INFLUENCE OF HERBICIDES ON GROWTH, YIELD AND CONTROLLING WEEDS IN DIRECT-SEEDED *AUS* RICE

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*This is to certify that the thesis entitled, "**INFLUENCE OF HERBICIDES ON GROWTH, YIELD AND CONTROLLING WEEDS IN DIRECT-SEEDED AUS RICE**" submitted to the Faculty of Agriculture, Sher-e-Bangla Agricultural University, Dhaka, in partial fulfilment of the requirements for the degree of **MASTER OF SCIENCE (M.S.) in AGRONOMY**, embodies the result of a piece of bonafide research work carried out by **Most. Israt Zahan Seba,** Registration no. **20-11125,** under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma.*

I certify that such help or source of information, as has been availed of during this investigation, has duly been acknowledged.

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Dedicated to

My

Beloved Parents

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INFLUENCE OF HERBICIDES ON GROWTH, YIELD AND CONTROLLING WEEDS IN DIRECT-SEEDED *AUS* RICE

ABSTRACT

A field experiment was carried out at the Agronomy field of Sher-e-Bangla Agricultural University, Dhaka, Bangladesh, from March to August 2022, to investigate the efficiency of herbicides against weeds and influence on growth, yield and yield contributing parameters of direct-seeded rice *aus* rice of Bangladesh. The experiment consisted of 13 treatments *viz*., Unweeded (control), partial weeding (two-hand weeding at 20 and 40 Days After Sowing), weed-free, Butachlor (25 kg ha^{-1}), Pendamethyline (2 L ha^{-1}), Pretilachlor (1 L ha^{-1}), Bispyribac-Sodium (25 g ha^{-1}), Butachlor (25 kg ha^{-1}) + Bispyribac-Sodium (25 g ha^{-1}), Pendamethyline (2 L ha^{-1}) + Bispyribac-Sodium (150 g ha^{-1}), Pretilachlor 6% + Pyrazosulfuron- ethyl 0.15% (2 kg ha^{-1}), Pretilachlor 30% + Pyrazosulfuron- ethyl 0.75% (2 kg ha^{-1}), Acitachlor 14% + Bensulfuron methyl 4% (3 kg ha^{-1}), 2, 4-D Amine (2.24 L ha^{-1}). The test rice variety was BRRIdhan 98. The experiment was laid out in a randomized complete block design having 3 replications. Seeds were sown directly on 29 March 2022. Seventeen weed species infested the experimental field belonging to 10 families, where the most dominating were broadleaf and grass weed species. Among the weeds, *Digitaria ischaemum* was the most dominant weed at 20, 40, and 60 DAS, followed by *Physalis heterophylla and Digitaria sanguinalis*. The sequential application of Pendimethalin and Bispyribac-Sodium herbicides treated plots recorded minimum weed density m^{-2} (0.0, 2.33, and 4.00) and weed dry weight (0.00, 0.57, and 1.25 g) at 20, 40, and 60 DAS, respectively. The highest weed control efficiency (100, 88.46 and 80.66 %) at 20,40 and 60 DAS among all herbicidal treatments and also the highest weed control index (97.31 and 99.16%, respectively) at 60 and 90 DAS. Among the weed management practices weed-free and partial weeding notably reduced the weed counts, higher growth and yield attributes and grain yields. It was statistically at par with applying Pendamethyline (2 L ha^{-1}) followed by Bispyribac-Sodium (25 g ha^{-1}), which ultimately gave the highest grain yield was obtained from weed free treatment followed by partial weeding. But from economic view of point, partial weeding and Pendimethalin + Bispyribac-sodium showed almost similar benefit-cost ratio.Therefore, Pendamethyline (2 L ha^{-1}) and Bispyribac-Sodium (25 g ha^{-1}) were found as the best broad-spectrum effective herbicides to manage the various weed flora in direct-seeded *aus* rice.

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LIST OF ACRONYMS AND ABBREVIATIONS

AEZ	Agro-Ecological Zone
BARI	Bangladesh Agricultural Research Institute
BAU	Bangladesh Agricultural University
BBS	Bangladesh Bureau of Statistics
BRRI	Bangladesh Rice Research Institute
CV%	Percentage of coefficient of variance
cv.	Cultivar
DAE	Department of Agricultural Extension
DAS	Days after sowing
^{0}C	Degree Celsius
et al.	And others
FAO	Food and Agriculture Organization
fb	Followed by
g	gram(s)
ha^{-1}	Per hectare
i.e.	That is
kg	Kilogram
Max.	Maximum
mg	Milligram
Min.	Minimum
MoP	Muriate of Potash
N	Nitrogen
No.	Number
NS	Not significant
%	Percent
SAU	Sher-e-Bangla Agricultural University
SRDI	Soil Resources and Development Institute
T	Ton
TSP	Triple Super Phosphate
Wt.	Weight

CHAPTER I

INTRODUCTION

Rice (*Oryza sativa* L.) is the most important food crop and a primary food source for more than one-third of the world's population (Sarkar *et al.,* 2017). Rice provides 27% of the dietary energy supply worldwide and 20% of dietary protein (Kueneman, 2006). It constitutes 95% of the cereal consumed and supplies more than 80% of the calories and about 50% of the protein in the diet of the general people of Bangladesh (Sarwar and Biswas, 2021). The world's rice demand is projected to increase by 25% from 2001 to 2025 to keep pace with population growth (Hossain *et al.,* 2016), and therefore, meeting this ever-increasing rice demand sustainably with shrinking natural resources is a great challenge. In Bangladesh, the majority of food grains come from rice. Rice has a tremendous influence on the agricultural economy of the country. The annual rice production in Bangladesh is about 36.28 million tons from 11.52 million ha of land (BBS, 2021).

There are three distinct growing seasons of rice in Bangladesh, according to changes in seasonal conditions such as *aus, aman,* and *boro*. More than half of the total production (55.50 %) is obtained in *boro* season, occurring in December–May, the second largest production in *aman* season (37.90 %) occurs in July-November, and little contribution from *aus* season (6.60 %) occurring in April-June (APCAS, 2016). Recently, food security especially attaining self-sufficiency in rice production, has been a burning issue in Bangladesh. The average rice yield is almost less than 50% of the world's average rice grain yield. The national mean yield (2.60 t ha^{-1}) of rice in Bangladesh is lower than the potential national yield (5.40 t ha^{-1}) and world average yield (3.70 t ha^{-1}) (Maniruzzaman *et al*., 2018). The lower yield of transplanted *aman* rice has been attributed to several reasons. In such conditions, increasing rice production can play a vital role. Therefore, attempts must be made to increase the yield per unit area by adopting modern rice varieties and applying improved technology and management practices (such as irrigation, spacing, weed, insect, etc.).

