WEED MANAGEMENT IN MECHANICALLY TRANSPLANTED RICE

Identifying the cost saving practices

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Executive summary

Weeds are the cause of serious yield reduction problems in rice production worldwide. Weed population varied depending on the predominant weed flora and on the control methods. An effective weed management practice could reduce the cost of weed control, increase weed control efficiency as well as yield of mechanically transplanted Aman rice. This study was conducted in the farmers' field at Bahirbagh and Provakordi under Gopalganj district of Bangladesh during the non-irrigated wet season (Aman) 2016 representing the silty loam soil in both the places with the objective to identify the effective weed management practices in rice cultivation transplanted by mechanical rice transplanter. Walk behind type 4-rows mechanical rice transplanter (DP480) transplanted twenty-day-old seedling at a pre-set spacing of 300×170 mm. Randomized complete block (RCB) design with three replications was applied with weeding practices of BW fb (followed by) one HW, BPW fb one HW, two HW, pyrazosulfuron-ethyl (PSE) fb one HW, weedy check, weed free and mulching fb two HW (farmers' practice) in two locations. The common weed species were found at the experimental site. At 20 DAT, the highest weed density was observed in Bahirbagh compared to Provakordi. In Bahirbagh, significantly lower weed infestation was observed in PSE fb one HW because of herbicide application at seven DAT, which is statistically similar to weedy check. In Provakordi, weeding infestation was not varied significantly among the treatments except weed free at both the 20 and 40 DAT. However, the highest weed biomass were found in two HW plots, which were statistically similar to BW fb one HW, BPW fb one HW and mulching fb two HW at 20 DAT in Bahirbagh. Weed biomass was naturally low in weedy check plots before the treatments apply, which was sharply increased at 40 DAT. Similar pattern was observed at 40 DAT whereas the lowest was observed in PSE fb one HW and mulching fb two HW. In Provakordi, there was no significant difference among the weed management practices except weed free at 20 DAT. At 40 DAT, significantly the highest weed biomass was observed in weedy check, which was statistically similar to BPW fb one HW and two HW. In Bahirbagh, weed control efficiency was the highest in PSE fb one HW during 1st weeding. The highest labor was required for one mulching fb two HW, which was similar to that of two HW and weed free whereas the lowest labor was required for PSE fb one HW, which was similar to BPW fb one HW and BW fb one HW in Bahirbagh. In Provakordi, significantly the highest labor was required in weed free, which was similar to mulching fb two HW. Weed management practices showed insignificant effect on grain yield in both locations. The BCR was accounted in PSE fb one HW (1.35), BW fb one HW (1.21), BPW fb one HW (1.20) whereas the lowest BCR was observed in weedy (0.83) and two HW (1.00). It can be concluded that pyrazosulfuron-ethyl, BRRI power weeder and BRRI weeder followed by hand weeding were found more suitable in mechanically transplanter rice field. In addition, one hand weeding is required in each weeding technology to get better weed control effect in wider spaced mechanically transplanted Aman rice production.

Keywords: Transplanter, weeder, herbicide, labor, yield and benefit-cost ratio

Acronyms and abbreviations

Aman	Paddy/Rice cultivated in rainy season (July to November)
Aus	Paddy/Rice cultivated in summer season (May to August)
BBS	Bangladesh Bureau of Statistics
BCR	Benefit cost ratio
Boro	Paddy/Rice cultivated in winter season (January to May)
BRRI	Bangladesh Rice Research Institute
DAE	Department of Agricultural Extension
DAS	Days after seeding
DAT	Day after transplanting
FMPHT	Farm Machinery and Postharvest Technology Division of BRRI
GoB	Government of Bangladesh
HT	Hand transplanting
MT	Mechanical transplanting
rpm	Revolution per minute
Tk	Taka
WCE	Weed control efficiency
WE	Weeding efficiency

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Introduction

Rice is grown in about 11.35 million hectare of land in three distinct rice growing season- namely Boro (Dec-April), Aus (April-July) and Aman (Aug-Nov) (Hussain *et al.,* 2012). The majority of rice area is covered by transplanted Aman rice comprising about 5.53 million hectare of the total rice area (BBS, 2015). Rice is predominantly grown by hand transplanting and required labor of 642-708 man-hr ha^{-1} of which seedlings raising and transplanting consumed 19-22% of the total labor requirement (Islam *et al.,* 2016). Hand transplanting of seedling is the most widely adopted and the most ancient method of rice transplanting. Hand transplanting is tedious and time consuming which are often the causes of delayed planting. The rice yield loss due to delayed planting were 60, 55 and 9 kg ha^{-1} day^{-1} in the Boro, Aman and early wet (Aus) seasons, respectively in Bangladesh (Sattar, 1999).

Cultivation process is changing rapidly from labor to power intensive operation due to unavailability of labor, burden to increase yield, save the crops from natural disaster and increase the cropping intensity. Mechanical transplanting improves labor efficiency, ensures timeliness in operation, faster transplanting and attains optimum plant density that contributes to high productivity (Islam *et al.,* 2016 and Manjunatha *et al.,* 2009).

Weed is a serious problem in rice cultivation. Weed infestation is a natural and acute phenomenon in rice field. Weed depends on availability of water supply, soil texture and structure, location of the field, weather and climatic condition of the field, depth of plough pan, and organic matter content of the soil (Hossen *et al.,* 2013). Uncontrolled or improperly controlled weeds compete for soil nutrition with more rapidity in growth and population and cause substantial reduction in yield and grain quality. Severe weed infestation is one of the important factors for such low yield. The prevailing climatic factors of Bangladesh are highly favorable for luxuriant growth of numerous species of weed, which offer a keen competition with rice crop (Alam *et al.,* 1995). Without weed control, yield losses have been estimated 16 to 48% for transplanted Aman rice (Alam *et al.,* 1996).

Weed management requires huge labor resulting in increase of production cost. Lower weeding cost is always preferable from the economic point of view. Proper weeding technology is also an important factor to the farmers in our country. Selection of efficient weeding system depends on weed flora, weed dynamics, weed intensity, time of weeding and soil moisture at the time of weeding. Weed management is implemented in traditional way by manual labor or in mechanized way by mechanical weeder, power weeder or applying herbicide. Usually, two to three hand weedings are done for growing a transplant rice crop depending upon the nature of weeds and their intensity of infestation. Manual weeding requires 98 man-hr ha^{-1} labor input and there is a great scope of saving up to 78% cost in weeding operation by adopting mechanical means of weeding (Islam *et al.,* 2016).

Mechanical rice transplanting is gaining popularity through the intervention of governmental and non-governmental organizations in Bangladesh as it saved labor, ensured timely transplanting and optimum plant density that contributed to high productivity (Islam *et al.*, 2016a). Many pre-requisite and requisite conditions for successful operation were not identified for Bangladesh condition. Seedling age and plant spacing is also different in mechanically transplanted field compared with the manually transplanted field. Weed management is thus an issue of reconsideration to suit with the mechanical interventions involved with the modern cultivation practices. Different weeding methods have been evaluated in manually transplanted rice field, there is little understanding of their efficacy for mechanically transplanted rice. So far, no meaningful initiative has been taken to identify the best weed management practices for mechanically transplanted rice in Bangladesh condition. Therefore, a study was conducted to evaluate the performance of different weed management practices in mechanically transplanted rice in the farmer's field during the non-irrigated wet season.

Justification

Labor shortages for rice transplanting are stimulating interest in mechanical transplanting. While the different weeding practices have been evaluated in manually transplanted rice, there is little understanding of their efficacy for mechanically transplanted rice. In Bangladesh, weeds were controlled by conventional practices that relied on the access to cheap readily-available labor. Besides being costly and time consuming, weeding needs right practices. It is urgently needed to overcome the labor shortages, reduce production cost and increase profitability of rice production. Mechanical rice transplanting has drawn considerable interest but little is known on the best weed management practices. With the progressive adoption of mechanization in rice cultivation, weeding system needs to be reevaluated to match and make best use of time, labor and money. Therefore, systematic study in farmers' participatory needs to be conducted to evaluate the different weed management practices in mechanically transplanted rice during non-irrigated wet (Aman) season. On the basis of above discussion, it was hypothesized that effective weeding practices would enhance the productivity and profitability of mechanically transplanted rice in wet season.

Therefore, objectives of this study, carried out on a farmer's field, were to evaluate the performance of weed management practices in mechanically transplanted rice and relate the yield and yield attributes to that achieved with weedy check and traditional weed management practices in the farmer's field. In addition, performance criteria and the economics of rice production under different weed management practices and performance criteria were assessed to determine the best weed management practices.

Literature review

Weed management plays a very important role in crop production having a great influence on the growth, yield and yield contributing characters of transplanted Aman rice. A number of experiments have been conducted in Bangladesh and elsewhere in the world to observe the effect of weed managements on these aspects. Some of the important research works relevant to the present study have been reviewed and discussed in this chapter.

Factors affecting weed infestation

Hossen *et al.* (2015) mentioned that, weeds depend on the availability of water supply, soil texture and structure, location of the field, weather and climatic condition of the field, depth of plow pan and organic matter content of the soil.

Khan (2013) observed that weeding regime had significant effect on all the parameters except 1000-grain weight. The highest grain yield (6.29 t ha^{-1}) was obtained from the weed free condition and it produces 37.33% higher yield than the no weeding condition.

Goel *et al.* (2008) reported that weeds compete with crop plants for nutrients and other growth factors and in the absence of an effective control measure, remove 30 to 40 percent of applied nutrients resulting in significant yield reduction.

The closely spaced crop effectively smothered the weeds growing under crop canopy by not providing sufficient space for weed growth complemented by restricting sunlight from penetrating downwards (Brar and Walia, 2001).

Cultural practices greatly alter the competitive relationship between rice and weeds. Hence, proper agronomic management practices like suitable crop establishment method, efficient fertilizer use and timely weed control have to be planned to attain the target food production (Nagaraju, 1994).

Weed spectrum in rice

Identification of weeds is the basic step for planning sound weed management program. Islam *et al.* (2017) stated that eight different weed species belonging to three families of which four annual and four perennial were found in the low land rice field. Among eight weed species, one was sedge, one was broad leaf and six were grasses. The most predominant weed species in the experimental plots was Chesra (*Scripus maritimus*). Other important weeds were Anguli (*Digitaria sanguinalis* L.; *Scop*), Durba (*Cynodon dactylon* L.; *pers*) and Chela ghash (*Rottboellia protensha Hack.*). The Khudeshama (*Echinochloa colonum* L.; *Beauv*) was the least abundant weed species in the experimental plot. Some upland weeds were observed in the fields due to dry land condition.

Zannat (2014) listed 18 commonly growing weed species in aromatic Aman rice cv. Bina dhan-9 and identified weed species like *Panicum repens, Oxalis corniculate, cyperus michelianus, Cyperus difformis, Fimbristylis diphylla, Leersia hexandra, Monochoria hastata, Scirpus mucronatus, Ludwigina prostrata, Echinochloa colonum, Cynodon dactylon, Polygonum orientale, Echinochloa crusgalli, Parapholis incurve* and *Eclipta alba.*

Ravisankar *et al.,* (2008) stated thatdominant grass weed species were *Echinochloa crusgalli* and *Echinochloa colona,* sedges were *Cyperusiria, Cyperus 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 percent, grasses 42.2 percent and sedges 23.6 percent of the total weed population under weedy conditions (Singh *et al.,* 2007). The wet seeded rice was infested with composite weed flora comprising of 51.5% grasses, 30.9% sedges and 17.5% broad-leaved weeds.

Islam *et al.* (2010) observed eleven weed species belonging to six families to infest the experimental field of which *Panicum respens* was the most important weed species and the other dominant species were *Digitaria sanguinalis, Rottboellia protensa, Leersia hexandra, Fimbristylis miliacea, Monochoria hastata,* and *Scirpus mucronatus* in respect to weed density.

Weed dry weight

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 system rice intensification (SRI) than conventional transplanted rice, which can be attributed to more inter space area and less population. 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 3,105 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 the application of 120: 60: 60 kg NPK ha^{-1}.

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.

Gogoi *et al.* (2000) reported that different weed control practices significantly reduced the dry matter accumulation of weed and increased the rice yield over the unweeded control in transplant rice.

Critical period of crop-weed competition

Chinnusamy *et al.* (2000) reported that maintaining a weed free period up to 45 DAT was essential to augment the yield of medium duration rice. Critical period for crop weed competition in rice was up to 40 days after transplanting (Thapa and Jha, 2002).

Nature of crop-weed competition

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.

Prasad (2011) reported that cultivars played an important role in crop-weed competition because of their diverse morphological traits, canopy structure and relative growth rate. A quick growing and early canopy cover enables a cultivar to compete better against weeds. Research evidences have shown that traditional tall cultivars like Nerica rice exert effective smothering effect on weeds.

Roy *et al.* (2009) mentioned that weed competes with rice plants severely for space, nutrient, air, water and light. Weeds under adverse condition affects plant height, leaf architecture, tillering habit, shading ability, growth pattern and life duration of rice cultivars.

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). Grassy weeds were heavy competitors with rice crop and were followed by sedges and broad leaved weeds (Umapathy and Sivakumar, 2000).

Jena *et al.*, 1999 found that grain yield significantly differed due to weed infestation. The yield was 0.98 t ha^{-1} in unweeded control plots, 1.56 t ha^{-1} with herbicide and 2.24 t ha^{-1} in manual weed control plots.

Nutrient removal by weeds

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 kharifin silt loam soil of Pantnagar.

Sudhalakshmi *et al.* (2005) reported that nutrient uptake by weeds was 30 kg N, 10 kg P and 17 kg K per hectare in transplanted rice in clay loam soil of Coimbatore. Weeds removed nutrients (N, P and K) eight times higher under direct seeded rice compared to that of puddled transplanting (Singh *et al.*, 2002).

Weeds usually grow faster than the crop plants and absorb added nutrient more rapidly and in larger quantities than by crops (De Datta and Baltazar, 1996) and thus deprive the supply of nutrients in time to the crop plants.

