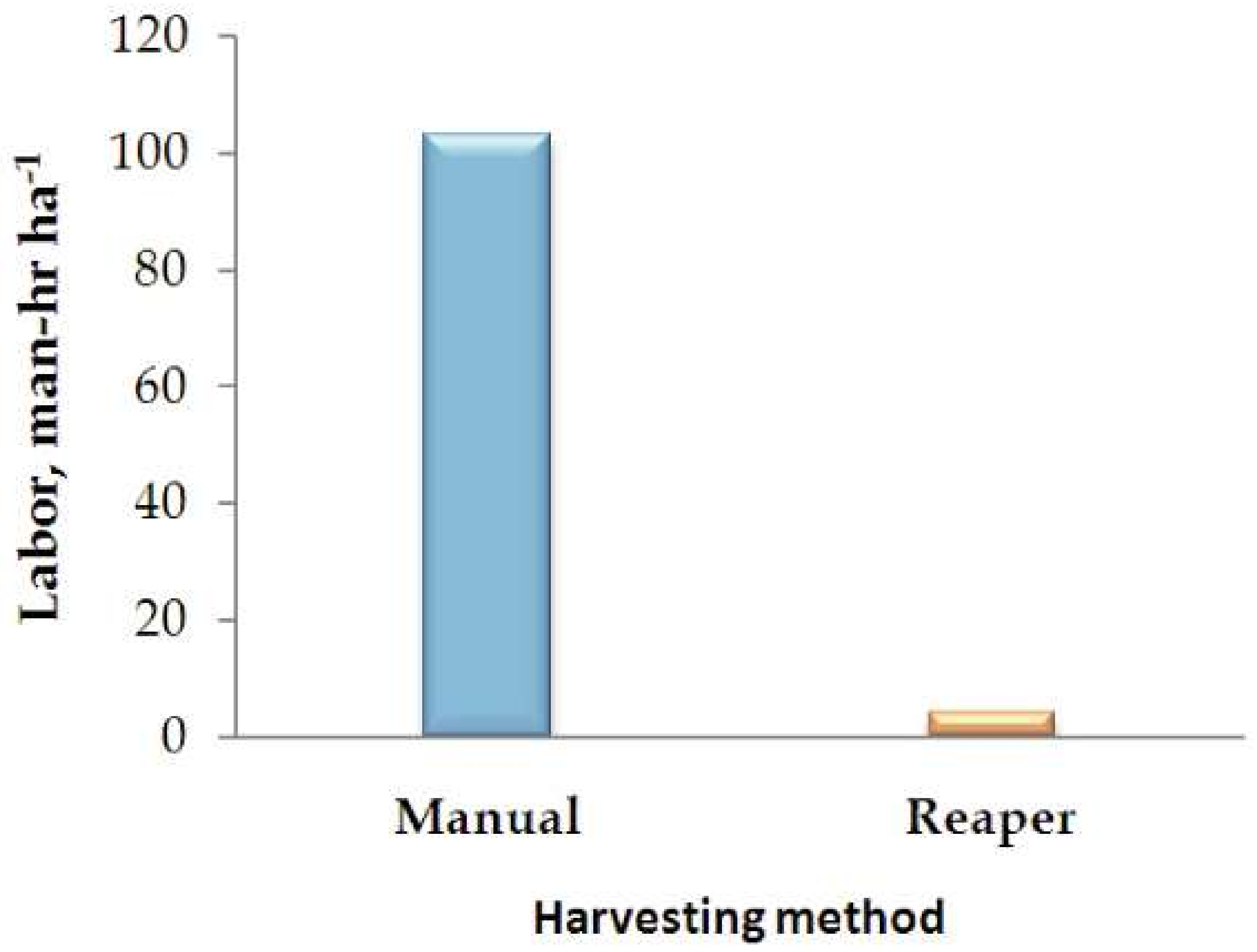


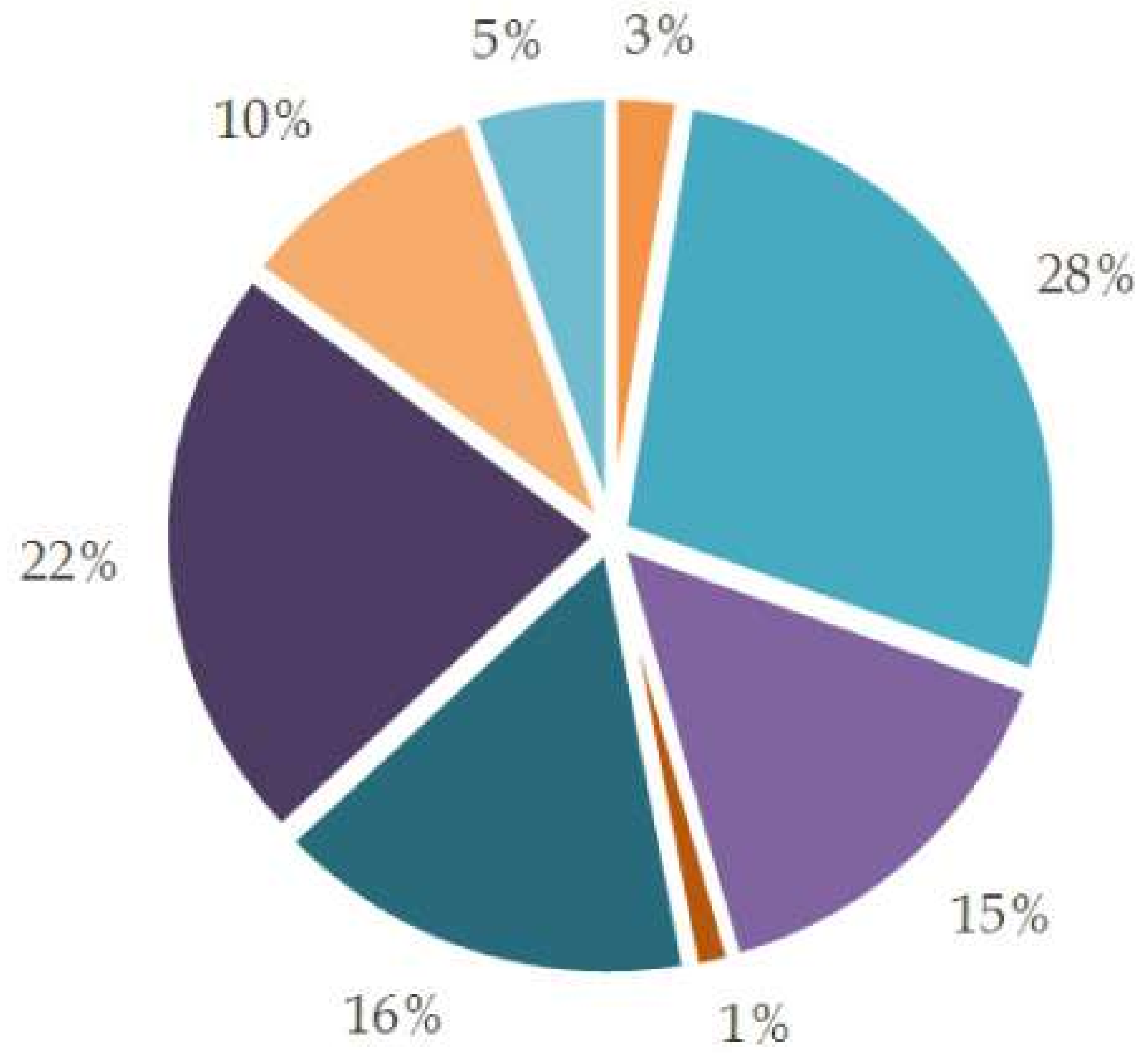
Fig. 5.11 Labor requirement in harvesting operation

Total labor requirement

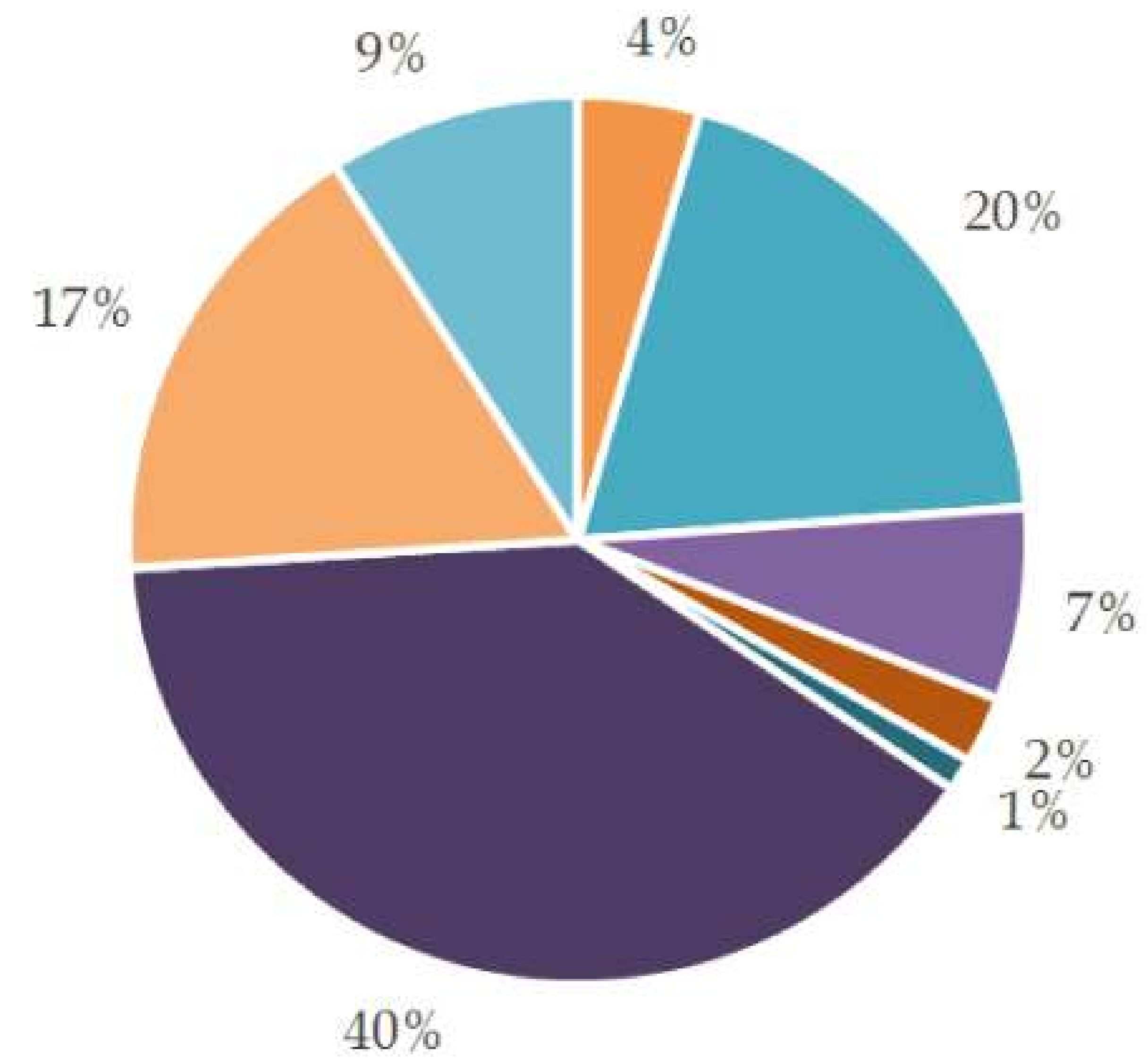
Table 5.2 presents the labor requirement from seedling raising to winnowing under selective mechanization in rice cultivation. The highest labor requirement was observed in S_1 maintaining traditional practice. Among the mechanical intervention of rice cultivation, the lowest labor requirement was observed in S_4 due to use of herbicide to control weeds. The results indicated that, 43, 46, and 48% labor was saved in S_2, S_3 and S_4 compared to S_1 indicating that selective mechanization in any form reduced the labor requirement drastically compared to traditional methods of crop cultivation. Figure 5.12 shows the comparative percentile distribution of time required for different operations.