Crop performance is closely related to weed growth. Weeds are the most important threat, resulting in yield losses between 30 and 98 percent (Ramana *et al.,* 2014). Among the harmful pest, weeds contribute to maximum losses in crop production, potentially reducing crop production by 34%, followed by animal pests (18%) and pathogens by 16% (Abbas *et al.,* 2018). The high competitive ability of weeds exerts a serious negative effect on crop production. Globally, yield losses due to pests have been estimated at approximately 40%, of which weeds caused the highest loss (32%) (Rao *et al.,* 2007). Weeds compete with rice plants severely for space, nutrients, air, water, and light, adversely affecting plant height, leaf architecture, tillering habit, and crop growth (Salam *et al*., 2020). In Bangladesh, weed infestation reduces the grain yield by 70-80% in *aus* rice (early summer), 30- 40% for transplanted *aman* rice (autumn), and 22-36% for modern *boro* rice varieties (winter rice) (BRRI, 2008). Although hand weeding is the popular method in Bangladesh, weed control is often imperfect or delayed due to the unavailability of labor during the peak period. Mechanical weeding and chemical weed control are the alternatives to hand weeding. In recent years, chemical weed control (herbicide application) has increased in Bangladesh (Ahmed *et al*., 2014).

In direct-seeded rice (DSR) cultivation, weed is the major constraint, mainly due to the absence of puddling in the field. The yield loss due to weed interference may be up to 100%. Transplanting of rice seedlings is an age-old practice, but in recent years, the non-availability of labor for timely transplanting is resulting in a reduced yield of rice (Budhar and Tamilselven, 2002). Direct-seeded rice (DSR) has several advantages over puddled transplanted rice like easier planting, timely sowing, less drudgery, early crop maturity by 7-10 days, less water requirement, better soil physical condition for next crop and low production cost, and more profit (Kumar and Ladha, 2011). However, weeds are the main biological constraint to the production of DSR (Rao *et al*., 2007, Chauhan and Johnson, 2010), which may cause a 60-80% reduction in rice grain yield.

In Bangladesh, scarcity of surface water has made groundwater an essential source to supplement dry season water demand to meet irrigation requirements. In the North-West (NW) region of the country, about 95% of irrigation water comes from groundwater, which is extracted, mainly by shallow tube-wells (STW) and deep tubewells (DTW), in addition to some small-capacity pumping technologies, such as hand pumps, popularly known as hand tubewells (HTWs), rower pumps, and treadle pumps. Because of the high groundwater withdrawal rate in conventional tillage-based puddled transplanted rice, water tables in some areas of Bangladesh have been declining, resulting in increased cost of water pumping (Mojid *et al.,* 2019). At the peak of the transplanting period, the labor demand pushes wages above normal rates. Farm labor costs are increasing because agriculture workers are now moving to the cities for employment in nonfarm jobs, such as in the textile and garment industries. As a result, it is difficult to find labor at the peak period of transplanting, which delays transplanting and often leads to using aged seedlings.

The key concerns, therefore, are how the water requirement of rice culture can be reduced and how farmers can avoid puddling and transplanting operations without yield loss. The development of alternative methods that are more water-efficient and less labor-intensive is thus important to enable farmers to produce more with less cost. These factors demand a major shift from PTR production to dry seeding of rice (DSR) in irrigated areas. DSR can reduce water and labor use compared with conventional transplanted rice by eliminating the puddling phase and not requiring continuous standing water (Singh *et al.*, 2013). DSR systems have several advantages over PTR systems (Rashid *et al.*, 2009). However, weeds are a severe problem in DSR and reduce the system's productivity. Weeds are more problematic in DSR than in PTR because crops and weeds emerge simultaneously without standing water to suppress weed emergence and growth. Timely weed control is crucial in improving the productivity and profitability of DSR (Chauhan and Jhonson, 2011).

Nowadays, herbicide use is gaining popularity in rice culture due to its rapid effects and less cost involvement than traditional methods of weeding (Hasan *et al*., 2016). However, removing weeds at their critical period by conventional means may not be possible at the peak period of labor demand. In such a situation, herbicides are promising weed control alternatives (MacLaren *et al*., 2020). But continuous and indiscriminate use of herbicides may alter their degradation and pose persistence problems due to residual effects beyond harvest, threatening health and ecology. Using herbicides with different modes of action and chemistry is desirable to reduce the problem of residue buildup, a shift in weed flora (Rajkhowa *et al.,* 2006), and the development of herbicide resistance in weeds (Rao, 1999). A good herbicide is effective against a broad spectrum of weeds when it does not injure the crop and remains in the soil sufficiently to control the weeds within the crop growth period. Modern herbicides are often synthetic mimics of natural plant hormones that interfere with target plant growth. Due to herbicide resistance –a major concern in agriculture – several products combine herbicides with different means of action. Integrated pest management may use herbicides alongside other pest control methods. Herbicide is also used in forestry, where certain formulations have been found to suppress hardwood varieties in favor of conifers after clear cutting, as well as pasture systems and management of areas set aside as wildlife habitats.