Effect of weed population on rice growth and productivity

Veeraputhiran and Balasubramanian (2010) observed that maintaining weed free condition till maturity produced the grain yield of 7,139 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.

Yield loss

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 weed population. However, above certain population limits, yield reductions become nearly constant due to self-competition among weed plants. Thura (2010) conducted field trials to evaluate the effectiveness of different weed control methods in the System of Rice Intensification (SRI) during dry and wet seasons in Myanmar and reported that, yield loss percent due to weed competition were ranged from 59.5 to 74.06% in dry season and from 49.97 to 73.4% in wet season, respectively.

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.

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).

Moorthy and Saha (2005) reported that the losses in grain yield due to weed competition for first 30, 60, and 90 days were 17.7, 11.8 and 5.0%, respectively. Singh *et al.* (2002) observed that maintaining weed free condition till maturity gave significantly higher grain yield due to more panicles m^{-2} and lower density and dry weight of weeds.

Sanjoy *et al.* (1999) observed that control of weeds played a key role in improving the rice yield because of 18% increased panicle m^{-2} due to weed control over its lower level, 32% number of grains $panicle^{-1}$ increased due to weed control over its lower level and significant yield increase was observed (43%) with weed control. Pernito *et al.*, (1996) found that plant height, panicle density, proportion of grains $panicle^{-1}$ and weight of 1000 seeds were increased by weed control treatments.

Moody and De Datta (1998) observed the highest grain yield loss 37% in BR2 in unweeded condition, and 17% in the farmers weeded condition. The lowest grain yield loss of 14% in unweeded condition was observed in Balam, which was only 5% in farmers weeded condition. Singh and Pillai (1996) stated that due to uncontrolled weed growth in dry seed bed rice, yield loss ranged 50-60%.

Njoku (1996) reported that uncontrolled weeds growth reduces yield of the principal crops while untimely weeding reduces the returns from the overall investments in the production of crops. Depending upon the weed density, 20-30% loss in grain yield is quite usual, which might increase up to 80% if adequate crop management practice is not observed (Gunasena and Arceo, 1981).

Reduction in yield due to weed alone is estimated at 16-42% depending on crop and location and involves one third of the cost of cultivation (Rangasamy *et al.*, 1993). Another study showed that delay and negligence in weeding operation affect the crop yield and the loss in crop yield due to weeds in upland crops vary from 40-60% and in many cases complete crop failure (Singh, 1988).

Weeding time

Weed management plays an important role on the performance of rice crop. Thus, the best weed management needs to be resorted to reduce weed infestation and maximum rice yield. Igbeka (1984) reported that timeliness rather than frequency of weeding is a major determinant of effective weed control.

Parvez *et al.* (2013) evaluated the effect of cultivar and weeding regime on the performance of transplant Aman rice. The experiment consists of two factors namely factor A: cultivar-as BRRI dhan41 and Nizershail, and factor B: weeding regime-as no weeding, one hand weeding at 21 DAT, two hand weeding at 21 and 42 DAT, application of pretilachlor herbicide, application of pretilachlor herbicide + one hand weeding at 21 DAT and weed free. The maximum weed growth was noticed with the dwarf cultivar BRRI dhan41 and minimum with taller cultivar Nizershail. Complete weed free resulted in the lowest weed population and weed dry weight followed by application of pretilachlor herbicide + one hand weeding at 21 DAT treatment. BRRI dhan41 produced the higher grain and straw yields than the cultivar Nizershail. The highest loss of grain yield was recorded in no weeding treatment and the lowest was recorded in weed free treatment followed by application of pretilachlor herbicide + one hand weeding at 21 DAT in transplant Aman rice (BRRI dhan41). The highest number of effective tillers hill^{-1}, the highest number of grains panicle^{-1} and the heaviest 1000 grain weight were observed in weed free treatment followed by application of pretilachlor herbicide + one hand weeding at 21 DAT.

Yeasmin (2008) evaluated the effect of weeding and fertilizer management on the yield performance of transplant Aman rice. It was found that BRRI dhan44 yielded the highest (4.85 t ha^{-1}) in three weeding (at 20, 35 and 50 DAT) treatment and the lowest grain yield was obtained in no weeding treatment.

Shamim *et al.* (2008) reported the methods of crop establishment, time of herbicide application and their interaction significantly influenced the number and dry weight of weeds. The highest number and dry weight of weed were recorded in direct seeded thin row, followed by direct seeded thick row and the lowest in transplanting. Again, the highest number and dry weight of weed were recorded in control and the lowest in herbicide application after three days of seeding or transplanting. Weed control efficiency was higher in those receiving early application of herbicide. The highest weed control efficiency was in herbicide application at three days after seeding or transplanting. Phytotoxicity of 22 herbicides increased with the earliness of herbicide application and highest phytotoxicity was observed in direct seeded thick row having herbicide application three days after sowing.

Aktaruzzaman (2007) reported that weeding regime exerted significant to influence on all the crop characters studied except panicle length and the highest grain yield (t ha^{-1}) was obtained from weed free treatment and the lowest value was obtained from no weeding treatment.

Hoque *et al.* (2003) conducted an experiment to assess the effect of varieties of transplanted Aman rice and weeding regimes on weed growth and yield of transplanted Aman rice. Five weeding were used in the experiment. The effect of weeding regimes produced significant differences on the weed growth and grain yield of transplant Aman rice. The reduction of weed dry matter was similar in both two weeding and three weeding regimes. The highest grain yield was noted under three weeding conditions (3.95 t ha^{-1}), which was at par with weed free (4.01 t ha^{-1}), but dissimilar to two weeding regimes (3.71 t ha^{-1}).

Weeding regime

Masum *et al.* (2007) conducted an experiment on row spacing and weeding regime and reported that weed free condition found to give highest value for all parameters of paddy studied and yields (5.15 t ha^{-1} grain and 7.13 t ha^{-1} straw) followed by three weeding. No weeding produced the lowest value for all characters including yield.

Islam (1995) found out the effect of cultivar and weeding regime on weed growth and performance of rice. He observed that the highest grain and straw yields ha^{-1} were obtained from completely weed free plots and the lowest from the no weeding plots. The highest plant height, number of effective tillers $hill^{-1}$, length of panicle and straw yield ha^{-1} were also observed in weed free plots.

Weed management methods

Weed management is implemented in traditional way by manual labor or in mechanized way by mechanical weeder, power weeder or applying herbicide.

Manual weeding

Pasha *et al.* (2012) carried out an experiment to study the effects of several weed control methods on yield and yield components of rice in northern part of Iran during 2011. They worked with seven treatments including hand weeding twice, powered weeding twice, powered weeding + hand weeding once, cono-weeder weeding twice, herbicide application + hand weeding once, control treatment and herbicide application once. Among the treatments, herbicide application + hand weeding once had the highest grain yield (4,584 kg ha^{-1}), while control treatment because of the high unfilled grain per panicle and less panicle number per square meter had the lowest grain yield (2,505 kg ha^{-1}).

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. Manual weeding is very effective but it is tedious, time consuming and expensive in large scale cultivation. Continuous rains in rainy season and unavailability of man power make manual weeding difficult (Puniya *et al.*, 2007).

Chander and Pandey (2001) observed that hand weeding increased grain as well as straw yields compared to herbicides and weedy check because of frequent elimination of weeds that resulted in the reduced weed competition.

Hossain (2000) studied the effects of different weed control treatments in rice as one hand weeding, two hand weeding, three hand weeding, ronstar, ronstar + hand weeding. He observed that yields and yield contributing characters increased with the increase in frequency of hand weeding. BRRI (1997) reported that two hand weeding performed better than chemical treatments but two hand weeding resulted in higher weeding cost than the herbicidal treatments.

Mechanical weeding

In the recent past, weed control is practiced more by chemical means supplemented by hand weeding. In the era of increasing labor scarcity and exploding pollution effects, weed management strategy could be reoriented towards mechanical means for satisfactory fertility and monetary benefits. Mechanical weeding is accomplished through incorporation of weeds insitu may help in effective recycling of the depleted nutrients, which in turn could have augmented the nutrient pool of the rhizosphere together with aeration of the root zone.

Islam *et al.* (2017) evaluated the field performance of BRRI (Bangladesh Rice Research Institute) power weeder and BRRI weeder in the farmers' field during Boro, 2015 season. Three treatments i.e. BRRI weeder (BW), BRRI power weeder (BPW) and hand weeding (HW) were used in the experiment. The effective field capacity of BW and BPW was 0.06 and 0.09 ha hr^{-1}, respectively. The weeding efficiency obtained the highest in HW (92%) followed by BPW (78%) and BW (73%). BW damaged the lowest (9%) plants compared to BPW (11%) and the damaged plants revived after few days. BW and BPW reduced 74 and 85% labor requirement in weeding operation compared to HW. HW showed the highest weeding cost compared to BPW. BRRI power weeder and BRRI weeder reduced the weeding cost, faster in weed control and improve labor efficiency without sacrificing grain yield. BRRI power weeder and BRRI weeder appeared as environment-friendly weed control technology compared to chemical control in low land rice cultivation.

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.

Uphoff (2002) reported that the mechanical hand weeder pruned some of the upper roots and encouraged deeper root growth. Randriamiharisoa (2002) noticed that the mechanical weeding using rotating hoe with small toothed wheels increased the soil pores so that roots and microbes could more easily gain access to oxygen and also significantly increase the tiller production. Rotary weeder was effective in controlling the weeds present in inter row space, but failed to control the weeds in intra row space or those in the vicinity of the crop (Choubey *et al.*, 1998).

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 conoweeder implement.Cono weeding alone was found to contribute 17.43% for grain yield when the average grain yield under the conoweeding 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 conoweeding 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 conoweeding had not set any notable impact on the nitrogen fractions of the rhizosphere soil (Sudhalakshmi *et al.*, 2005). The use of conoweeder resulted in 10 per cent grain yield increase during wet season while the yield increase was only three percent higher in dry season than conventional method of weeding (Thiyagarajan *et al.*, 2002).

Weeding by mechanical or power weeder eliminates weed at root level saving labor, currency and additionally loosen the soil providing better aeration and water intake capacity (Biswas, 1990). However, adoption of power weeder can lead to additional consumption of non-renewable fuel.

Chemical weed control

Chemical weed control has become popular in Bangladesh mainly due to scarcity of labor during peak growing season and lower weeding cost by using herbicides. For the last few decades, herbicides have contributed tremendously to agriculture. In large scale rice farming, herbicide based weed management has become the smartest and most viable option as against the scarcity and high costs of labor (Anwar *et al.*, 2012).

Hassan and Upasani (2015) conducted an experiment to find out the effect of establishment and weed control method on weed dynamics, growth and productivity of rice under wet land situation. The treatment comprised of four methods of crop establishment i.e. transplant, SRI, drum seeded and broadcast in main plot and four methods of weed control - pyrazosulfuron 0.02 kg ha^{-1} PE + mechanical weeding at 25 DAS or DAT, weeding by cono weeder at 25 DAS or DAT, hand weeding at 25 and 40 DAS or DAT, and weedy check in sub plot. The result revealed that among establishment and weed control methods, transplant and application of pyrazosulfuron 0.20 kg ha^{-1} + one mechanical weeding at 25 DAS or DAT were most productive. Application of pyrazosulfuron 0.20 kg ha^{-1} + one mechanical weeding at 25 DAS or DAT in transplanted or broadcasted rice was the most effective in suppressing weed population and weed dry matter accumulation thereby producing higher rice grain yield compared to other weed control methods.

Islam *et al.* (2016) conducted experiments in the farmer's field during wet season (June to November) 2015 in Bangladesh. 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.

Poornima *et al.* (2015) stated that pyrazosulfuron-ethyl is a low dose high efficacy herbicide coming under the group of sulfonylureas, which is effective for controlling a wide range of weeds in low land rice. Field experiments were conducted for two consecutive seasons, i.e., second and third crop seasons at the Instructional Farm, College of Agriculture, Vellayani to estimate the residues of pyrazosulfuron-ethyl in soil, rice grain and straw. The experiment was laid out in randomized block design, which consisted of eight treatments with three replications. The treatments included four different levels of pyrazosulfuron-ethyl (15, 20, 25 and 30 g ha^{-1}), butachlor (1.5 kg ha^{-1}), weed free check, unweeded check and hand weeding twice (at 20 and 40 days after transplanting). The results of the experiment revealed a total absence of pyrazosulfuron-ethyl in soil, rice grain and straw, i.e., no detectable residue could be observed.

Ramesha *et al.* (2015) evaluated the phytotoxicity and bio-efficacy of pyrazosulfuron-ethyl 10% WP (5, 10, 15 and 20g ha^{-1} as spray) against the weeds in transplanted rice. Sprays of saathi (market sample) @ 15g ha^{-1}, pretilachlor 50% EC @ 500 ml ha^{-1}, hand weeding at 15 and 40 days after 15 planting (weed free check) and weedy checks (untreated check) were also maintained. Application of pyrazosulfuron-ethyl 10% WP at 20 g ha^{-1} was most effective in controlling the associated weeds and increasing the grain yield of rice without any phytotoxic effect.

Zahan *et al.* (2015) revealed that pyrazosulfuron-ethyl followed by orthosulfamuron and (butachlor+propanil) reduced weed biomass by 96-97% compared to non-treated weedy plots. On the other hand, pyrazosulfuron-ethyl with one post-emergence herbicide either (butachlor+propanil) or 2,4-D reduced weed by 91 to 92%. Butachlor followed by orthosulfamuron followed by (butachlor+propanil) also reduce weed biomass by 91% compared to nontreated control. Only pyrazosulfuron-ethyl followed by orthosulfamuron and (butachlor+propanil) achieved yields close to those of the weed-free treatments (5.42-6.04 t ha^{-1}). Among the herbicide treatments in 2014, sole application of butachlor produced low grain yield similar to the non-treated crop (2.76-3.1 vs 3.13 t ha^{-1}) suggesting low activity of this herbicide on weed control in unpuddled soil. The results suggest that pyrazosulfuron-ethyl was the most fourteen effective pre-emergence herbicide in unpuddled transplanting system especially when applied with orthosulfamuron and/or (butachlor+propanil) or 2, 4-D as a post-emergence herbicides.