Table 5.2 Labor requirement in different treatments

Activity	Treatment			
	S_1	S_2	S_3	S_4
Seedling raising	31 (5%)	62 (17%)	62 (18%)	59 (17%)
Land preparation	16 (2%)	16 (4%)	16 (5%)	16 (5%)
Transplanting	150 (23%)	9 (2%)	9 (3%)	9 (3%)
Weeding	98 (15%)	26 (7%)	9 (3%)	2 (1%)
Fertilizer and insecticide application	9 (1%)	9 (2%)	9 (3%)	9 (3%)
Harvesting	103 (16%)	4 (1%)	4 (1%)	4 (1%)
Carrying	144 (22%)	144 (39%)	144 (41%)	144 (43%)
Threshing	62 (10%)	62 (17%)	62 (18%)	62 (18%)
Winnowing	33 (5%)	33 (9%)	33 (9%)	33 (10%)
Total	**646 (100%)**	**365 (100%)**	**348 (100%)**	**338 (100%)**



S_1



S_2

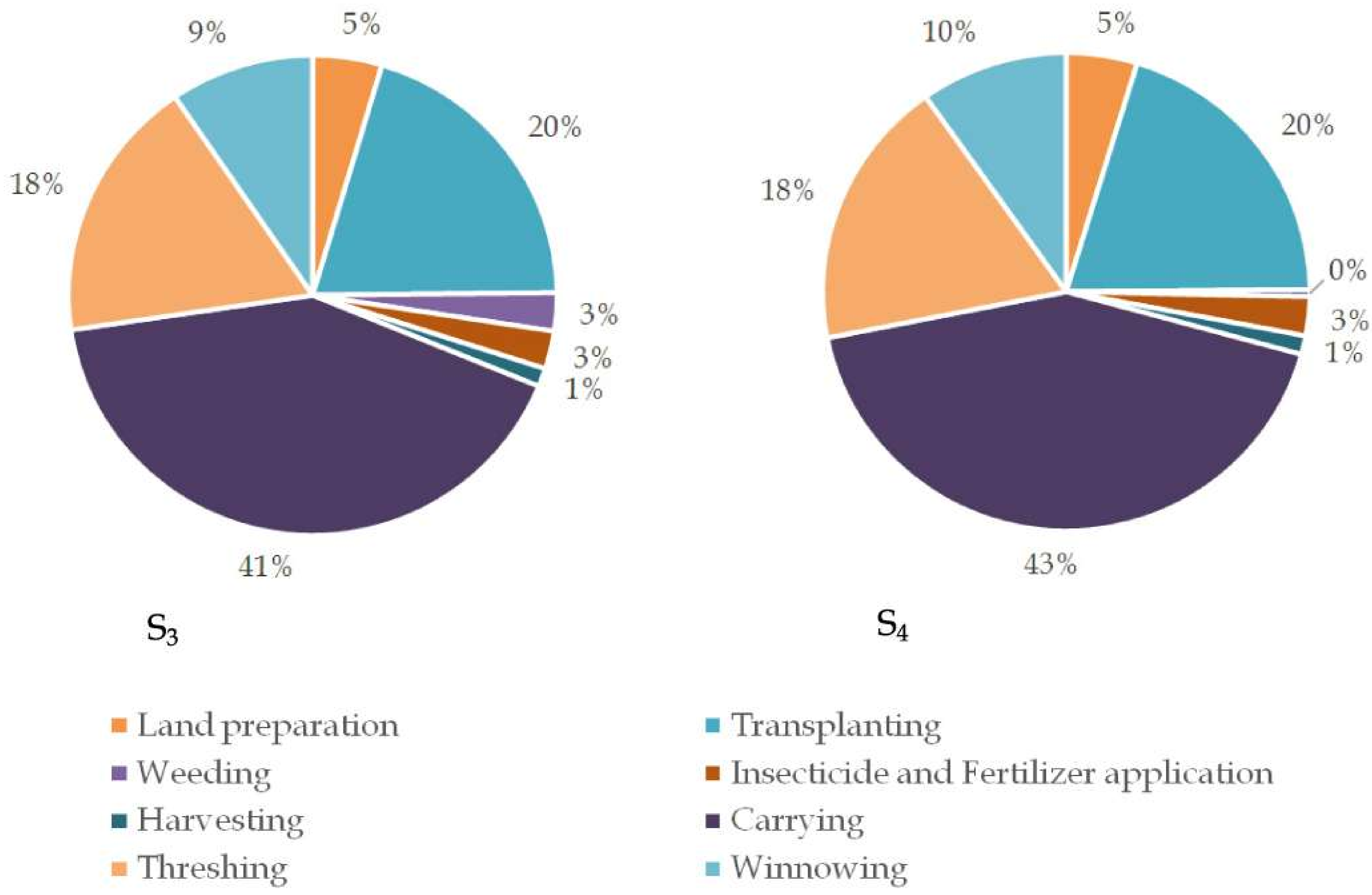


Fig. 5.12 Labor distribution in selective mechanization

Economic analysis

Transplanting cost

Seedling establishment cost in mechanical transplanting (Tk 4,703 ha^{-1}) showed 38% higher than traditional seedbed preparation (Tk 2,899 ha^{-1}) due to higher labor requirement in seedling raising and nursery management. On the other hand, cost of manual transplanting (Tk 7,510 ha^{-1}) observed 49% higher than mechanical transplanting (Tk 3,809 ha^{-1}) due to labor intensive operation. Mechanical transplanting including seedling raising saved 18% cost compared to hand transplanting method due to less operational time required by mechanical transplanter (Fig. 5.13).