Weed management is a challenging task in sustainable rice production. Physical and cultural methods of weed control are laborious and expensive. In contrast, chemical control is cheaper and less time-consuming despite some detrimental environmental effects of its inappropriate application. Adopting DSR technology leads to a shift in weed flora composition towards difficult-to-control weeds. In this situation, herbicides are becoming more popular in DSR because they are more effective, easy to apply, provide selective control, save on labor, and cost less. Some herbicides have been launched in Bangladesh for wide-spectrum weed control in rice. However, the information on its efficacy against weeds in direct-seeded rice varieties is very meager in the literature. Crop safety to new herbicides is another concern, particularly in rice. Considering the above facts and acknowledging the importance of optimization of weed control, the objectives of the present study were:

- To study the herbicidal effect on weed infestation in direct-seeded *aus* rice
- To find out the effect of herbicides on the growth and yield of *aus* rice
- To work out the economics of the treatments

CHAPTER II

REVIEW OF LITERATURE

Reduction in crop yields due to weeds results from their multiferous ways of interfering with crop growth and culture. Weeds compete with crops for one or more plant growth factors such as mineral nutrients, water, solar energy, and space, and they can also host pests and diseases that can spread to cultivated crops and hinder crop cultivation operations. From an agronomic point of view, weed management has become a vital issue for modern rice cultivation. Among all weed control methods, applying herbicide is the most effective for controlling weeds and increasing yield. If the proper crop management systems are followed, rice productivity and total rice production in Bangladesh still have the scope to increase. As the practices of applying herbicides in direct-seeded rice have been recently introduced in Bangladesh, there is meager literature on it. Therefore, an effort has been made to review the available literature on the influence of herbicides on the increasing growth, yield, and controlling weeds in direct-seeded *aus* rice of Bangladesh. Considering these points, the available literature is reviewed in this chapter under the appropriate head.

2.1 Direct-seeded rice cultivation and constraints

Iqbal *et al*. (2017) reported that direct-seeded rice (DSR) is the only viable option for rice production under shrinking water resources; however, effective weed management is essential to harvest good crop yield.

Hossain *et al*. (2016) reported that about 350 species have been reported as rice weeds. The grasses are ranked as first in direct-seeded rice (DSR) cultivation systems. Rice and weed seedlings emerge simultaneously, and there is no standing water to suppress weed emergence and growth at crop emergence. For this reason, weeds are considered one of the major biological constraints in DSR and cause a substantial rice yield loss. Weeds are mainly controlled using herbicides or manually. However, manual weeding is becoming less effective because of labor crises at critical times and increased labor costs. Herbicides are replacing manual weeding as they are easy to use. Still, there are concerns about the sole use of herbicides, such as the evolution of resistance in weeds, shifts in weed populations, the cost of weed management to farmers, and concerns about the environment. There is a need to integrate different weed management strategies to achieve effective and sustainable weed control in

DSR systems. Different rice ecosystems and cultural practices determine the dominant weed species or group, rice-weed competition, and weed control strategy.

Kumar and Ladha (2011) reported that direct-seeded rice (DSR) has several advantages over puddled transplanted rice easier planting, timely sowing, less exertion, early crop maturity by 7-10 days, less water requirement, better soil physical condition for the next crop and low production cost and more profit.

Chauhan and Johnson (2010) found that weeds are the main biological constraints to the production of DSR, which may cause a 60-80% reduction in rice grain yield.

Budhar and Tamilselven (2002) reported that transplanting rice seedlings is an age-old practice. Still, in recent years, the non-availability of labor for timely transplanting is resulting in a reduced rice yield.

2.2 Presence of weed species in rice field

Iqbal *et al*. (2017) experimented in the field area of Rice Research Institute, Kala Shah Kaku, Pakistan, during the growing season in 2013 to identify appropriate herbicides to control weeds effectively in dry direct-seeded rice. Randomized complete block design (RCBD) was used with three replications. The main weeds identified with dry direct-seeded rice included *Echinochloa colona, Echinochloa crus-galli, Diplachne fusca, Cyperus iria, Cyperus difformis, Scirpus meritimus, Cyperus rotundus, Marsilia minuta,* and *Conyza stricta*.

Singh *et al.* (2014) conducted a field experiment during the Kharif season of 2011 and 2012 at G.B.Pant University of Agriculture and Technology, Pantnagar, to find out the efficacy of bispyribac-sodium in managing weeds in direct-seeded rice. The soil was loamy, medium in organic matter (0.67%), available phosphorous (17.5 kg ha^{-1}), and potassium (181.2 kg ha^{-1}) with pH 7.5. The experiment consisted of nine treatments with three doses of bispyribac-sodium 15, 20, and 25 g ha^{-1} as test product at two stages of its application, i.e., 1-3 leaf stage and 4-6 leaf stage, along with bispyribac-sodium (standard check) 20 g ha, weed free and weedy check. The experiment was laid out in a randomized block design with three replications. The rice variety “Pant Dhan 12” was sown on June 30, 2011, and June 16, 2012. The crop was raised with a recommended package of practices. The data on weed density m^{-2} and total weed biomass were taken 45 days after sowing. Effective tillers m^{-2} area, 1000 grain weight (g), and grain yield (kg ha^{-1}) of rice were recorded at the time of rice harvest. The data on the density and biomass of weeds were subjected to log transformation by adding 1.0 to the original values before statistical analysis. The herbicides were applied using a Maruti Foot Sprayer fitted with flat fan nozzle and 375 L ha^{-1} water volume. Weed flora consisted of *Echinochloa colona, Eleusine indica* and *Leptochloa chinensis* among grasses; *Celosia argentia*, a broad-leaved weed, and *Cyperus rotundus* and *Fimbristylis milliaceae* among sedges. However, very low density of other weeds, viz. *Echinochloa crusgalli*, *Commelina benghalensis, Phyllanthus niruri* and *Eclipta alba* were also found. Bispyribac-sodium caused a significant reduction in the total density and biomass of weeds when compared with the weedy check.