Singh *et al.* (2014) conducted an experiment to evaluate the performance of transplanted rice under pre-emergence herbicides and hand weeding techniques. The treatment consists of seven weed management techniques viz., butachlor @ 1.5 kg ai ha^{-1}, butachlor @ 1.0 kg ai ha^{-1} + 2 4 D @ 1.0 kg ai ha^{-1}, bensulfuron methyl 0.6% + pretilachlor 6% G @ 10.0 kg ha^{-1}, chlorimuron + metsulfuron-methyl 20 WP @ 4 g ai ha^{-1}, pyrazosulfuron-ethyl @ 30 g ai ha^{-1}, two hand weeding at 25 and 50 days after transplanting, weedy check (control). The highest grain yield (7.2 t ha^{-1}) was obtained from two hand weedings as a result of reduced dry weight of weeds and higher values of yield components. This was statistically at par with pre emergence application of pyrazosulfuron-ethyl (6.7 t ha^{-1}) and ready mix chlorimuron + metsulfuron methyl (6.2 t ha^{-1}). The highest net return (RS 53,950 ha^{-1}) and BCR (2.39) was also obtained with two hand weedings followed by pyrazosulfuron-ethyl and chlorimuron + metsulfuronmethyl application.

Pal *et al.* (2012) studied the efficacy of pyrazosulfuron-ethyl against weeds in transplanted rice which was studied during 2008 and 2009 at regional research substation, Chakdaha under Bidhan Chandra Krishi Viswavidyalaya, West Bengal, India. Pyrazosulfuron-ethyl at 42.0 g ha^{-1} applied at 3 DAT was most effective in managing associated weed species and yielded maximum rice yield (3.3 t ha^{-1}) with lower weed index (10.8%).

Bari (2010) conducted an experiment with eight herbicides in transplanted wetland rice during Aman season to study the effect of weed control and rice yield. The highest grain yield of 4.08 t ha^{-1} was obtained from butachlor while the lowest grain production (2.83 t ha^{-1}) was harvested in the plots receiving MCPA @ 125% of the recommended rate.

Kabir *et al.* (2008) conducted an experiment from June to December 2003 to assess weed dynamics and yield performance of transplanted Aman rice (cv. BRRI dhan39) in different weed control treatments. Weed density, weed biomass and weed control efficiency were significantly influenced by different weed control treatments under good water management practices. Other than weed free treatment, butachlor 5 G @ 2 kg ha^{-1} applied at 7 DAT along with one hand weeding at 40 DAT showed the best performance under good water management with minimum weed density (16 g m^{-2}) as well as weed biomass (9.27 g m^{-2}) and the highest weed control efficiency (82.57%). The highest grain yield (5.22 t ha^{-1}) was obtained under good water management in weed free treatment followed by butachlor 5G @ 2 kg ha^{-1} and one hand weeding (4.96 t ha^{-1}) under same water management.

Mukherjee and Malty (2007) conducted an experiment in transplanted rice, with butachlor 1.0 kg ha^{-1} at 3 days after transplanting + almix 20 WP (chlorimuron-7 ethyl + metsulfuron-methyl) 4.0 g ha^{-1} at 20 days after transplanting registered higher weed control efficiency and grain yield compared with season long weed control weed-free condition.

Dhiman (2006) reported the efficacy of various combinations of 2,4-D axilofos and chlorinuron in controlling weed infesting rice. Application of 500g 2, 4-D ha^{-1} in combination with chlorinuron resulted in the highest control of grasses, sedges and broad level weeds and produced the tallest plants, the highest number of effective tillers $hill^{-1}$ and grain yield (5.83 t ha^{-1}). Herbicides in combination with hand weeding can help in obtaining higher crop yield with less cost and efforts (Shathyamoorthy *et al.*, 2004).

Dhiman and Singh (2005) conducted an experiment at 2001 and 2002 in India to evaluate the effects of low doses of herbicides on weeds, nutrient uptake and yield of transplanted rice. The treatments were 2,4-D @ 500 g ha^{-1}, Anilofos @ 400 g ha^{-1}, hand weeding at 20, 40 and 60 days after transplanting and weedy control. Pre-emergence applications of 2,4-D recorded the lowest weed density and biomass among the herbicidal treatments 2,4-D and hand weeding significantly influenced nutrient uptake by the crop and gave the highest grain yields. The lowest uptake was recorded in weedy control. 2,4-D registered 88% and 83% higher grain yield in 2001 and 2002 respectively, compared with the weedy control.

Saha (2005) compared the efficacy of butachlor (948 g ha^{-1}), pretilachlor (500 or 750 g ha^{-1}), pyrazosulfuron-ethyl (40 or 50 g ha^{-1}), bensulfuron methyl (40 or 50 g ha^{-1}) + butachlor (938 g ha^{-1}) and hand weeding 2 (20 and 40 DAT) or 3 (20, 40 and 60 DAT) times for controlling weed flora. Results indicated that all treatments significantly reduced weed dry matter and density. The highest grain yields 5.75 t ha^{-1} was obtained from pyrazosulfuron-ethyl applied at 40 or 50 g ha^{-1}.

Halder *et al.* (2005) studied the comparative efficacy of pyrazosulfuron-ethyl (PSE) alone and its combination with molinate against weed complex of Boro paddy at the University Teaching Farm, Bidhan Chandra Krishi Viswavidyalaya, Nadia, West Bengal. The result of the experiment revealed that among all the chemicals tried in that investigation PSE 10% WP @ 16 g ha^{-1} was the best in reducing weed population and weed dry weight without showing any phytotoxic symptoms in 23 rice. Though hand weeding twice at 20 and 40DAT gave the maximum grain yield, benefit: cost ratio clearly showed that PSE 10% WP@ 15 g ha^{-1} was the right herbicide to replace the hand weeding treatment.

Ahmed *et al.* (2003) said that cinosulfuron, pretilachlor and the BRRI weeder performed better than farmers existing weed control practices of hand weeding with reduced weeding cost.

Bhowmick *et al.* (2000) observed that post emergence application of ethoxysulfuron + anilofos (0.02 + 0.375 kg ha^{-1}) at 10 DAT was statistically similar with hand weeding at 20 and 40 DAT in controlling weeds of transplanted rice effectively and the grain yields were also comparable. Butachlor 1 kg ha^{-1} at 5 DAT + 2, 4-D Na salt 0.4 kg ha^{-1} at 25, 18 DAT, pretilachlor 0.04 kg ha^{-1} at 5 DAT and oxadiagyl 0.1 kg ha^{-1} at 5 DAT were also promising.

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.

Biological control

Anyawu *et al.* (1976) reported that biological control of weeds includes the use of cover crops and leguminous which are grown in association with the crops. The cover crops creep on the land to cover the soil, thereby preventing development of weeds by chocking them out. The use of mucuna mulch can be used as an effective supplement with mechanical weed control. The effectiveness of supplementing mucuna mulching weed control must be considered with appropriate hand-pulling of weed using a special V-shaped hoe and mowing weeds with about a 2-kW engine mower. The combination of two or more methods of weed control at low input levels should be considered to reduce the weed competition to the possible minimum level; this was observed as the most appropriate solution to the problem of weed control by Singh *et al.* (1985).

Economics of different weed management practices

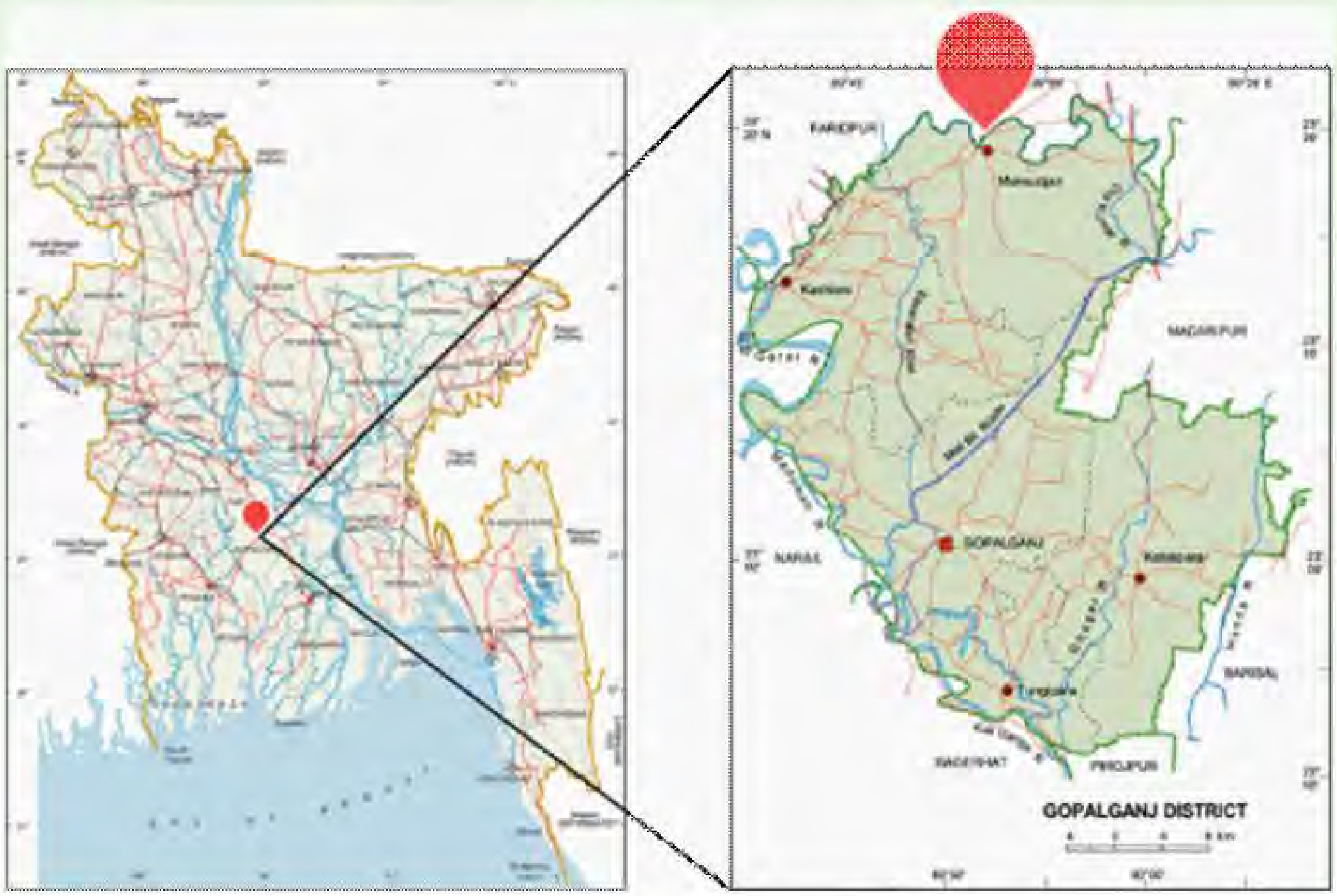
Hand weeding is laborious and generally more expensive. The weed control cost is maximum for hand weeding (two hand weeding at 30 and 45 DAT) and the lowest for chemical weed management (Hasanuzzaman *et al.*, 2007).

Khare and Jain (1995) reported that rotary weeder attained the highest net profit because of less cost of cultivation and thus resulted in the highest value of B:C ratio of 1.90 in sandy loam soil during wet season at Jabalpur.

Materials and methods

Study location

The experiment was conducted in the farmers' field at Bahirbagh and Provakordi under Muksudpur upazila, Gopalganj district of Bangladesh during wet season 2016 (Map 3.1). The experimental field is located in between 22°40'-23°25'N and 89°40'-90°10' Eon 2.7m altitude from the mean sea level (MSL). It is under Gopalganj-Khulna Bills under AEZ-14 (UNDP-FAO, 1988). The climate of this region is tropical. The average annual rainfall and temperature are 1809 mm and 25.8°C, respectively.



Map 3.1 Location of the experimental site

Soil sample collection and analysis

A metal core (50 mm height and 49.8 mm diameter) was used to collect soil samples from three different places at the depth of 0-150 mm to identify soil textural class, pH, organic matter and soil fertility classes. Samples were analyzed in the Soil Analytical Laboratory, Seed and Agro Enterprise, Gazipur. The soils of the experimental location represented the silty loam soil (Table 1). Textural class was determined by the USDA Soil Texture Triangle (Blake, 1986). Table 3.1 presents the fertility classes.

Cropping system

The cropping system in both the experimental sites was lentil-jute-T.Aman.

Table 3.1 Soil conditions of the experimental fields

Characteristics	Bahirbagh	Provakordi
Soil texture	Silt loam	Silt loam
pH	7.80	7.62
Organic matter (g kg^{-1})	15.40	22.80
N (g kg^{-1})	0.82	1.12
P (µg g^{-1})	6.31	39.41
K (µg g^{-1})	0.08	0.14

Note: Soil of Bahirbagh experimental plots contained 33.48% sand, 11.37% clay and 55.15% silt and Provakordi experimental plots contained 35.18 % sand, 12.97%clay and 51.85% silt.

Experimental design and treatments

Experimental plots were designed considering the ease of rice transplanter (4-row walking type rice transplanter, model: DP 480) operation. Average sub-plot size of the experimental field was 234 m^2 (17.0 m long and 14.0 m width) in Bahirbagh whereas, it was 210 m^2 (20.0 m long and 10.5 m width) in Provakordi. Buffer spacing between treatments was 0.5 m. The following seven weeding treatments were arranged in a randomized complete block (RCB) design with three replications. Each of the replication represented a block in the experiment.