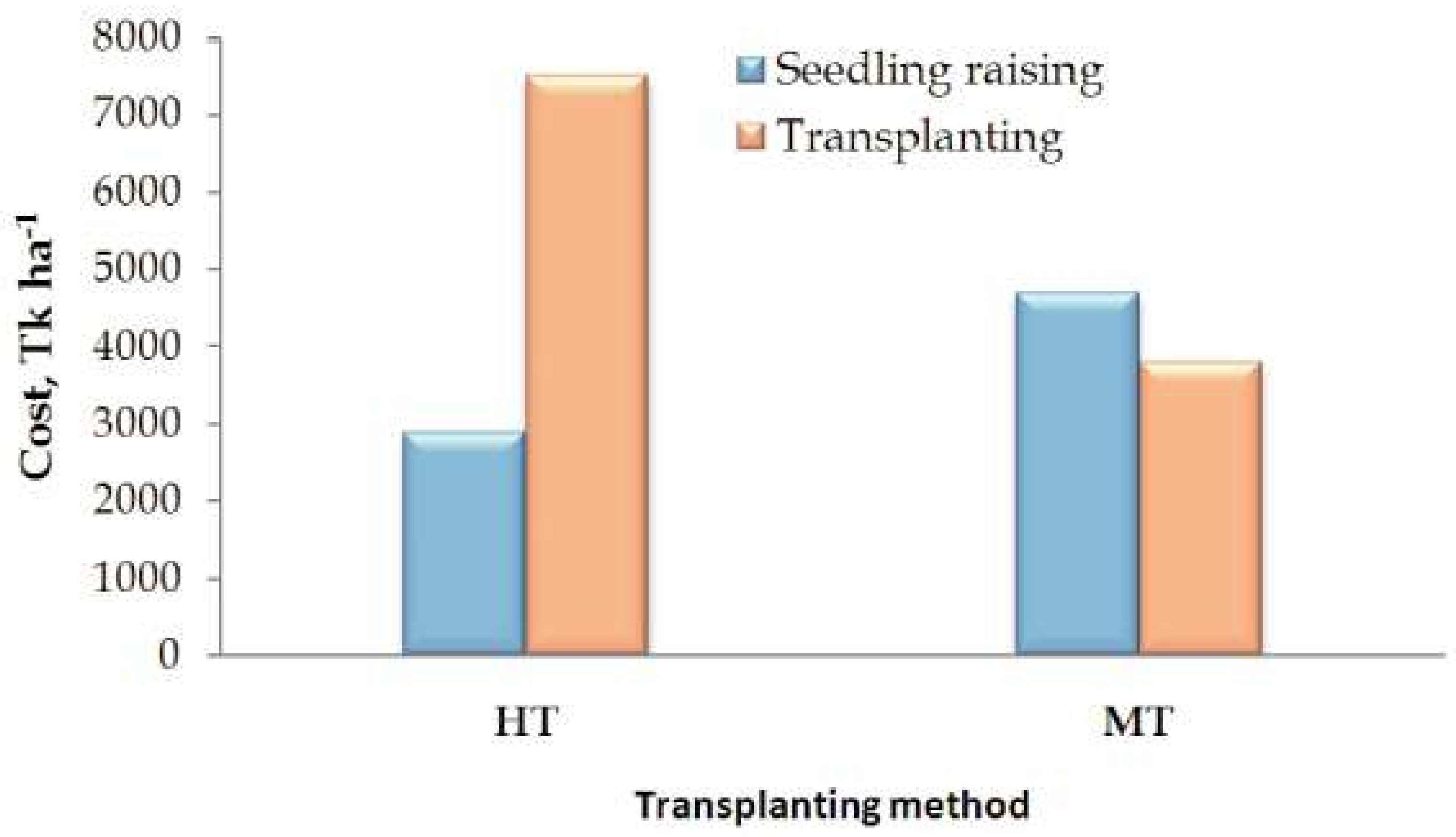


Fig. 5.13 Transplanting cost in different methods

Weeding cost

Hand weeding (Tk 4,920 ha^{-1}) required the highest weeding cost followed by BPW (Tk 1830 ha^{-1}), BW (Tk 1,355 ha^{-1}) and HC (Tk 890 ha^{-1}) (Fig. 5.14). BW, BPW and herbicide saved 72, 63 and 82% cost compared to hand weeding.