Ahmed *et al.* (2014) conducted a field experiment at the research farm of the Regional Agricultural Research Station of the Bangladesh Agricultural Research Institute in Jessore, Bangladesh, in the boro (dry) season of 2011-12 and the aman (wet) season of 2012. Different rice varieties are recommended for use in different seasons, from which BRRI dhan28 (140 d duration) and BRRI dhan49 (135 d duration) were selected for the boro and aman seasons, respectively. Ten weed control treatments were used in each season: (i) weed-free, (ii) partial weedy, (iii) oxadiargyl (80 g ai ha−1 applied at 2 DAS) followed by ethoxysulfuron (18 g ai ha^{-1} applied at 21 DAS), (iv) pendimethalin (850 g ai ha^{-1} applied at 2 DAS) followed by ethoxysulfuron (18 g ai ha−1 applied at 21 DAS), (v) acetachlor + bensulfuranmethyl (240 g ai ha^{-1} applied at 2 DAS) followed by ethoxysulfuron (18 g ai ha^{-1} applied at 21 DAS), (vi) pyrazosulfuron (15 g ai ha^{-1} applied at 2 DAS) followed by ethoxysulfuron (18 g ai ha^{-1} applied at 21 DAS), (vii) oxadiargyl (80 g ai ha^{-1} applied at 2 DAS) followed by a one-time hand weeding (HW) at 35 DAS, (viii) pendimethalin (850 g ai ha^{-1} applied at 2 DAS) followed by a one-time HW at 35 DAS, (ix) acetachlor + bensulfuranmethyl (240 g ai ha^{-1} applied at 2 DAS) followed by a one-time HW at 35 DAS, and (x) pyrazosulfuron (15 g ai ha^{-1} applied at 2 DAS) followed by a one-time HW at 35 DAS. Weed species varied with the growing seasons. Some species were not common in both seasons. For example, *Amaranthus spinosus L., Anagalis arvensis L., Cleome rutidosperma DC,* and *Cynodon dactylon (L.) Pers*. was present only in the boro season and *Ageratum conyzoides L.* was present only in the aman season. Such variations might be the result of the seasonal adaptation of weeds. In addition, non-rice crops were grown before the start of the experiment. This may be another reason for the variation. In the boro season, temperatures were low, up to 60 DAS, but it later increased. Because of low initial temperatures, crop and weed growth was slow. However, the growth of some species (e.g., *Cyperus rotundus L., Cynodon dactylon*, and *Cleome rutidosperma*) was unaffected by the low temperatures and severely suppressed crop growth at its early stages in the boro season. Another interesting observation was that some weed species (e.g., *A. arvensis, Galinsoga ciliate Blake,* and *Phyllanthus niruri L.*) emerged later than usual, which could be their strategy to “escape” the application of preemergence herbicides. The dominant weed species in the experiments were *Celosia argentea L., Cyperus rotundus*, *Dactyloctenium aegyptium (L.)* Willd*., Digitaria ciliaris (Retz.) Koel., E. colona, Eleusine indica (L.) Gaertn, G. ciliate,* and *P. niruri*. The application of pre-emergence herbicides significantly reduced weed density compared with the control plots (partial weedy). At 20 DAS (before application of postemergence herbicide), plots treated with pre-emergence herbicides had 45–70% lower weed density than the partial weedy plots. Among the herbicide treatments, oxadiargyl-treated plots had the lowest total weed density (157 plants m^{-2}), followed by those treated with acetachlor + bensulfuranmethyl (181 plants m^{-2}). The highest weed density was recorded in the plots treated with pyrazosulfuron. In terms of weed groups, the lowest grass density was recorded in the plots treated with pendimethalin (88% less than in the partial weedy check) and the highest was recorded in the plots treated with pyrazosulfuron (only 10% less than in the partial weedy check). Against broadleaved and sedges, acetachlor + bensulfuraonmethyl, oxadiargyl, and pyrazosulfuron performed well (63–70% fewer broadleaved weeds and 54–70% fewer sedges compared to the partial weedy check), while pendimethalin performed poorly (suppressed only 37% and 18% of broadleaved and sedges, resp.). The observed effectiveness of pendimethalin in the control of grasses and its poor control of sedges and broadleaved weeds are consistent. At 35 DAS (after application of postemergence herbicides and before HW), total weed density and weed biomass were greatly affected by herbicide treatments. Plots treated with pre-emergence herbicides had 39–76% and 23–45% lower weed densities (326 and 293 plants m^{-2} in the boro and aman seasons, resp.) compared with the partial weedy check. However, the values were 66–88% and 46–65%, respectively, when plots were treated with both pre-and post-emergence herbicides.

2.3 Effect of herbicide on weed control treatments

Bhuiyan and Mahbub (2020) reported that the lower weed biomass as well as higher weed control efficiency in all the growing seasons exhibited by Bensulfuron methyl 1.1% + Metsulfuron methyl 0.2%+ Acetochlor 14% WP. Weed control efficiency improved with increases in herbicide dose irrespective of weed species.

Mishra (2019) reported that the lowest weed dry weight was recorded with the application of Bensulfuron methyl 60gha^{-1} + Pretilachlor 600 gha^{-1} at 3 DAT with 8.13, 21.3, and 26.9 g m^{-2} at 30, 60, and 90 DAT, respectively might be due to effective control of weeds during early stages of crop growth by the herbicide. Untreated weedy check produced the maximum weed dry weight at all the crop growth stages (31.3 to 54.3g m^{-2}) because of higher weed intensity and its dominance in utilizing the sunlight, nutrients, moisture, etc.

Suryakala *et al.* (2019) stated that all the weed control measures caused a significant reduction in the density of all the weeds over the weedy check. Weed dry matter was highly influenced by the differential application of herbicides, their combinations, and integration with manual weeding. Significantly lowest weed dry matter (26.82 kg ha^{-1}) was recorded in treatment *i.e.*, Pretilachlor + Pyrazosulfuron-ethyl + Bispyribac-sodium, followed by Pretilachlor + Pyrazosulfuron-ethyl+ Fenoxaprop-p-ethyl (70.07 kg ha^{-1}), and the treatment twice hand weeding on 20 and 40 DAT (74.54 kg ha^{-1}) was on par. The highest weed dry matter production of 349.38 kg ha^{-1} on 60 DAT was recorded in unweeded control.

Das *et al.* (2017) reported that among the tested herbicides, bispyribac-sodium 10 WP at 30 g ha^{-1} applied at 25 days after transplanting (DAT) was most effective in checking all types of weed population and their growth, resulting in the lowest biomass of weeds due to its higher weed control efficiency.