T_1 = BW fb one HW
T_2 = BPW fb one HW
T_3 = Two HW
T_4 = Pyrazosulfuron-ethyl (PSE) fb one HW
T_5 = Weedy check
T_6 = Weed free and
T_7 = Mulching fb two HW (Farmers' practice)

Description of the technology

Transplanter

Self-propelled four rows walking-type rice transplanter (DP-480) was used to transplant seedling (Photo 3.1). It has a fixed row spacing of 30 cm and has the provisions for adjustments of planting depth, number of seedlings dispensed per hill, hill spacing and planting speed.

Photo 3.1 Walking type 4-row rice transplanter

BRRI weeder (Photo 3.2a)

Price : 800/-
Line spacing : 20, 25 cm
Capacity : 10 deci hr^{-1}
Man and woman can operate the machine easily

BRRI power weeder (Photo 3.2b)

Engine type : Petrol engine
Weight : 16.5 kg
Price : 60,000/-
Line spacing : 30 cm
Capacity : 33 deci hr^{-1}

Photo 3.2a BRRI weeder

Photo 3.2b BRRI power weeder

General information of the experiment

High yielding inbreeds rice variety BRRI dhan39 was transplanted as variety in Aman season. Experimental operations were conducted based on the guideline ofthe selected variety (Table 3.2). Twenty-one (21) and 22-day-old seedlings were transplanted in the experimental plots of Bahirbagh and Provakordi, respectively.

Table 3.2 General information regarding experimental characteristics

Location	Variety	Field size (ha)	Date of seeding	Date of transplanting	Date of harvesting	Crop duration (day)
Bahirbagh	BRRI dhan39	0.51	29 Jun 2016	19 Jul 2016	02 Nov 2016	123
Provakordi		0.55	26 Jul 2016	17 Aug 2016	27 Nov 2016	121

Land preparation

Jute was the previous crop of the experimental field. Average 20-25 mm height of jute stem kept in the field during land preparation. A rotary tiller powered by 2-WT was used for land preparation. Three rotary tillage passes in saturated soil, followed by one leveling, were the operations for land preparation (Photo 3.3).

Photo 3.3 Tillage by power tiller

Seedlings raising

Plastic tray (280×580×25 mm) was used for raising seedlings. Clod-free sandy loam soil collected from the respective field was used to fill-up the trays. A total of 130 g of pre-germinated seeds were spread uniformly on each tray. When the radicals and coleoptiles elongate to 1/3 of seed length is desired for pre-germinated seed to broadcast. After sowing, fine and loose soil was spread over the seeds to 3-5 mm depth. Sprinkling water was applied twice a day until complete seed emergence (Photo 3.4). Seedlings of 125 to 150 mm height with 2-3 leaves wereused in the experiment of Bahirbagh and Provakordi, respectively.

Photo 3.4 Seedling raising

Transplanting

Walk behind 4-rows mechanical rice transplanter (model-DP480) was operated at a pre-set spacing of 300×170 mm. There are three options in the rice transplanter to adjust the hill spacing (plant-to-plant spacing). The transplanter was set to maintain 170 mm distance between hills spacing in the row. Spacing between rows (line to line spacing) was fixed to 300 mm for the rice transplanter. The transplanting depth control lever was adjusted to the medium mode during field operation to maintain 20-30 mm depth of seedlings placement. Number of seedlings hill^{-1} were adjusted based on seedling density setting (Photo 3.5). There were nine options to select number of seedlings hill^{-1}. The picker was set at point 4 to maintain similar numbers of seedlings hill^{-1} in all treatments for both the locations.

Photo 3.5 Mechanical transplanting

Data collection on hill spacing

Hill to hill distance of the transplanted seedling varied from pre-set spacing of the transplanter for slippage or skidding with soil conditions. Hill to hill distance of the transplanted seedling was measured randomly in three places of each sub-plot from 1.0 m of length. Number of plants hill^{-1} and missing hills also collected after transplanting from 0.25 m^2 of area of each sub plots. Gap filling was done manually after two days to maintain the same number of hills in each plot.

Measurement of plant height and tiller count

Four sticks were placed randomly in each plot to make quadrate and data on plant height and tiller numbers were taken at 20 days intervalwithin the quadrate (Photo 3.6).

Photo 3.6 Measurement of plant height and tiller count

Weed management

Weeds were managed according to the design and treatments (Photo 3.7). BW and BPW were operated at 25 DAT in both the locations. Post emergence herbicide pyrazosulfuron-ethyl was applied to control weeds of T_4 (herbicide application for weed control) at 7 DAT at the rate of 150 g ha^{-1} whereas treatment T_5 (no weeding) was not weeded during the crop growing periods. One manual weeding was done at 45 DAT to control the weeds of T_1, T_2, T_3 and T_4 plots. Whereas, T_6 (weed free) was weeded at 22, 30, 40 and 50 DAT to keep the field weed free throughout the crop growing period. In case of T_7, weeds were controlled by the farmers manually at 15, 25 and 40 DAT.

Photo 3.7 Weeding operation

Weeding efficiency

Weeding efficiency (WE) of the different weeding practices was measured by counting the number of weeds of the pre-selected area before and after weeding. At each sampling time, three quadrates of 0.5 m × 0.5 m were placed randomly in each sub-plot and weeds were collected from each quadrate before and after weeding. Weeding efficiency of T_4 (herbicide application to control weeds) was measured in compared with the weedy check by subtracting the number of weeds of the same area of T_4 from weedy check (T_5) at the time weeding of the other treatments. Weeding efficiency was calculated using following equation (Remesan *et al.*, 2007).

$$E_W = \frac{W_1 - W_2}{W_1} \times 100$$

Where,

EW = Weeding efficiency (%)
W_1 = Number of Weed population before weeding
W_2 = Number of Weed population after weeding

Weed control efficiency

Weed control efficiency (WCE) of the different weeding practices were measured based on the number of weeds in the weedy check plots. Numbers of weeds in the other treatment plots were measured after weeding from the pre-selected area. At each sampling time, three quadrates of 0.5 m × 0.5 m were placed randomly in the each sub-plot and weeds were collected from each quadrate after weeding. Weed control efficiency was calculated using the following equation according to Rao (1988).

$$E_{CW} = \frac{W_c - W_t}{W_c} \times 100$$

Where,

ECW = Weed control efficiency (%)
Wc = Number of Weed population in the weedy check plot
Wt = Number of Weed population after weeding in other plots

Tiller damage

It is the measure of damage on crop plants while weeding operation done and it depends on the uniformity of plant to plant spacing, skill of the operator, field condition, standing water condition of the experimental fields. Minimum standing water (around 10 mm) was maintained during weeding. In order to determine the damaged plant, bamboo frame of 0.50 × 0.50 m was thrown in the field randomly in three places of each plot and the number of damaged plants in the frame was counted (Tewari *et. al.*, 1993) (Photo 3.8). Number of tiller damage during weeding practices was calculated by the following equation:

$$DTR = \frac{Q_2}{Q_1} \times 100$$

Where,

DTR = Damaged tiller ratio (%)
Q_1 = Number of plants in 1 m2 area before weeding
Q_2 = Number of damaged plants in 1 m^2 area after weeding

Photo 3.8 Weed count and weed sample collection

Pest management

Pest attacked the plants severely during the study period. However, pests were controlled by two application of Furadan 5G and Theovit 80 WG along with Virtako 40 WG pesticide to control yellow stem borer and other insect infestation at 28 and 48 DAT in both the locations (Photo 3.9). Pesticide was mixed with 500-600 liter of water to spray in one hectare of land (Table 3.3).

Table 3.3 Information regarding insecticide application in the field

Brand	Ingredient	Dose ($kg\ ha^{-1}$)	Control against
Furadan 5 G	Carbofuran	15	Effective against nematode and other insects.
Virtako40 WG	Chlorantraniliprole + thiamethoxam	0.01	Effective against rice yellow stem borer
Theovit 80 WG	Sulphur	2.5	Effective against powdery mildew disease and also reduce the sulphurdeficiency (yellowing of younger leaves) symptoms.

Photo 3.9 Pesticide spraying

Fertilizer management

The recommended fertilizer doses for Aman season (cv. BRRI dhan39) was applied at the same rate for all treatments (BRRI, 2013). Diammoniumphosphate (DAP), muriate of potash (MoP), zinc sulphate ($ZnSO4$) and gypsum fertilizers were applied to soil before transplanting as basal. Urea (N) was broadcast in three equal splits at seven days after transplanting, vegetative stage and before panicle initiation. Table 3.4 presents the rate of recommended fertilizer.

Table 3.4 Fertilizer application rate as basal and top dressing

Location	Basal dose (kg ha^{-1})				Urea top dose (kg ha^{-1})			
	DAP	MoP	Gypsum	Zinc Sulphate	1st	2nd	3rd	Total
Bahirbagh	125	125	40	8	60	70	60	190
Provakordi	100	100	40	6	50	70	50	170

Irrigation water management

Experimental plots were irrigated as and when needed. During transplanting, minimum standing water was maintained in the field to reduce the floating hills as well as missing hills. Bunds around the individual plots were repaired as and when necessary to control the water flow between the plots. Excess water was drained out from the plots before 15 days of harvest to enhance maturity of the crop.

Weed density and weed biomass

Weed density and weed biomass were measured before weeding at 25 and 45 DAT in both the locations except T_7 treatment, where it was measured at 20 and 40 DAT. At each sampling time, three quadrates of 0.5 m× 0.5 m were placed randomly in each sub-plot and weeds were collected from each quadrate. Collected weeds were counted and biomass was measured after the samples were oven-dried at 70°C for 72 h. Weed density and biomass data were converted to density or biomass per m^2.

Weed dynamics

Weed dynamics were measured to observe the increase rate of the weed infestation with time. Weed density was measured immediate before and after weeding and 10 days after weeding. Weed dynamics were observed at 1st and 2nd weeding periods. At each sampling time, three quadrates of 0.5 × 0.5 m were placed randomly in each sub-plot and weeds were collected from each quadrate. Collected weeds were only counted and converted as number of weeds per square meter.

Labor requirement

The number of human labor involved in each operation from seedling raising to processing were measured to calculate the benefit-cost ratio under different treatments.

General performance parameters

Machines used in different operations were rice transplanter, mechanical and power weeder, self-propelled reaper, open drum threshers and winnower. Most of the performance parameters of the rice transplanter, mechanical and power weeder are common (i.e. forward speed, theoretical and actual field capacity, effective operating time, field efficiency and fuel consumption) as discussed sequentially (Hunt, 1995). All these parameters were used to calculate cost of production and benefit-cost ratio of Aman rice production under different weeding practices.

The time required by a machine to travel certain distance in the field was recorded and then machine forward speed computed using the following equation:

$$S = \frac{D}{t} \times 3.6 \quad (1)$$

Where,

S = Machine forward speed (km hr^{-1})

D= Distance (m)

t = Time required to cover the distance D (sec)

Theoretical field capacity was calculated as a function of speed and operating width by the following equation:

$$C_0 = \frac{W \times S}{C} \quad (2)$$

Where,

C_0 = Theoretical field capacity (ha hr^{-1})

W = Operating width of the machine (m)

C = Constant (10)

Actual field capacity was calculated as a function of total area and total field time by the following equation

$$Ca = \frac{A}{T} \quad (3)$$

Where,

Ca = Actual field capacity (ha hr^{-1})

A= Total area covered (ha)

T= Total operating time required for transplanting (hr)

The effective operating time of the machine, as a function of time required by it to cover a unit of area performing its task successfully, was measured by the following equation

$$E_T = \frac{1}{Ca} \quad (4)$$

Where,

ET = Effective operating time (hr ha^{-1})

The field efficiency, as a function of theoretical and actual field capacity was calculated by the following equation;

$$Ef = \frac{Ca}{C_0} \times 100 \quad (5)$$

Where,

Ef = Field efficiency (%)

The fuel consumption was measured from the amount of refill after finishing an operation and was calculated by using the following equation:

$$F = \frac{Ft}{T} \quad (6)$$

Where,

F = Fuel consumption rate (L hr^{-1})

Ft = Total fuel used during operation (L)

T = Total time needed for operation (hr)

Operating cost of weeder

Operating cost (Tk hr^{-1}) of weeder was calculated considering the fixed cost (Tk hr^{-1}) and variable cost (Tk hr^{-1}) using the method mentioned in Hunt (1995). Depreciation, interest on investment, tax, insurance and shelter are the components of fixed cost and calculated using the following equations.

a) Annual depreciation, $D = \frac{P - S}{L}$ (7)

Where,

D = Depreciation (Tk yr^{-1})

P = Purchase price of the weeder (Tk)

S = Salvage value (Tk)

L = Working life of the weeder (yr)

b) Interest on investment, $I = \frac{P + S}{2} x i$ (8)

Where,

i = rate of interest

c) Tax, insurance and shelter cost, T = 3 % of purchase price.

Total fixed cost per year, FC (Tk yr^{-1}) = (a + b + c)

In variable cost calculation, the cost of fuel, lubrication, daily service, power and labor were considered. These costs increase with the increase of machine use and vary to a large extent in direct proportion to days of use per year.

d) Labor cost per hour, L(Tk hr^{-1})
e) Fuel cost per hour, F (Tk hr^{-1})= Fuel consumption (L hr^{-1}) × Fuel price (Tk L^{-1})
f) Lubrication oil cost per hr, O = 3 % of fuel cost
g) Repair and maintenance cost, R&M (Tk hr^{-1}) = 3.5% of purchase price (Tk yr^{-1})/ average annual use (hr yr^{-1})
h) Total variable cost, VC (Tk hr^{-1}) = (d + e + f + g)

Yield and yield contributing character

Tiller number and plant height were assessed from 12 hills per plot at 10-day intervals. Crops were harvested when 85-90% of the grains become golden. It was threshed, cleaned, dried and weighed to collect necessary data on various crop characters. The harvested crop of each plot was bundled separately, tagged and carried to a clean threshing floor. Sample bundles were then dried in sunshine, threshed and then seeds were cleaned. Rice grain yield per plot was recorded from a pre-selected 10 m^2 harvest area and was determined with the adjustment to 14 % moisture content (Photo 3.10). For computing above ground biomass and yield attributes, samples from 1 m^2 quadrates were collected from outside of the pre-selected 10 m^2 area of each plot. Straw yield (above ground biomass), plant height, panicle length, number of tillershill-1 and number of panicles $hill^{-1}$, filled and unfilled spikelets $panicle^{-1}$ and 1000 grains weight were recorded from these quadrates.