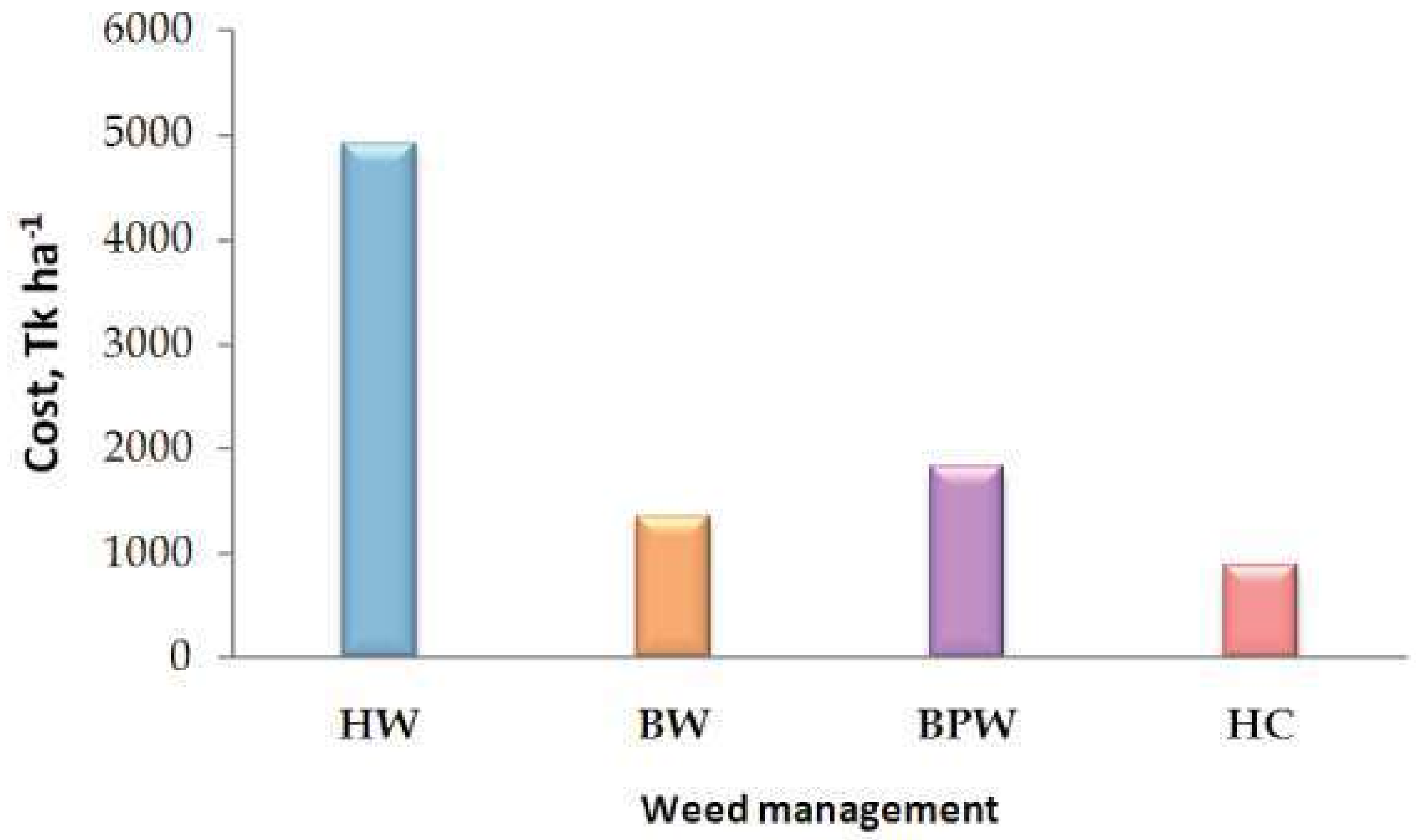


Fig. 5.14 Weeding cost in different methods

Harvesting cost

Manual harvesting cost (Tk 5,158 ha^{-1}) was much higher because of higher labor involvement and increased wage rate in peak season (Fig. 5.15). Harvesting by reaper (Tk 1,446 ha^{-1}) saved 72% of cost than that in manual harvesting method, which was lower than 89% as reported by Rahman (2004).

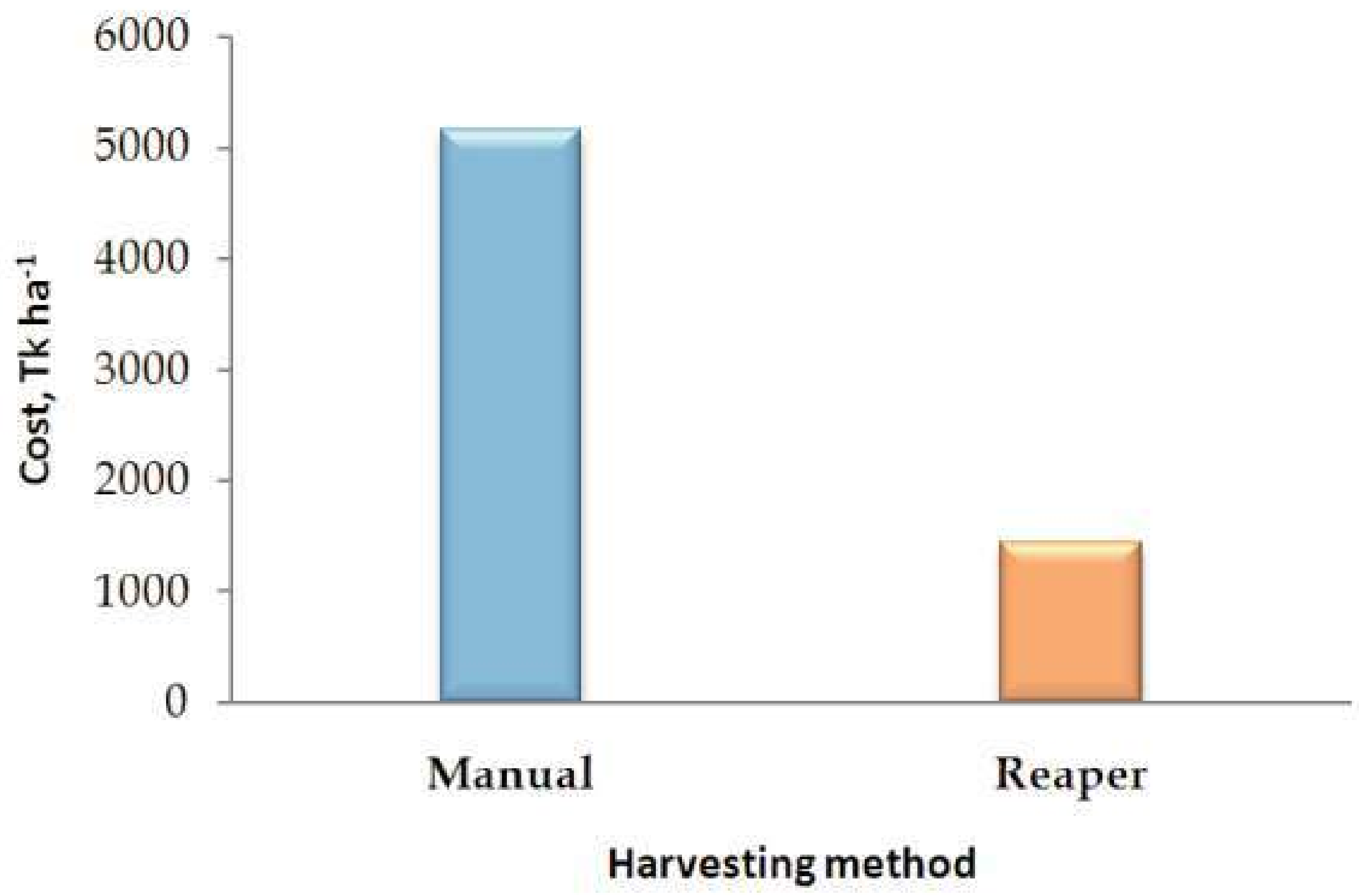


Fig. 5.15 Harvesting cost in different methods

Fuel cost

Fuel (diesel and petrol) cost was the highest in S_3 (Tk 2,775 ha^{-1}) because of use of power weeder on top of transplanter, reaper and open drum thresher resulting higher carbon di-oxide emission (Fig. 5.16). S_2 (Tk 1,762 ha^{-1}) and S_4 (Tk 1,762 ha^{-1}) imposed similar cost whereas S_1 (Tk 783 ha^{-1}) was the lowest fuel consuming selective mechanization method.