Iqbal *et al.* (2017) experimented on the twelve pre- and post-emergence herbicidal treatments and compared them with the weedy check. A pre-emergence herbicide was applied just after seeding, and the post-emergence herbicides were applied at 21 and 40 days after seeding (DAS). Weed density m^{-2} was recorded at 20 and 45 days after seedling. The best weed control (94.8 - 98.1%) was achieved with two sprays (21 & 40 DAS) of post-emergence herbicide (Bispyribac-Sodium) followed by a single application (21 DAS) of the same herbicide, which gave weed control of 77.5 to 82.3 %. orthosulfamuron, penoxsulam and ethoxysulfuron as post-emergence herbicides were found more effective against broad-leaf weeds and sedges than grasses. As regards paddy yield, it was found to be maximum (3.97 - 4.14 t ha-1) with the twice application of bispyrabic sodium (Clover 20% SC or Nominee 20% SC) whereas the lowest paddy yield was recorded in the case of weedy check (0.41 t ha^{-1}). The number of productive tillers m-2, filled grains $panicle^{-1,}$ and 1000-grain weight (g) were also higher in the plots having twice the application of Bispyribac-Sodium than other herbicidal treatments and weedy checks. Thus, in the fields with mixed weed flora (grasses, broad leaf weeds and sedges), twice application of Bispyribac-Sodium applied 21 and 40 days after sowing at the rate of 250 ml ha^{-1} or 200 g ha^{-1} gave good results, however, in plots where only broad-leaf weeds and sedges predominate, ethoxysulfuron at the rate of 50 g ha^{-1} or orthosulfamuron at the rate of 120 g ha-1 were found to be more appropriate suitable herbicides to be used.

Ahmed *et al.* (2014) experimented on ten weed control treatments, i.e., (i) weed-free, (ii) partial weedy, (iii) oxadiargyl (80 g ai ha^{-1} applied at 2 DAS) followed by ethoxysulfuron (18 g ai ha^{-1} applied at 21 DAS), (iv) pendimethalin (850 g ai ha^{-1} applied at 2 DAS) followed by ethoxysulfuron (18 g ai ha−1 applied at 21 DAS), (v) acetachlor + bensulfuranmethyl (240 g ai ha^{-1} applied at 2 DAS) followed by ethoxysulfuron (18 g ai ha^{-1} applied at 21 DAS), (vi) pyrazosulfuron (15 g ai ha^{-1} applied at 2 DAS) followed by ethoxysulfuron (18 g ai ha^{-1} applied at 21 DAS), (vii) oxadiargyl (80 g ai ha^{-1} applied at 2 DAS) followed by a one-time hand weeding (HW) at 35 DAS, (viii) pendimethalin (850 g ai ha^{-1} applied at 2 DAS) followed by a one-time HW at 35 DAS, (ix) acetachlor + bensulfuranmethyl (240 g ai ha^{-1} applied at 2 DAS) followed by a one-time HW at 35 DAS, and (x) pyrazosulfuron (15 g ai ha^{-1} applied at 2 DAS) followed by a one-time HW at 35 DAS. At 20 DAS (before application of postemergence herbicide), plots treated with pre-emergence herbicides had 45–70% lower weed density than the partial weedy plots. Among the herbicide treatments, oxadiargyl-treated plots had the lowest total weed density (157 plants m^{-2}), followed by those treated with acetachlor + bensulfuranmethyl (181 plants m^{-2}). The highest weed density was recorded in the plots treated with pyrazosulfuron. In terms of weed groups, the lowest grass density was recorded in the plots treated with pendimethalin (88% less than in the partial weedy check), and the highest was recorded in the plots treated with pyrazosulfuron (only 10% less than in the partial weedy check). Against broadleaved and sedges, acetachlor + bensulfuraonmethyl, oxadiargyl, and pyrazosulfuron performed well (63–70% fewer broadleaved weeds and 54–70% fewer sedges compared to the partial weedy check). In comparison, pendimethalin performed poorly (suppressed only 37% and 18% of broadleaved and sedges, resp.). The observed effectiveness of pendimethalin in the control of grasses and its poor control of sedges and broadleaved weeds are consistent. At 35 DAS (after application of postemergence herbicides and before HW), total weed density and weed biomass were greatly affected by herbicide treatments. Plots treated with pre-emergence herbicides had 39–76% and 23–45% lower weed densities (326 and 293 plants m^{-2} in the boro and aman seasons, resp.) compared with the partial weedy check. However, the values were 66–88% and 46– 65% when plots were treated with both pre-and post-emergence herbicides.

Kumar *et al.* (2014) indicated that pre-emergence application of bensulfuron methyl + pretilachlor at 660 g a.i. ha^{-1} on 3 DAT and one hand weeding on 35 DAT recorded significantly higher grain and straw yield (6710 and 7717 kg ha^{-1}, respectively), lower weed population (31.33 no. m^{-2}), and their dry weight (37.80 kg ha^{-1}).

Singh *et al.* (2014) found that the weed control efficiency (WCE) was highest in the weed-free plot. Among the herbicidal treatments, the highest WCE was recorded with the application of bispyribac-sodium at 25 g ha^{-1} applied at the 1-3 leaf stage, followed by its lower dose, i.e., 20 g $ha^{-1,}$ which was at par with the application of Bispyribac-Sodium at 25 g ha^{-1} applied at 4-6 leaf stage.

Priya and Kubsad (2013) reported higher weed control efficiency and lower weed index in herbicide treatments compared to weedy check owing to lower weed dry weight, higher weed control efficiency, and lower weed index due to effective control of complex weed flora.

Walker *et al.* (2002) reported that various herbicides give satisfactory weed control without reducing yield and increasing weed population pressure even if applied at lower rates. Weed control efficiency at a reduced dose of herbicide tends to be lower than recommended doses, although in many cases it may be 60–100% and acceptable commercially. Application of both pre and post-emergence herbicides at proper dose suppresses weed flora effectively, however, the use of a single herbicide rarely gives an effective weed control in rice.

2.4 Effect of herbicides on crop characters

Plant height

Manisankar *et al.* (2019) revealed that application of glyphosate 2.5 kg ha^{-1} in rice as a pre-plant herbicide registered significantly higher growth parameters like plant height, tillers, and dry matter production and yield attributes and grain yield (4232 kg ha^{-1}) than control.

Das *et al.* (2017) reported that the application of herbicides did not show any phytotoxic symptoms on rice plants.

Number of total tillers

Paulraj *et al.* (2019) carried out a field study during the Samba season of 2017 to evaluate the efficacy of pre and post-emergence herbicides in transplanted rice. The herbicides evaluated were Pretilachlor 6% + Pyrazosulfuron-ethyl 0.15% GR @ 10 kg ha^{-1} along with post emergence herbicides Fenoxaprop-p-ethyl 9.3% w/w @ 875 ml ha^{-1}, Bispyribac-sodium 10% SC @ 200 ml ha^{-1}. Results of the study revealed that among the treatments, (Pretilachlor + Pyrazosulfuron ethyl) + Bispyribac-sodium recorded the highest number of tillers of 434 m^{-2}. The treatment (Pretilachlor + Pyrazosulfuron ethyl) + Fenoxaprop-p-ethyl was next in order, and the treatment twice hand weeding on 20 and 40 DAT were on par. The least number of tillers of 323 m^{-2} were recorded in unweeded control.