Photo 3.10 Harvesting of sample area and threshing

Economic analysis

Cost of rice production under different weeding practices was calculated based on total production cost. Rental charge of the land and input costs were the components of production cost. Seedling raising, land preparation, fertilizer, labor, herbicides, weeding, transplanter operation, intercultural operation, irrigation, harvest and post-harvest costs were the components of input cost. Market price of the crop was collected from local markets. Price of the product and production costs were used to calculate gross return, gross margin and benefit-cost ratio. The benefit-cost ratio (BCR) was computed as the gross return divided by production cost. Gross margin was also calculated by subtracting the total inputs from gross return (Appendix-IV). The total production cost was calculated by summing up the costs in individual operation. The term 'operation' refers to each of the production steps as like as from seedlings raising to winnowing. Costs of material, labor and machine were considered under respective operations.

Statistical analysis

Data were analyzed as a single factorial design according to Gomez and Gomez (1984) using Statistix 10 program (Statistix 10 software, 2013). Means were compared with the least significant difference (LSD) test. Simple correlation analysis was carried out with Excel 2010 to determine the relationship of grain yield to yield attributes.

Photo 3.11 Initial field condition

Photo 3.12 Crops at maturity stage

Photo 3.13 Monitoring the research field

Results and discussions

This chapter contains result of the field experiments with scientific arguments. Effects of weed management on plant growth, yield and cost characteristics of rice cultivation have been presented in tabular and graphical format.

Plant spacing and seedling dispensed per stroke

The ultimate productivity of a crop is determined by plant population (Baloch *et al.*, 2007). Before operation of the transplanter, plant to plant spacing was set at 17 cm, and seedling density was set at 4. In actual field condition, plant to plant spacing was obtained 17.1 and 17.4 cm in Bahirbagh and Provakardi, respectively due to variation of water height and soil settling period, which caused the slippage and skidding of the transplanter (Islam *et al.*, 2016b). Seedling dispensed per hill largely depended on the seedling density in tray and seedling density setting in machine. The seedling dispensed per stroke was 3.9 and 3.8 number in Bahirbagh and Provakardi, due to variation of seedling density in tray (Fig. 4.1). Uniformity of spacing and seedlings dispensed per stroke can be maintained using the same quality of seedling with same setting of the transplanter during operation.

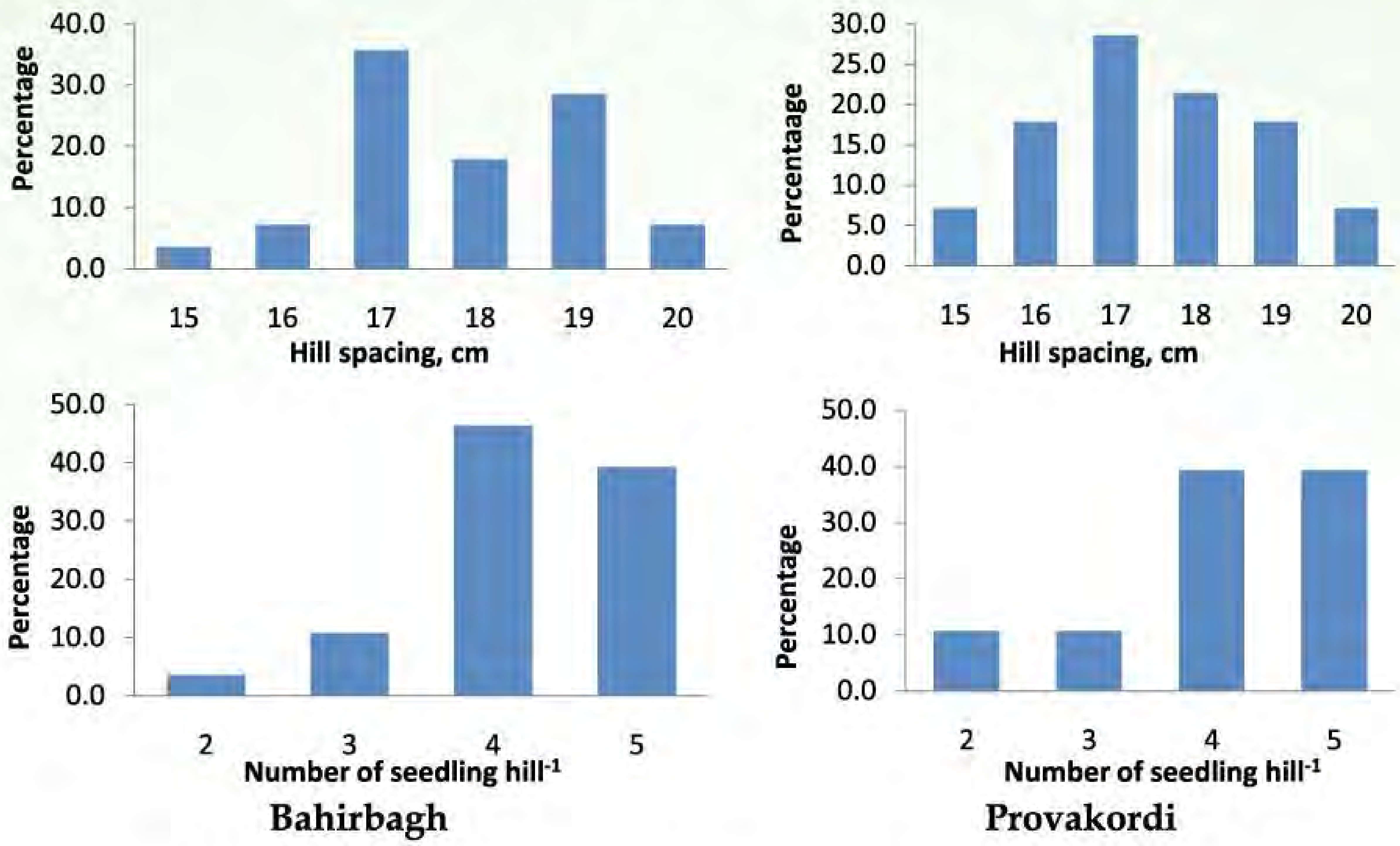


Fig. 4.1 Plant spacing and seedling density at Bahirbagh and Provakordi

Weed species

The common weed species were observed in experimental sites (Photo 4.1 and 4.2). The most predominant weed species in the experimental plots was *Cyperus rotundus, Cynodon dactylon, Digitaria ischaemum, Eleusine indica, Alternanthera philoxeroides and Monochoria vaginalies.*

Cyperus rotundus

Cynodon dactylon

Digitaria ischaemum

Eleusine indica

Alternanthera philoxeroides

Monochoria vaginalies

Photo 4.1: Major weed species in both the location

Cyperus difformis

Nicotiana plumbaginifolia

Ranunculus scleratus

Photo 4.2: Minor weed species in both the locations

Weed density

Weed density was counted at 20 and 40 DAT (Table 4.1).Weed density was influenced by location and weeding practices. The highest number of weeds wasobserved in Bahirbagh compared to Provakordi at 20 and 40 DAT, perhaps due to variation of soil fertility and weed seed bank. In Bahirbagh, the lowest weed infestation was observed in PSE fb one HW plots because of herbicide application at seven DAT, which was statistically similar to weedy check indicating that only application of PSE was not sufficient to control weed. Therefore, additional one HW is required to control remaining weeds. However, significantly higher weed infestation was observed in two HW plots and mulching fb two HW plots.

After 2nd weeding, weed management practices showed significant effect on weed density. All the weed control treatments significantly reduced the weed density over weedy check in both the locations except BW fb HW in Bahirbagh. BRRI weeder fb one HW demonstrated significantly higher number of weeds at 40 DAT because weeds in between plants was not removed during weeder operation, which leads to more weeds infestation. In Provakordi, weed infestation was not varied significantly among the treatments both at 20 and 40 DAT. However, lower infestation was observed in power weeder and herbicide treated plots. In these two locations, weeding density mainly varied with the variation of soil fertility and cropping systems.

Table 4.1 Weed density (no. m^{-2}) as influenced by weed management practices

Weeding method	Bahirbagh		Provakardi	
	20 DAT	40 DAT	20 DAT	40 DAT
BW fb one HW	575.1	1208.0	369.3	430.7
	(23.90)	(32.59)	(118.60)	(20.67)
BPW fb one HW	527.6	795.5	205.3	474.7
	(22.95)	(27.87)	(13.88)	(21.38)
Two HW	885.3	851.5	332.4	552.4
	(29.52)	(29.10)	(17.39)	(23.29)
PSEfb one HW	171.1	229.3	240.9	608.0
	(12.86)	(15.14)	(15.48)	(23.58)
Weedy check	428.4	541.8	119.1	646.2
	(21.2)	(23.22)	(10.89)	(25.34)
Weed free	0.0	0.0	0.0	0.0
	(0.71)	(0.71)	(0.71)	(0.71)
Mulching fb two HW	657.3	419.6	220.4	503.6
	(25.38)	(20.48)	(14.62)	(21.09)
Mean	**463.6**	**578.0**	**212.5**	**459.4**
	(19.43)	**(21.30)**	**(13.08)**	**(19.44)**
$LSD_{0.05}$	274.84	727.7	260.16	476.03
	(5.41)	(1027)	(7.59)	(9.99)
CV (%)	33.33	70.78	68.82	58.25
	(15.66)	(27.1)	(32.6)	(28.89)

Note: L_1= Bahirbagh, L_2= Provakordi, BW=BRRI weeder, BPW= BRRI power weeder, PSE = Pyrazosulfuron-ethyl, fb=followed by, HW=hand weeding, NS=Not significant, figures in the parentheses indicate square root transformed ($\sqrt{x}$) original value which are more than 10 and ($\sqrt{x+0.5}$) which are equal or less than 10.

Weed biomass

Weed biomass varied significantly with the weed management practices in both the locations at 20 and 40 DAT (Table 4.2). In Bahirbagh, the highest weed biomass was observed in two HW treatments,which were statistically similar to BW, BPW and one mulching fb two HW at 20 DAT and the lowest weed biomass was observed in PSE fb one HW treatments. However, BW fb one HW, BPW fb one HW, weedy check and two HW gave significantly higher weed biomass at 40 DAT, whereas the lowest was observed in PSE fb one HW and one mulching fb two HW treatments. BRRI weeder fb one HW and BPW fb one HW demonstrated significantly higher weed biomass due to weeds were remained in the intra plant spacing during weeder operation. In Provakordi, allthe weed management practices showed insignificant effect on weed biomass at 20 DAT. At 40 DAT, the significantly highest weed biomass was observed in weedy check, BPW fb one HW and two HW treatments and lowest weed biomass was observed in one mulching fb two HW and PSE fb one HW treatments.

Table 4.2 Weed biomass (g m^{-2}) as affected by weed management practices

Weeding method	Bahirbagh		Provakardi	
	20 DAT	40 DAT	20 DAT	40 DAT
BW fb one HW	26.6 (5.05)	106.0 (9.92)	23.7 (4.80)	52.0 (7.13)
BPW fb one HW	26.0 (5.08)	97.9 (9.86)	55.5 (6.95)	60.3 (7.64)
Two HW	33.9 (5.75)	57.6 (7.53)	36.5 (5.46)	63.1 (7.76)
PSEfb one HW	10.5 (3.19)	16.3 (4.01)	24.4 (4.76)	27.9 (5.27)
Weedy check	19.2 (4.36)	84.5 (9.14)	17.9 (4.17)	117.4 (10.50)
Weed free	0.0 (0.71)	0.0 (0.71)	0.0 (0.71)	0.0 (0.71)
Mulching fb two HW	22.2 (4.69)	26.5 (5.14)	43.9 (6.26)	51.2 (7.07)
Mean	**19.8** **(4.12)**	**55.5** **(6.62)**	**28.8** **(4.73)**	**53.1** **(6.58)**
$LSD_{0.05}$	12.56 (1.24)	52.79 (2.63)	44.70 (3.55)	62.49 (3.37)
CV (%)	35.71 (16.92)	53.42 (22.3)	87.15 (42.14)	66.12 (28.82)

Note: L_1= Bahirbagh, L_2= Provakordi, BW=BRRI weeder, BPW= BRRI power weeder, PSE = Pyrazosulfuron-ethyl, fb=followed by, HW=hand weeding, NS=Not significant, figures in the parentheses indicate square root transformed ($\sqrt{x}$) original value, which are more than 10 and ($\sqrt{x+0.5}$) which are equal or less than 10.

Weed dynamics

1st weeding at 20 DAT

Weed dynamics was measured during tillering and vegetative periods of crops to investigate the increasing pattern of weeds during the critical period of weed infestation time. During 1st weeding, weeding practices were influenced significantly before, immediate after and after 10 days of weeding (Table 4.3). Before weeding, maximum number of weeds were found in weedy check, which was similar to two HW and PSE fb one HW whereas minimum number of weeds were observed in BPW fb one HW, BW fb one HW and mulching fb two HW treatments in Bahirbagh. Other weeding practices gave statistically similar and minimum intensity of weeds. Similar patterns of weeds of immediate after weeding were observed at 10 AW.Weeds were increased proportionately during 1st weeding in Bahirbagh.

In Provakordi,weeding practices only influenced significantly after weeding whereas before weeding and after 10 days of weeding were not varied significantly. Weedy check gave significantly higher number of weeds, which was similar to BW fb one HW, PSE fb one HW and mulching fb two HW treatments. Significantly lower weeds were observed in two HW and BPW fb one HW treatments. Immediate after weeding, BW fb one HW demonstrated significantly higher weeds compared to BPW fb one HW due to difference in operational width of the weeder. The uprooting efficiency of BW was low due to wider spacing of plant in mechanically transplanted plots. BW was designed to operate in 20 cm line spacing whereas line to line spacing of mechanically transplanted field was 30 cm. Islam *et al.* (2017) mentioned that 75% weeds can be controlled by using BW in 20 cm line spacing field.