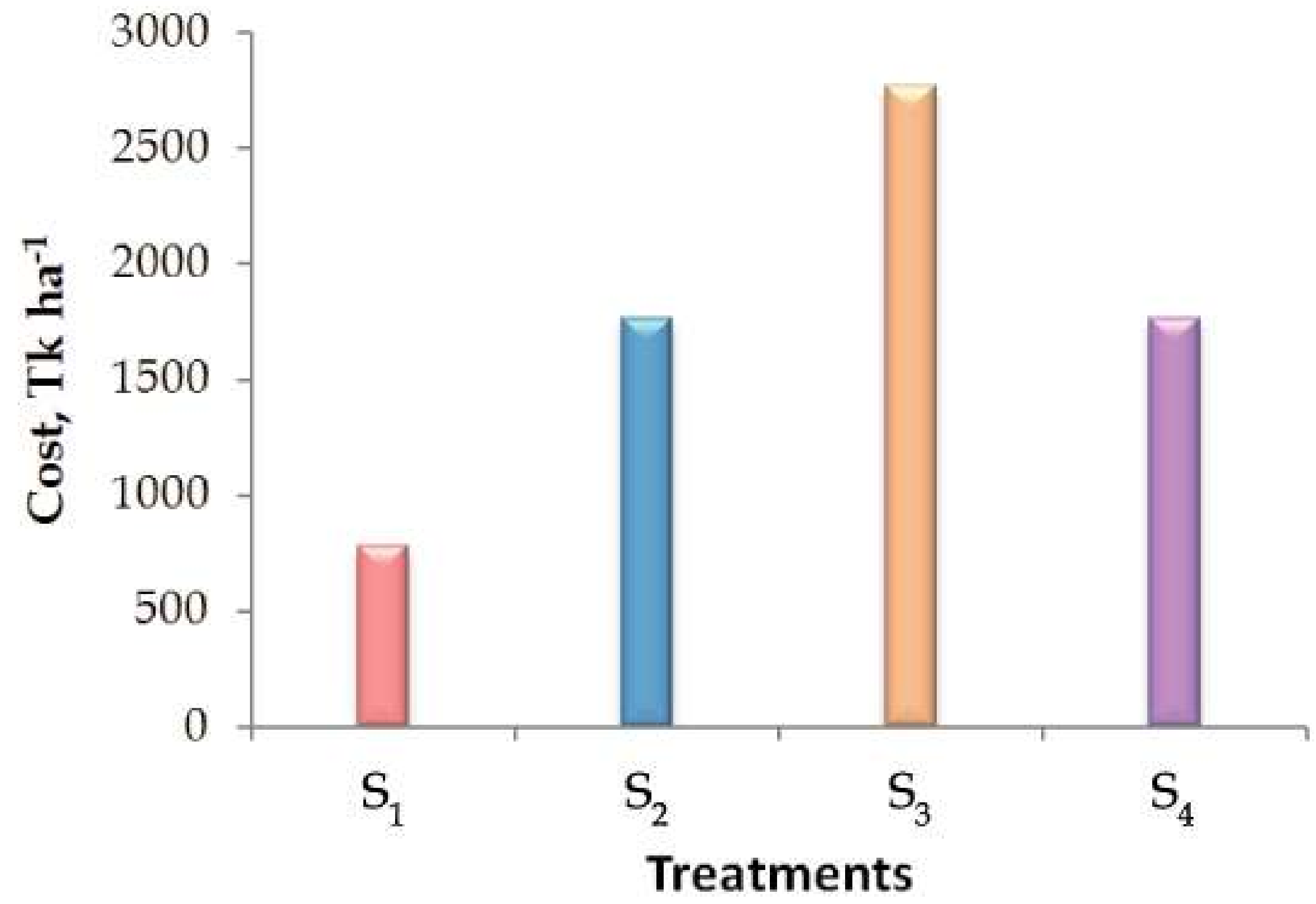


Fig. 5.16 Fuel cost in selective mechanized cultivation

Total production cost

Table 5.3 presents the production costs in different treatments along with respective operation. Operations like land preparation, fertilizer, irrigation, insecticide, carrying, threshing and winnowing took same expense across treatments. Significant variation was observed in seedling raising, transplanting, weeding and harvesting because of difference in methods and machinery use. Cost analysis shows that the highest investment was required in S_1 followed by S_3 due to higher labor requirement as well as labor wage among all. The lowest cost was obtained in S_4 followed by S_2 because of the use appropriate technology. Irrespective of the combination of technology, selective mechanization saved 11-12% production cost compared to the use of traditional technology.