Lodhi (2016) reported that different weed control treatments caused remarkable variations in the number of tillers m^{-2} at different days after transplanting. Weedy check plots have the minimum number of tillers m^{-2}, which increased appreciably at all the growth intervals as the plots received weed control treatments. Application of Bensulfuron methyl + Pretilachlor (60+600) g ha^{-1} resulted in a markedly higher number of tillers m^{-2} over the rest of the doses (48+480) and (72+720) g ha^{-1} and check herbicide Pendimethalin and Butachlor at all growth intervals.

Number of effective tillers

Yadav *et al.* (2018) observed that the number of effective tillers m^{-2} under pretilachlor + pyrazosulfuron-ethyl 615gha^{-1} was at par with all other treatments except being superior to pyrazosulfuron-ethyl 15 g/ha and weedy check during both years.

Jabran *et al.* (2012) carried out a study with three herbicides (pendimethalin, penoxsulam, and bispyribac-sodium) and were evaluated for weed control in direct-planted rice on sandy loam soil. Weedy check and weed-free plots were established for comparison. Experiment results revealed that the herbicides' application effectively improved the yield and yield-related traits of DPR (Direct planted rice) over the control. The maximum amount of productive tillers (36.3) was recorded in the weed-free treatment, followed by the bispyribac-sodium (35.7) treatment. In contrast, the minimum number of productive tillers (24.3) was recorded in the weedy check.

Number of non-effective tillers

Chowdhury (2012) noticed that weed controlled by Sunrise 150WG gave the highest effective tillers hill^{-1} while ineffective tillers hill^{-1} were found from no weeding treatment.

Raju *et al.* (2003) reported that the use of weedicide (Safener and Butachlor) gave the highest tiller hill$^{-1,}$ and the control plot produced maximum non-effective tiller.

Panicle length

Jabran *et al.* (2012) carried out a study with three herbicides (pendimethalin, penoxsulam, and bispyribac-sodium) and were evaluated for weed control in direct-planted rice on sandy loam soil. Weedy check and weed-free plots were established for comparison. Experiment results revealed that the herbicides' application effectively improved the yield and yield-related traits of DPR (Direct planted rice) over the control. The maximum panicle length (23.5cm) was observed in the Bispyribac-sodium treatments and the minimum panicle length (16.4cm) in the weedy check.

Mahajan *et al.* (2003) stated that the application of Pretilachlor alone or in combination with Safener and hand weeding gave the highest panicle length.

Filled grains

Paulraj *et al.* (2019) reported that pre-emergence herbicide application of Pretilachlor + Pyrazosulfuron-ethyl followed by post-emergence herbicide application of Bispyribac-sodium produced more yield attributes and yield than unweeded control. The reason might be that the weed-free situation at the early stage favored the vigorous growth of seeding, without any crop weed competition, and sustained nutrient availability leads to better uptake of NPK by the crop might have contributed to synchronous tillering and spikelet formation leading to a higher number of panicles m^{-2} and higher post-flowering photosynthesis and higher number of filled grains $panicle^{-1}$.

Teja *et al.* (2017) stated that effective and timely management of weeds through herbicide application facilitated the crop plants to have sufficient space, light, nutrients, and moisture, and thus the yield components like the number of filled grains per panicle increased.

1000-grain weight

Daniel *et al.* (2012) reported that the application of pendimethalin 0.75 kg ha^{-1} + HH at 40 days after sowing, followed by anilophos 0.40 kg/ha + one hand hoeing at 20 and 40 DAS and butachlor 1.00 kg ha^{-1} + one hand hoeing, recorded higher rice yields component like productive tillers $hill^{-1}$ (11.9), panicle weight (3.9g), number of grain /panicle (128.0) and test weight (25.5g).

Jabran *et al.* (2012) reported that the highest 1000 grains weight (22.5 g) of rice was observed in weed-free conditions, and the lowest 1000 grains weight (17.4 g) was observed in the weedy check.

Grain yield

Suryakala *et al.* (2019) conducted a study was during the Samba season of 2017 to evaluate the efficacy of pre and post-emergence herbicides in transplanted rice in the Cuddalore district. The new herbicides evaluated were Pretilachlor 6% + Pyrazosulfuron-ethyl 0.15% GR @ 10 kg ha^{-1} along with post emergence herbicides Fenoxaprop-p-ethyl 9.3% w/w @ 875 ml ha^{-1}, Bispyribac-sodium 10% SC @ 200 ml ha^{-1}. Results of the study revealed that significantly higher grain yield and straw yield were recorded with Pretilachlor + Pyrazosulfuron-ethyl + Bispyribac-sodium (5163 and 7654 kg ha^{-1}) followed by Pretilachlor + Pyrazosulfuron-ethyl + Fenoxaprop-p-ethyl(4965 and7366 kg ha^{-1}) and was at par with twice hand weeding on 20 and 40 DAT (4787 and 7150 kg ha^{-1}), respectively. The lowest grain and straw yield (3046 and 4600 kg ha^{-1}) were recorded with unweeded control, respectively indicating the importance of weed management in the critical growth period of rice by herbicide application.

Das *et al.* (2017) reported that the effective control of weeds starting from the early crop growth stage might have resulted in better growth and yield of rice. The variation in grain yield under different treatments was the result of variation in weed density and weed biomass.

Hossain and Mondal (2014) observed that tank-mix application of Bispyribac + Ethoxysulfuron, Pretilachlor, Metsulfuron-methyl + chlorimuron-ethyl and Pretilachlor + Bensulfuron resulted in more rice grain yield than their sole application.

Singh *et al*. (2014) found that the effectiveness of the treatments influenced rice grain yield and yield attributing characters (tillers m^{2} and grains panicle^{-1}). The highest grain yield of rice was recorded with weed free (4.03 t ha^{-1}), which was at par with bispyribac-sodium 20 and 25 g ha^{-1}.