Table 4.3 Weed dynamics (no.m^{-2}) as affected by weeding methods (during 1st weeding)

Weeding method	Bahirbagh			Provakardi		
	BFW	AW	10AW	BFW	AW	10AW
BW fb one HW	898.0	458.3	595.7	358.7	219.7	283.3
	(29.5)	(20.5)	(23.0)	(18.9)	(14.8)	(16.5)
BPW fb one HW	1168.3	463.0	805.7	319.3	87.7	213.3
	(33.6)	(21.3)	(27.6)	(17.2)	(8.5)	(13.3)
Two HW	1535.3	595.7	858.0	282.0	114.3	193.0
	(38.7)	(23.9)	(29.0)	(16.4)	(10.4)	(13.7)
PSE fb one HW	655.7	719.7	981.3	104.67	106.33	308.0
	(25.47)	(26.62)	(30.6)	(10.23)	(10.31)	(16.9)
Weedy check	2404.3	2095.7	1389.0	298.7	298.7	405.3
	(48.7)	(44.2)	(37.2)	(17.3)	(17.3)	(19.9)
Weed free	0.0	0.0	0.0	0.0	0.0	0.0
	(0.7)	(0.7)	(0.7)	(0.7)	(0.7)	(0.7)
One mulching fb two HW	1099.0	528.0	722.0	210.7	145.0	169.0
	(33.0)	(22.9)	(26.8)	(13.7)	(10.7)	(12.2)
Mean	**1108.7**	**694.3**	**764.5**	**224.87**	**138.82**	**224.6**
	(29.9)	**(22.9)**	**(25.0)**	**(13.49)**	**(10.38)**	**(13.3)**
$LSD_{0.05}$	750.58	768.21	551.1	NS	147.38	NS
	(10.1)	(9.74)	(10.37)	(7.08)	(6.21)	(7.69)
CV (%)	38	62.19	40.52	59.28	59.68	62.4
	(18.9)	(23.94)	(23.3)	(29.56)	(33.65)	(32.49)

Note: BFW= Before weeding, AW= After weeding, 10AW= 10 days after weeding, BW=BRRI weeder, BPW= BRRI power weeder, PSE = Pyrazosulfuron-ethyl, fb=followed by, HW=hand weeding, NS=Not significant, figures in the parentheses indicate square root transformed ($\sqrt{x}$) original value which are more than 10 and ($\sqrt{x+0.5}$), which are equal or less than 10.

2^{nd} *weeding at 40 DAT*

During 2^{nd} weeding, weed dynamics were also calculated to observe the weeding patterns (Table 4.4). Weed management practices showed significant effect on weed population in Bahirbagh at BFW, AW and 10AW. Before weeding, the significantly highest number of weeds were observed in one mulching fb two HW followed by all others plots. At 10AW, mulching fb two HW demonstrated the highest number of weeds, which was similar to PSE fb one HW whereas the lowest and similar number of weeds were observed in the rest of the treatments. Weed population sharply increased at 10 AW except weedy check. In weed check, some weeds died due to inter weed competition. Weedy check showed the significantly highest number of weeds than the other weed management practices and remained unchanged between AW and 10 AW. At 10 AW, weed numbers are at par among the BW fb one HW, BPW fb one HW, two HW, PSE fb one HW and mulching fb two HW treatments.

Table 4.4 Weed dynamics (no.m^{-2}) as affected by weeding methods (during 2^{nd} weeding period)

Weeding method	Bahirbagh			Provakardi		
	BFW	AW	10AW	BFW	AW	10AW
BW fb one HW	856.7	381.3	632.7	318.7	172.7	267.7
	(27.5)	(18.1)	(23.4)	(16.9)	(12.5)	(16.2)
BPW fb one HW	1131.0	612.7	626.7	264.0	96.7	203.7
	(32.8)	(24.6)	(24.7)	(15.0)	(8.9)	(14.0)
Two HW	1176.0	514.0	704.0	268.3	121.7	221.7
	(34.0)	(22.6)	(26.2)	(15.9)	(10.9)	(14.7)
PSEfb one HW	1469.0	230.7	697.6	336.3	89.27	253.3
	(38.0)	(15.2)	(26.3)	(17.5)	(9.1)	(15.3)
Weedy check	1571.0	1571.0	882.7	496.3	305.3	503.3
	(39.5)	(39.5)	(29.0)	(22.2)	(16.4)	(22.3)
Weed free	0.0	0.0	0.0	0.0	0.0	0.0
	(0.7)	(0.7)	(0.7)	(0.7)	(0.7)	(0.7)
Mulching fb two HW	3241.0	599.0	1420.0	267.3	95.7	228.3
	(56.9)	(24.7)	(37.6)	(15.5)	(9.6)	(14.6)
Mean	**1349.2**	**558.4**	**709.1**	**278.7**	**125.89**	**239.7**
	(32.8)	**(20.7)**	**(24.0)**	**(14.8)**	**(9.7)**	**(14.0)**
$LSD_{0.05}$	720.55	316.24	515.59	NS	NS	149.73
	(11.64)	(7.22)	(10.7)	(10.47)	(7.32)	(4.81)
CV (%)	30.02	31.84	40.87	74.88	83.14	35.11
	(19.94)	(19.6)	(25.1)	(39.71)	(42.36)	(19.33)

Note: BFW= Before weeding, AW= After weeding, 10AW= 10 days after weeding, BW=BRRI weeder, BPW= BRRI power weeder, PSE = Pyrazosulfuron-ethyl, fb=followed by, HW=hand weeding, NS=Not significant, figures in the parentheses indicate square root transformed ($\sqrt{x}$) original value, which are more than 10 and ($\sqrt{x+0.5}$), which are equal or less than 10.

Weeding efficiency

Weeding efficiency (WE) of weeder depended on the severity of weed, soil moisture and weeding regime. WE of BPW was 52% more than that of BW (Fig. 4.1). Because BW eliminated weeds within 20 cm of spacing as the width of BW was 20 cm and 10 cm space remain unweeded in mechanically transplanted rice field. BW having the width of 20 cm is not suitable for mechanically transplanted rice. Therefore, the width of BW should be increased to get the better WE. On the other hand, BPW exerted the sufficient power in rotor and caused better blades grips with soil, resulting in higher WE of the weeder. Generally, WE depends on the weeder type, weed species and the weeding time. If weeding is delayed, the WE will be decreased for excessive growth of weeds in soil and improper involvement of machine blades in soil depth. Islam *et al.* (2016b) and Islam *et al.* (2017) tested the WE of BW and BPW in two types of soil in wet season rice cultivation and found the WE of BPW was higher than BW. Alizadeh (2011) tested the WE of two types of weeder in low land rice cultivation in Iran and found that WE of power weeder (84%) was higher than the rotary weeder (73%). Subudhi (2004) reported that the efficiency of different types of hand operated weeder is between 76 to 91%. These findings are consistent to the results of the present experiment.

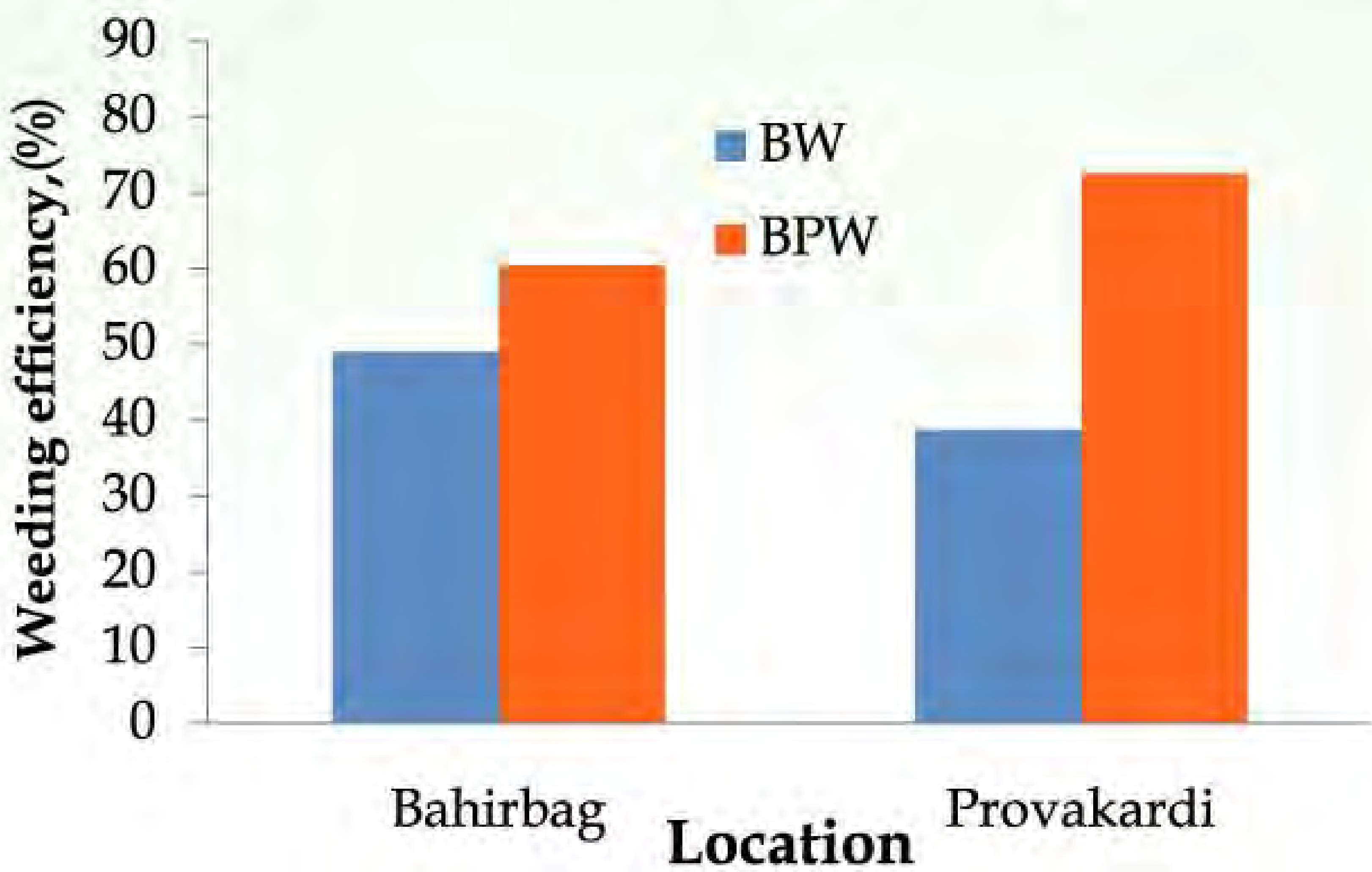


Fig. 4.1 Weeding efficiency of two types of weeder

Weed control efficiency

Weed control efficiency (WCE) varied in wide range among the treatments in both the locations and weeding times. At 20 DAT, both the BW and BPW fb one HW demonstrated the higher WCE in Bahirbagh, while only BPW fb one HW gave the higher WCE in Provakordi. Contrary to, PSE fb one HW gave the lowest weed control efficiency in both the locations (Table 4.5). It might be due to insufficient dose or improper application of herbicide in the plots. Whereas at 40 DAT, PSE fb one HW showed higher WCE in Bahirbagh (85%) and Provakardi (71%), respectively. This is due to poor growth of weeds in later stage for herbicide effect on weeds. Bhuiyan (2016) reported that higher WCE (>80%) was achieved with the treatment of mefenacet + bensulfuron methyl and pyrazosulfuron-ethyl at 30, 55 and 80 DAS.

In direct wet seeded rice. BRRI power weeder fb one HW gave lower weed control efficiency at 40 DAT compared to 20 DAT. It indicated that BPW operation at 20 DAT is more effective compared to HW at 40 DAT over the weedy check. Bhuiyan and Gazi (2010) reported that mefenacet + bensulfuron methyl 53%WP @ 594 g ai ha^{-1} lead to higher WCE (> 80%) and lowest number and dry weight of weeds which ultimately resulted in higher yield attributes and grain yield of rice.

Table 4.5 Weed control efficiency as affected by weed management practices (%)

Weeding method	Bahirbagh		Provakardi	
	20 DAT	40 DAT	20 DAT	40 DAT
BW fb one HW	78	76	26	43
BPW fb one HW	78	61	71	68
Two HW	72	67	62	60
PSEfb one HW	66	85	64	71
Mulching fb two HW	75	62	51	69

Note: BW=BRRI weeder, BPW= BRRI power weeder, PSE = Pyrazosulfuron-ethyl, fb=followed by and HW=hand weeding

Field capacity

Field capacity is an important factor for any kind of machine operation. Field capacity of BPW and BW was obtained 0.07 and 0.03 ha hr^{-1}, respectively (Fig. 4.2). Islam *et al.* (2016b) and Islam *et al.* (2017) studied the field capacity of BW and BPW in other soil types and obtained almost similar results due to variation of soil types. Operator's skill influenced the performance of weeder. At the end of each pass, operator lifted the machine, placed the machine in another new rows and started operation. This increased the turning time loss, which reduced the field capacity of the BPW.