Table 5.3 Operation-wise cost in mechanized cultivation

Operation	S_1 Tk ha^{-1}	S_2 Tk ha^{-1}	S_3 Tk ha^{-1}	S_4 Tk ha^{-1}
Seedling raising	2,899	4,703	4,703	4,703
Land preparation	7,753	7,753	7,753	7,753
Transplanting	7,510	3,809	3,809	3,809
Irrigation	3,000	3,000	3,000	3,000
Weeding	4,920	1,355	1,830	890
Fertilizer and Insecticide application	13,579	13,579	13,579	13,579
Harvesting	5,158	1,446	1,446	1,446
Carrying	7,283	7,283	7,283	7,283
Threshing	4,115	4,115	4,115	4,115
Winnowing	1,890	1,890	1,890	1,890
Total	**58,107**	**48,935**	**49,410**	**48,469**
Land value	20,000	20,000	20,000	20,000
Interest	1,953	1,723	1,735	1,712
Total production cost	**80,060**	**70,659**	**71,145**	**70,181**

Labor and material cost

Table 5.4 shows the distinctive presentation of labor and material cost in different treatments. It was observed that, traditional farmers' practice took significantly more labor cost than the other three mechanized methods. Labor cost drastically reduced to 45% whereas, material cost increased to 22% in selective mechanization due to use of different farm machinery and technology. Material cost was higher in mechanized method compared to traditional one due to rental charge of machine and corresponding fuel cost.

Table 5.4 Labor and material cost in selective mechanization

Parameter	S_1 Tk ha^{-1}	S_2 Tk ha^{-1}	S_3 Tk ha^{-1}	S_4 Tk ha^{-1}
Labor cost	32,907 (57%)	18,791 (38%)	17,955 (36%)	17,511 (36%)
Material cost	25,200 (43%)	30,144 (62%)	31,455 (64%)	30,958 (64%)
Total	**58,107 (100%)**	**48,935 (100%)**	**49,410 (100%)**	**48,469 (100%)**

*Figure in the parentheses indicate the percentage

Effect of mechanization systems on production cost and return

Table 5.5 shows the crop production cost along with gross and net return in different treatments. Gross return was calculated based on the local market price of paddy and straw. It was observed that, total production cost was the highest in S_1 because of higher labors involvement compared to other treatments. On the other hand, gross return was found to be the highest in S_4 because of higher yield but the net return peaked in S_2 because of lower input cost against moderately good yield. It was observed that, S_2 imposed the highest BCR among all four treatments due to lower input cost alongside moderate good yield.

Table 5.5 Effect of mechanization Systems on gross return, net return and benefit cost ratio (BCR)

Treatment	Production cost Tk ha^{-1}	Return from grain Tk ha^{-1}	Return from straw Tk ha^{-1}	Gross return Tk ha^{-1}	Net return Tk ha^{-1}	Benefit cost ratio (BCR)
	A	B	C	D=B+C	E=D-A	F=D/A
S_1	80,060	71,848	10,746	82,594	2535	1.03
S_2	70,659	78,077	11,678	89,755	19,097	1.27
S_3	71,145	76,945	11,509	88,454	17,309	1.24
S_4	70,181	79,721	11,924	91,645	21,463	1.31

Conclusions and Recommendations

Conclusions

Manual transplanting, weeding, harvesting are labor intensive, time consuming and expensive operations in crop cultivation. Mechanical intervention in all stages saved labor, cost and ensured faster operation. Mechanical transplanting with herbicide application and harvesting by reaper was proven to be the most cost and labor saving set of selective mechanization with significant effect on grain yield compared to traditional method of rice cultivation. However, there is an environmental concern on the use of herbicide. On the other hand, BRRI weeder with mechanical transplanting and harvesting by reaper was the second most labor and cost saving set of selective mechanization and also found environmentally safer ensuring consistency in performance. Under above considerations, BRRI weeder with mechanical transplanting and harvesting by reaper could be recommended to the farmers.

Recommendations

- Modification works should be done on the power weeder to minimize crop damage.
- This experiment should be continued in different locations in *boro* and *aus* season to validate the data.

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Appendices

Appendix 1a Unit price of fertilizer, herbicide and pesticide (2015)

Insecticide/herbicide	Unit	Tk unit^{-1}	Fertilizer	Unit	Tk unit^{-1}
Rifit	L	9,000	Urea	kg	17
Nativo	kg	7,625	TSP	kg	22
Virtako	kg	15,000	MP	kg	15
Difer	L	3,000	Gypsum	kg	16
			Zinc	kg	150

Appendix 1b Price list seed, grain and by-product (2015)

Crops	Seed rate	Price Tk kg^{-1}		
	kg ha^{-1}	Seed	Grain	Straw
Paddy	35	35	15.62	11,250

Appendix 1c Wage rate, water charge, fuel price (2015)

Activity	Unit	Tk unit^{-1}	Activity	Unit	Tk unit^{-1}
Land preparation	man-hr	50	**Machine rent**		
Seeding	man-hr	50	Transplanter	hr	263
Leveling	man-hr	50	Power weeder	hr	42
Manual transplanting	man-hr	50	Mech. Weeder	hr	4
Mechanical transplanting	man-hr	100	Reaper	hr	153
Weeding	man-hr	50	Thresher	hr	25
Manual harvesting	man-hr	50	Winnower	hr	10
Mechanical harvesting	man-hr	100	Diesel	l	69
Threshing	man-hr	50	Petrol	l	100
Winnowing	man-hr	50	Water	ha	3000
			Land rent	ha/season	20,000
			Interest rate	%	12