Bari *et al.* (1995) reported that herbicide treatments contributed to higher yield performance compared to control in all the growing seasons.

Straw yield

Hossain (2015) reported that the straw yield of rice differs, due to the application of different mix herbicides comparable to the weedy check. The highest straw yield (4.25 t ha^{-1}) was recorded from Propyrisulfuron @ 380 ml ha^{-1} + Propanil 60 WG @ 1500 g ha^{-1} herbicide treated plot while the lowest straw yield (1.42 t ha^{-1}) was found from weedy check.

Chowdhury (2012) carried out an experiment at Sher-e- Bangla Agricultural University Agronomy field and scored the highest straw yield from the pre-emergence herbicide Sunrice 150WG treated plot.

Biological Yield

Hasanuzzaman *et al.* (2008) observed that the biological yield was influenced by the effectiveness of the herbicidal treatments, where Ronstar® 25EC @ 1.25 L ha^{-1} + IR5878® 50 WP @ 120 g ha^{-1}), showed as highest biological yield.

Harvest Index

Hossain (2015) reported that the harvest index is significantly influenced due to different herbicide applications. Maximum harvest index (48.0 %) when rice was treated with Propyrisulfuron @ 130 ml ha^{-1}+Propanil 60 WG @ 2000 g ha^{-1} herbicide and the lowest harvest index (37.53 %) in weedy check, which was due to the reason that the effective weed control in these combinations increased the number of productive tillers, dry crop matter, and the plants produced longer panicles which ultimately improve grain yield by reducing the crop weed competition as compared to the weedy check.

2.5 Economic viability

Salam *et al.* (2020) experimented at the Agronomy Field Laboratory, Bangladesh Agricultural University, Mymensingh during the period from December 2017 through May 2018 to evaluate the effect of weed management practices on the performance of boro rice varieties and reported that from the economic analysis of the study the highest BCR was obtained from BRRI dhan29 with the application of pre-emergence herbicide followed by one hand weeding at 40 DAT which was close to BRRI dhan29 with the application of early post-emergence herbicide, BRRI dhan74 with the application of pre-emergence herbicide Superhit and BRRI dhan74 with the application of early post-emergence herbicide. The lowest BCR was obtained from BRRI dhan28 with no weeding (control) treatment

Mishra (2019) reported that the pre-emergence application of Bensulfuron methyl 60g/ha + Pretilachlor 600 g/ha at 3 DAT recorded the higher gross return of Rs.72320.8 ha^{-1} with a net return of Rs. 30688.2 ha^{-1} over farmer's practice were in one hand weeding at 40 DAT observed the gross return of Rs 64944 ha^{-1} with a net return of Rs 19631.8qha^{-1}. Higher B: C ratio (1.74) was found in improved technology due to higher net return as compared to farmer's practice (1.43). The weedy check showed the lowest net return this was due to higher yield with the use of herbicide in the early growth stage.

Suryakala *et al.* (2019) reported that application of (Pretilachlor + Pyrazosulfuron ethyl) + Bispyribac-sodium registered the higher net income of Rs.52170 ha^{-1} and return $rupee^{-1}$ invested of Rs. 2.52. It was followed by (Pretilachlor + Pyrazosulfuron ethyl) + Fenoxaprop-p-ethyl. The lowest net income of Rs. 21171 ha^{-1} and return $rupee^{-1}$ invested of Rs. 1.71 was recorded in unweeded control.

Barla and Upasani (2018) experimented to know the effect of upland rice varieties on the relative composition of weeds in Jharkhandduring the wet cropping season of 2011 and 2012 at Zonal Research Station, East Singhbhum under upland ecology to assess and identify crop parameters responsible for competitiveness of rice varieties. Total thirteen upland varieties including ten improved and three traditional varieties were tested under weedy and weed-free conditions. Results revealed that among varieties Vandana produced significantly higher grain yield (3.0tha^{-1}) over other varieties consequently recorded higher net return and B: C ratio similar to variety Anjali.

Sunil *et al.* (2010) reported that pre-emergence application of bensulfuron methyl + pretilachlor (6.6 GR) @ 0.06 + 0.6 kg ha^{-1} + one inter cultivation at 40 DAS recorded significantly higher grain and straw yields (4425 and 5020 kg ha^{-1}), lower weed population, and dry weight (17 and 2.32 g m^{-2}). This treatment also resulted in higher net returns and a B: C ratio.

Based on the above research, it is revealed that herbicide application for direct-seeded rice fields' plays a significant role in successful rice production. Therefore present research was conducted to ensure effective and economical weed control in direct-seeded *aus* rice of Bangladesh.

CHAPTER III

MATERIALS AND METHODS

A field experiment was conducted during March to July, 2022 to study the ''Influence of herbicides on growth, yield and controlling weeds in direct-seeded aus rice" at Sher-e-Bangla Agricultural University, Dhaka-1207. The details of materials used and techniques adopted during the investigation are described in this chapter.

3.1 Location of the experimental site

3.1.1 Geographical location

The experiment was conducted at the Agronomy field of Sher-e-Bangla Agricultural University (SAU), Sher-e-Bangla Nagar Agargaon, Dhaka, 1207. The experimental site is geographically situated at 23°77′ N latitude and 90°33′ E longitude at an altitude of 8.6 meters above sea level.

3.1.2 Agro-Ecological Zone

The experimental field belongs to the Agro-Ecological Zone (AEZ) of "The Modhupur Tract", AEZ-28. This was a region of complex relief and soils developed over the Modhupur clay, where floodplain sediments buried the dissected edges of the Modhupur Tract, leaving small hillocks of red soils as 'islands' surrounded by floodplain sediments buried the dissected edges of the Modhupur Tract, leaving small hillocks of red soils as 'islands' surrounded by floodplain. Appendix-I shows a better understanding of the experimental site in the Map of AEZ of Bangladesh.

3.2 Experimental duration

The experiment was conducted from March to July, 2022 in the *aus* season.