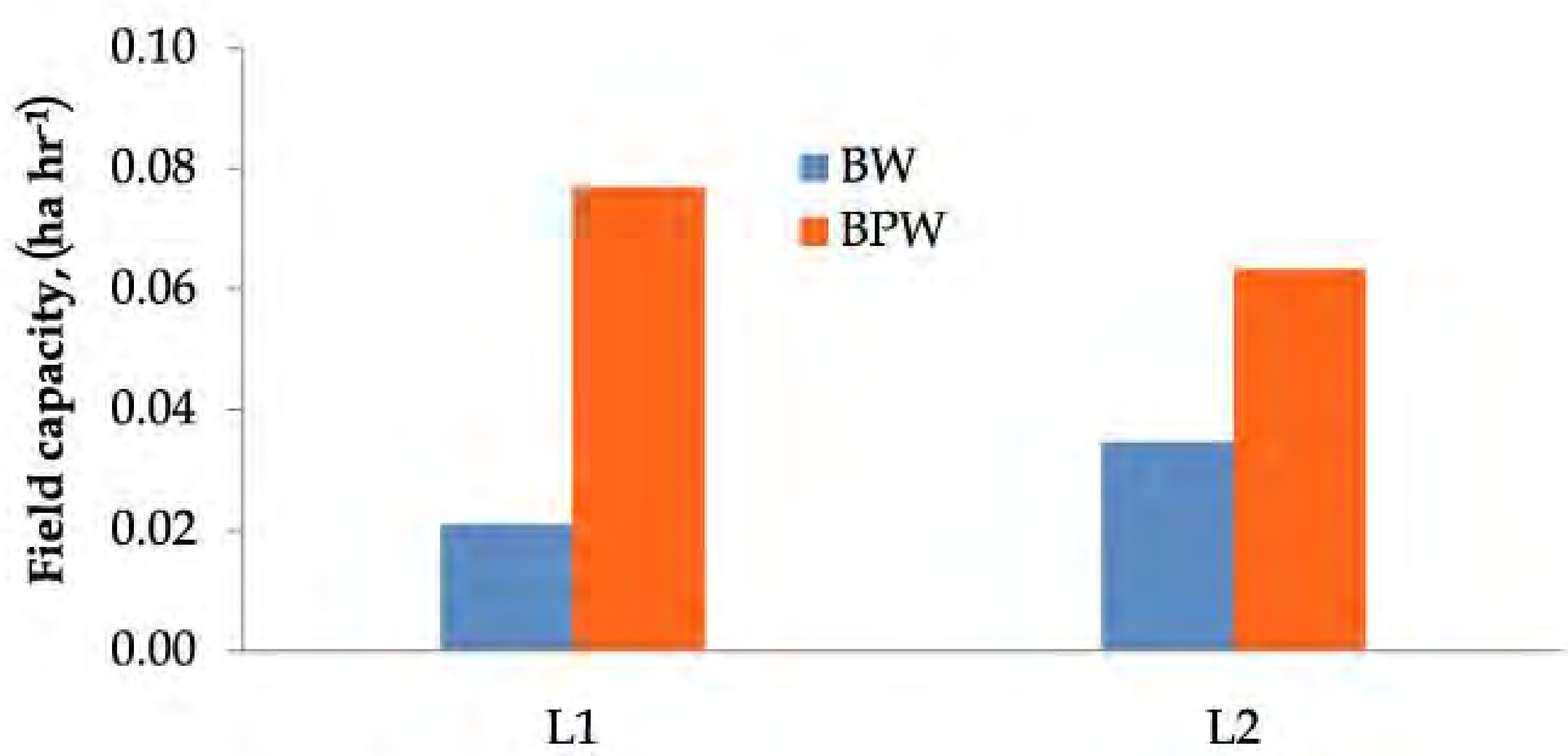


Fig. 4.2 Field capacity of BW and BPW

Tiller damage

Plant spacing is an important factor for successful weeding operation. Results indicated that 14-15% plants were damaged during operation of the BPW in Bahirbagh and Provakordi, respectively (Fig. 4.3). The damaged plants were revived after few days. Similar results were obtained by Islam *et al.* (2016b) and Islam *et al.* (2017). The movement of weeder machines encountered difficulties in BPW because of the distribution pattern and shading of plant over spaces between the rows.

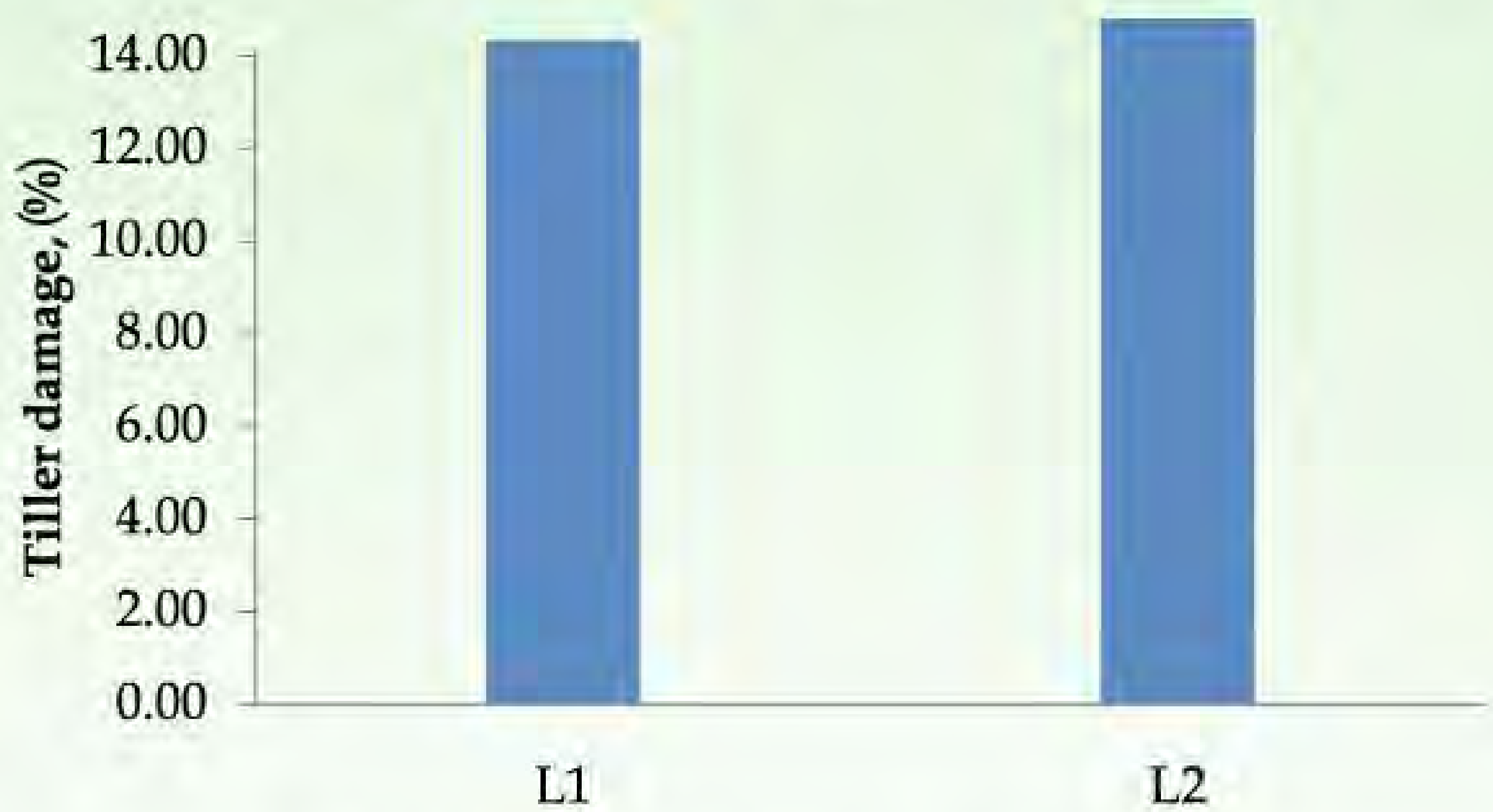


Fig.4.3 Tiller damage by BPW

Labor requirement and cost of weeding

Labor requirement and cost for weeding in rice production is one of the major input cost. Both the labor requirement and cost for weeding was varied significantly with the weeding practices (Table 4.6). In Bahirbagh, the highest labor was required for mulching fb two HW which was similar to two HW whereas the lowest labor was required in PSE fb one HW, which was similar to BPW. Weeding cost is linearly proportional with the labor requirements for different weed management practices. In Provakordi, significantly higher labor was required in weed free, which was similar to mulching fb two HW whereas the lowest and similar labor was required for the rest weed management practices. Alizadeh (2011) mentioned that the labor input in mechanical weeder was obtained 36 man-hr ha^{-1} whereas 112 man-hr ha^{-1} in hand weeding which was higher than the present finding. This might be due to the variation in weed density, type of weed and weeding regime.

Table 4.6 Labor requirement and cost ofweeding as affected by weed management practices

Weeding method	Labor (man-hr ha^{-1})		Cost (Tk ha^{-1})	
	Bahirbagh	Provakordi	Bahirbagh	Provakordi
BW fb one HW	538	222	20436	9667
BPW fb one HW	402	322	16519	15406
Two HW	897	335	33622	14676
PSEfb one HW	278	207	10413	9046
Weedy check	0	0	0	0
Weed free	737	580	23042	25358
Mulching fb two HW	1074	345	40260	15079
Mean	561	287	20613	12747
$LSD_{0.05}$	194.14	242.43	7368.2	10732
CV (%)	19.46	47.43	20.09	47.32

Note: BW=BRRI weeder, BPW= BRRI power weeder, PSE = Pyrazosulfuron-ethyl, fb=followed by and HW=hand weeding, NS=Not significant

Crop performance

Crop performance was measured in terms of plant height and number of tillers per hill at different days after transplanting.

Plant height

Plant height varied significantly with the weeding practices from 20 to 100 DAT at every 10 days interval except 20 and 40 DAT (Fig.4.4). Plant height increased sharply from 20 to 70 DAT. At 100 DAT, the lowest plant height was observed inweedy check, which was statistically similar toall other treatment except BPW and two HW in Bahirbagh. In Provakordi, plant height varied significantly with the weeding practices only at 60 and 70 DAT where weedy check showed significantly lower plant height (Fig.4.4).

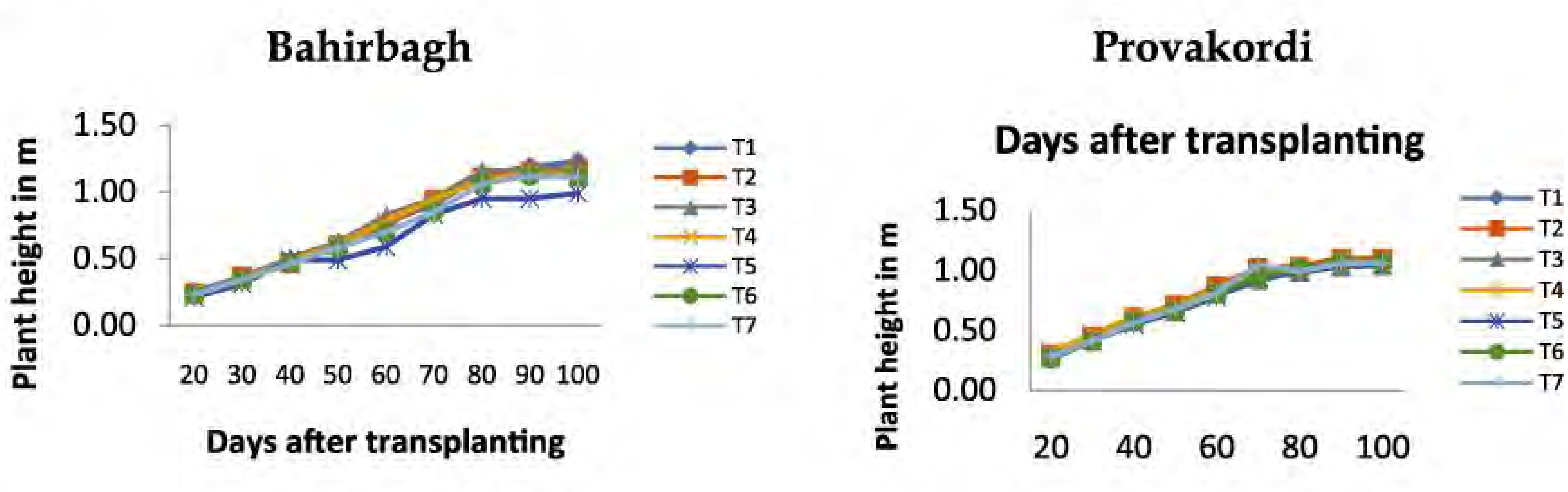


Fig. 4.4 Plant height as affected by weed management practices

Tiller production

Tiller production was not varied significantly with the different weed management practices at 70, 80, 90 and 100 DAT while it was varied from 20 to 60 DAT in Bahirbagh (Fig. 4.5). In Provakordi, significantly higher plant population was observed at 30 and 40 DAT only (Fig. 4.5).

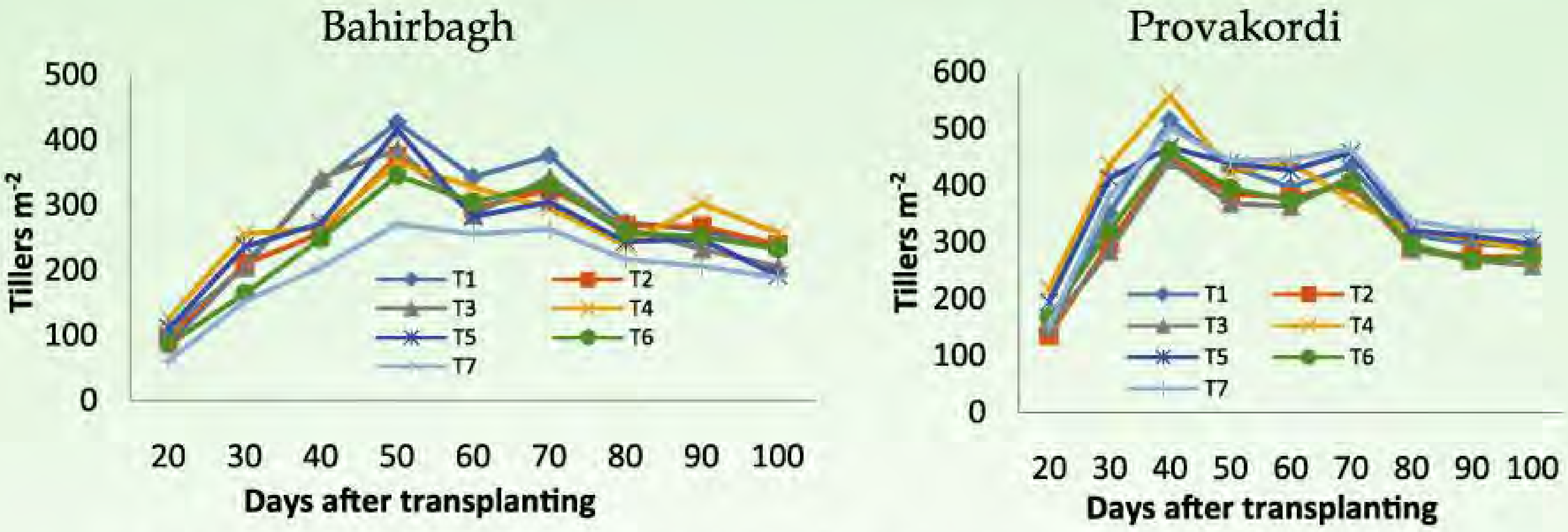


Fig. 4.5 Plant population as affected by weed management practices

Yield and yield contributing characters

Weed management practices showed significanteffect on grain yield in Bahirbagh.Weedy check gave significantly lower yield followed by mulching fb two HW while yield of paddy in other weeding practices gave statistically similar yield (Table 4.7). It might be the variation of effective tilleror filled grains panicle^{-1} or 1000-grains weight (Table 4.8). In Bahirbagh, panicle length, unfilled grain per panicle and 100 grain weight did not vary with the weeding practices while filled grains per panicle and panicles m^{-2} varied significantly (Table 4.9). In Provakordi, except weedy check, all other treatments gave statistically similar yield (Table 4.8). Averaged over two locations, PSE fb one HW gave higher yield followed by BPW fb one HW, BW fb one HW and weed free.

Table 4.7 Yield as affected by weed management practices

Weeding methods	Yield (t ha^{-1})		Mean
	Bahirbagh	Provakordi	
BW fb one HW	5.7	4.7	5.2
BPW fb one HW	5.5	5.0	5.3
Two HW	5.4	4.7	5.0
PSEfb one HW	5.7	5.2	5.4
Weedy check	3.0	3.6	3.3
Weed free	5.6	4.8	5.2
One mulching fb two HW	4.6	5.2	4.9
Mean	**5.1**	**4.7**	**-**
$LSD_{0.05}$	0.75	0.50	-
CV (%)	12.55	9.01	-

Note: BW=BRRI weeder, BPW= BRRI power weeder, PSE = Pyrazosulfuron-ethyl, fb=followed by and HW=hand weeding, NS=Not significant

Table 4.8 Yield contributing characters as affected by weed management practices

Weeding methods	Panicle length (cm)		Panicles m^{-2}		Filled grain $panicle^{-1}$		Unfilled grain $panicle^{-1}$		1000 grain wt (gm)	
	L_1	L_2	L_1	L_2	L_1	L_2	L_1	L_2	L_1	L_2
BW fb one HW	25.8	24.4	181.5	225.2	140.57	103.7	22.7	44.0	23.0	21.1
BPW fb one HW	27.1	25.3	189.0	241.4	119.83	91.6	42.5	40.2	24.6	22.5
Two HW	26.0	24.8	184.1	259.7	127.83	84.8	36.1	40.8	23.6	21.8
PSEfb one HW	26.0	24.1	227.2	256.4	106.00	96.9	22.4	32.3	24.2	22.0
Weedy check	23.6	24.9	153.6	144.8	94.20	108.1	32.5	31.9	22.7	21.9
Weed free	25.3	23.4	221.2	239.5	108.53	88.1	27.4	17.9	24.0	22.0
One mulching fb two HW	25.0	23.7	184.3	290.5	113.43	86.4	23.9	26.6	22.7	21.3
Mean	**25.5**	**24.4**	**191.6**	**236.8**	**115.8**	**94.2**	**29.6**	**33.4**	**23.5**	**21.8**
$LSD_{0.05}$	NS	NS	NS	38.11	NS	13.17	NS	NS	NS	NS
CV, %	6.12	3.29	13.97	9.05	14.64	7.86	28.74	33.4	3.61	5.36

Note: L_1= Bahirbagh, L_2= Provakordi, BW=BRRI weeder, BPW= BRRI power weeder, PSE = Pyrazosulfuron-ethyl, fb=followed by, HW=hand weeding and NS=Not significant

Economic analysis

Operation cost of BRRI power weeder and BRRI weeder for weeding is presented in Appendix II and III, respectively. Economic analysis including cost of production and return is presented in appendix IV and V. PSEfb one HW (1.35), BW fb one HW (1.21) and BPW fb one HW (1.21) accounted the highest BCR while weedycheck (0.94) and two HW (1.06) gave the lowest BCR in Bahirbagh (Table 4.9). Similar pattern of BCR was observed in Provakordi.

Table 4.9 Benefit-cost ratio as affected by weed management practices in mechanically transplanted rice

Weeding method	Input cost (Tk ha^{-1})		Gross return (Tk ha^{-1})		Gross margin (Tk ha^{-1})		BCR		
	L1	L2	L1	L2	L1	L2	L1	L2	Mean
BW fb one HW	97,985	85,427	120,840	101,050	22,855	15,623	1.23	1.18	1.21
BPW fb one HW	94,765	91,854	116,600	107,500	21,835	15,646	1.23	1.17	1.20
Two HW	113,920	91,037	114,480	101,050	560	10,013	1.00	1.11	1.06
PSEfb one HW	87,925	84,732	120,840	111,800	32,915	27,068	1.37	1.32	1.35
Weedy check	76,263	74,600	63,600	77,400	-12,663	2,800	0.83	1.04	0.94
Weed free	102,070	103,001	118,720	103,200	16,650	199	1.16	1.00	1.08
One mulching fb two HW	93,908	91,488	97,520	111,800	3,612	20,312	1.04	1.22	1.13

Note: L_1= Bahirbagh, L_2= Provakordi, BW=BRRI weeder, BPW= BRRI power weeder, PSE = Pyrazosulfuron-ethyl, fb=followed by, HW=hand weeding and NS=Not significant

Conclusion and recommendations

Conclusion

Considering weeds dynamics, weeding efficiency and cost as well as benefit-cost ratio pyrazosulfuron-ethyl, BRRI power weeder and BRRI weeder followed by hand weeding were found more suitable in mechanically transplanter rice field. It can be mentioned here that additional one hand weeding is required in each weeding technology to get better weed control effect in wider spaced mechanically transplanted rice field.

Recommendations

1. This study needs to be repeated in different soil condition, variety and season.
2. The width of BRRI weeder should be increased for operating in the wider spaced mechanically transplanted rice field.
3. Initiatives need to be undertaken to disseminate the BRRI power weeder to the end users.

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Appendices

Appendix I Fixed cost of BRRI weeder and BRRI Power weeder

Sl. No.	Items	BPW ($Tk\ yr^{-1}$)	BW ($Tk\ yr^{-1}$)
1	Purchase price (P) (Tk)	60,000	800
2	Salvage value (S) (Tk) (10% of p)	6,000	80
3	Working life (L) (yr)	10	4
4	[1]Average annual use (Au) ($hr\ yr^{-1}$)	720	720
5	Annual depreciation, D=(P-S)/L	5,400	180
6	Interest on investment, I=(P+S)/2*I, where rate of interest is 12%	3960	52.8
7	Tax, insurance, T=3% of P	1800	24
8	Total fixed cost (D+I+T) ($Tkyr^{-1}$)	11160	256.8

Note: [1]Average annual use= 3 season, 30 days $season^{-1}$ and 8hrs day^{-1} equal to 720 hrs

Appendix II Variable and operating cost of BRRIweeder

Sl. No.	Items	Bahirbagh	Provakardi
1	Labor cost per hour, L ($Tk\ hr^{-1}$)	37.5	37.5
2	RPM hr^{-1} =3.5 % of purchase price	3.9	3.9
3	Total variable cost ($Tk\ hr^{-1}$)	41.4	41.4
4	Total operating cost ($Tk\ hr^{-1}$) (Fixed cost+ Variable cost)	41.7	41.7
5	Time for weeding ($hr\ ha^{-1}$)	40.1	31.4
6	Operating cost for weeding ($Tk\ ha^{-1}$)	1673	1310

Appendix III Variable and operating cost of BRRI Power weeder

Sl. No.	Items	Bahirbagh	Provakardi
1	Labor cost per hour, L ($Tk\ hr^{-1}$)	50.0	50.0
2	Fuel cost ($Tk\ hr^{-1}$)	75.0	54.2
3	Lubricant cost ($Tk\ hr^{-1}$) (lubricant cost is 3% of fuel cost)	2.3	1.6
4	RPM hr^{-1} =3.5 % of purchase price	2.9	2.9
5	Total variable cost ($Tk\ hr^{-1}$)	130.2	108.8
6	Total operating cost ($Tk\ hr^{-1}$) (Fixed cost+ Variable cost)	145.7	124.3
8	Time for weeding ($hr\ ha^{-1}$)	14.7	16.1
9	Operating cost for weeding ($Tk\ ha^{-1}$)	2001	2016

Note: Normal farm labor cost, 300 Tk day^{-1} and skilled labor cost, 400 Tk day^{-1}. BRRI weeder can be operated by normal farm labor whereas skilled labor for BRRI power weeder and Petrol price , 90Tk L^{-1}

Appendix IV Benefit-cost ratio as affected by weed management practices in mechanically transplanted rice in Bahirbagh

Inputs cost (Tkha^{-1})	**T_1**	**T_2**	**T_3**	**T_4**	**T_5**	**T_6**	**T_7**
Seedling preparation	6,025	6,025	6,025	6,025	6,025	6,025	6,025
Land preparation (tillage)	6,500	6,500	6,500	6,500	6,500	6,500	6,500
Ridge making, leveling, canal making etc.	500	500	500	500	500	500	500
Transplanting	6,500	6,500	6,500	6,500	6,500	6,500	6,500
Weeding	19,394	16,519	33,622	10,413	-	23,042	15,755
Fertilizer (Basal)	5,865	5,865	5,865	5,865	5,865	5,865	5,865
Fertilizer (Urea)	3,040	3,040	3,040	3,040	3,040	3,040	3,040
Pesticide	2,662	2,662	2,662	2,662	2,662	2,662	2,662
Irrigation cost	10,000	10,000	10,000	10,000	10,000	10,000	10,000
Harvesting, carrying, threshing and winnowing	12,000	12,000	12,000	12,000	12,000	12,000	12,000
Land rent	15,000	15,000	15,000	15,000	15,000	15,000	15,000
Total input cost	**87,486**	**84,611**	**101,714**	**78,505**	**68,092**	**91,134**	**83,847**
Interest on investment @ 12%	10,498	10,153	12,206	9,421	8,171	10,936	10,062
Gross total input cost	97,985	94,765	113,920	87,925	76,263	102,070	93,908
Gross return (Tk ha^{-1})							
Paddy (t ha^{-1})	5.7	5.5	5.4	5.7	3	5.6	4.6
Straw (t ha^{-1})	4.56	4.4	4.32	4.56	2.4	4.48	3.68
Return from paddy	114,000	110,000	108,000	114,000	60,000	112,000	92,000
Return from straw	6,840	6,600	6,480	6,840	3,600	6,720	5,520
Gross return (Tk ha^{-1})	120,840	116,600	114,480	120,840	63,600	118,720	97,520
Gross margin (Tk ha^{-1})	22,855	21,835	560	32,915	-12,663	16,650	3,612
BCR	**1.23**	**1.23**	**1.00**	**1.37**	**0.83**	**1.16**	**1.04**

Appendix V Benefit-cost ratio as affected by weed management practices in mechanically transplanted rice in Provakordi

Inputs cost (Tkha^{-1})	T_1	T_2	T_3	T_4	T_5	T_6	T_7
Seedling preparation	6,025	6,025	6,025	6,025	6,025	6,025	6,025
Land preparation (tillage)	6,500	6,500	6,500	6,500	6,500	6,500	6,500
Ridge making, leveling, canal making etc.	500	500	500	500	500	500	500
Transplanting	6,500	6,500	6,500	6,500	6,500	6,500	6,500
Weeding	9,667	15,406	14,676	9,046	-	25,358	15,079
Fertilizer (basal)	4,700	4,700	4,700	4,700	4,700	4,700	4,700
Fertilizer (urea)	2,720	2,720	2,720	2,720	2,720	2,720	2,720
Pesticide	2,662	2,662	2,662	2,662	2,662	2,662	2,662
Irrigation cost	10,000	10,000	10,000	10,000	10,000	10,000	10,000
Harvesting, carrying, threshing and winnowing	12,000	12,000	12,000	12,000	12,000	12,000	12,000
Land rent	15,000	15,000	15,000	15,000	15,000	15,000	15,000
Total input cost	**76,274**	**82,013**	**81,283**	**75,653**	**66,607**	**91,965**	**81,686**
Interest on investment @ 12%	9,153	9,842	9,754	9,078	7,993	11,036	9,802
Gross total input cost	85,427	91,855	91,037	84,731	74,600	103,001	91,488
Gross return (Tk ha^{-1})							
Paddy (t ha^{-1})	4.7	5	4.7	5.2	3.6	4.8	5.2
Straw (t ha^{-1})	3.76	4	3.76	4.16	2.52	3.84	4.16
Return from paddy	94,000	100,000	94,000	104,000	72,000	96,000	104,000
Return from straw	7,050	7,500	7,050	7,800	5,400	7,200	7,800
Gross return (Tk ha^{-1})	101,050	107,500	101,050	111,800	77,400	103,200	111,800
Gross margin (Tk ha^{-1})	15,623	15,645	10,013	27,069	2,800	199	20,312
BCR	**1.18**	**1.17**	**1.11**	**1.32**	**1.04**	**1.00**	**1.22**