3.3 Soil characteristics of the experimental field

The soil of the experimental site was silty clay loam in texture belonging to the Tejgaon series. The area represents the Agro-Ecological Zone of the Madhupur tract (AEZ No. 28) with pH 5.8–6.5, ECE-25–28 Soil samples from 0-15 cm depths were collected from the experimental field. The analytical data of the soil sample collected from the experimental area were analyzed in the Soil Resources Development

Institute (SRDI), Soil Testing Laboratory, Khamarbari, Dhaka, and have been presented in Appendix II.

3.4 Climatic condition of the experimental field

The experimental area was under the subtropical climate and was characterized by high temperature, high humidity, and heavy precipitation with occasional gusty winds during the period from March to August, but scanty rainfall associated with moderately low temperature prevailed during the period from March to August. The meteorology center in Dhaka recorded the monthly means of daily maximum, minimum and average temperature, relative humidity, total rainfall, and sunshine hours during the experiment period (Appendix III).

3.5 Crop/Planting materials

BRRI dhan98 was used as a test crop in the experiment. The salient feature of rice varieties is given below:

BRRI dhan98 is cultivable during the *Aus* season. The newly developed BRRI dhan98 produces 5.0-5.8 t ha^{-1} yield. The grain size and shape of the variety are long and slender, and the grain is golden. Its growth duration is 112 days which is similar to BR26. The weight of thousand matured grains of this variety is around 22.6 gm. The grain contains 27.9% amylose and 9.5% protein. The cooked rice is whitish. Then the breeding line's yield performance was tested in different farmers' fields in the country in 2017-2018. Thus it was found that the life cycle of the breeding line is similar to BR26, having a higher yield. After checking the results of such testing and retesting, the NSB team finally decided to release it as a new *Aus* variety for cultivation throughout the country.

3.6 Seed collection and sprouting

BRRI dhan98 is collected from BRRI (Bangladesh Rice Research Institute), Joydebpur, Gazipur. Healthy and disease-free seeds were selected following standard techniques. Seeds were immersed in water in a bucket for 24 hrs. These were then taken out of the water and kept in gunny bags. The seeds started sprouting after 48 hrs, suitable for sowing in 72 hrs.

3.7 Preparation of experimental field

The experimental field was first opened on 21 March, 2022 with the help of a power tiller; later, the land was irrigated and prepared by three successive ploughings and cross-ploughings. Various kinds of weeds and developments of pest crops were disposed of from the field. After final land preparation, the field layout was made on 27 March, 2022. Each plot was cleared in and finally leveled out with the help of a wooden board.

3.8 Fertilizer management

Plant nutrients *viz*. N, P, K, S, and Zn for rice were given through urea 150 kg ha^{-1}, triple superphosphate 90 kg ha^{-1}, muriate of potash 40 kg ha^{-1}, gypsum 60 kg ha^{-1}, and zinc sulphate 10 kg ha^{-1}, respectively. Based on the soil test, the following doses of fertilizers were applied according to the recommendation by BRRI for cultivating *aus* rice. All fertilizers except urea were applied as basal doses at final land preparation. Urea was applied in three equal splits. The first dose of urea was used at the last land preparation. The second dose of urea was added as top dressing at 25 days (active vegetative stage) after sowing, and the third dose was applied at 50 days (panicle initiation stage) after sowing, according to the BRRI.

3.9 Experimental design and layout

The experiment was laid out in an RCBD design having three replications. There were 13 treatment combinations and 39 unit plots. The unit plot size was 4.5 m^2 (3 m × 1.5 m). The unit plots were separated by 1.0 m and 0.50 m spacing. Plant-to-plant spacing was 25 × 25 cm. The layout of the experimental field is shown in Appendix- IV.

3.10 Experimental treatments

The experiment consisted of 13 treatments, as mentioned below:

T_0 = Unweeded (Control)

T_1 = Partial Weeding (Two time hand weeding at 20 and 40 DAS)

T_2 = Weed Free

T_3 = Pre-emergence herbicide (Butachlor @ 25 kg ha^{-1})

T_4 = Pre-emergence herbicide (Pendamethyline @ 2 L ha^{-1})

T_5 = Post-emergence herbicide (Pretilachlor @ 1 L ha^{-1})

T_6 = Post-emergence herbicide (Bispyribac-Sodium @ 25 g ha^{-1})

T_7 = Pre+ Post-emergence herbicide (Butachlor @ 25 kg ha^{-1} + Bispyribac-Sodium @ 25 g ha^{-1})

T_8 = Pre+ Post-emergence herbicide (Pendamethyline @ 2 L ha^{-1} + Bispyribac-Sodium @ 25 g ha^{-1})

T_9 = Mixed Herbicide (Pretilachlor 6% + Pyrazosulfuron- ethyl 0.15% @ 2 kg ha^{-1})

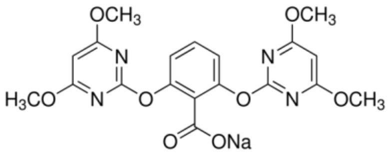
T_{10} = Mixed Herbicide (Pretilachlor 30% + Pyrazosulfuron- ethyl 0.75% @ 2 kg ha^{-1})

T_{11} = Mixed Herbicide (Acitachlor 14% + Bensulfuron methyl 4% @ 3 kg ha^{-1})

T_{12} =Late Post-emergence (2, 4-D Amine @ 2.24 L ha^{-1})

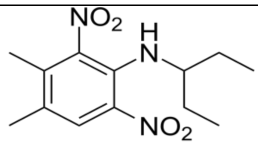
3.11 Description of the herbicides, used for weeds control in the experimental field

3.11.1 Bispyribac-Sodium

Trade name	Xtrapower 20WP
Name of registration holder	ACI Formulation Limited
IUPAC Name	sodium 2,6-bis(4,6-dimethoxypyrimidin-2-yloxy) benzoate
Structural formula	
Molecular weight	452.3
Formulation types	Wettable powder herbicide
Mode of actions	A post-emergence herbicide for the control of grasses, sedges, and broad-leaved weeds in paddy rice and other crops/situations. It is a selective, systemic post-emergent herbicide. After application, it gets absorbed by foliage and roots. Inhibits plant amino acid synthesis – Acetohydroxyacid synthase (AHAS).
Target Weeds	Alligatorweed, duckweed, mosquito fern, water fern, water hyacinth, water pennywort, parrot feather; annual bluegrass; creeping bentgrass
Major crops	Aquatic situations such as transplanted rice (Paddy), drainage

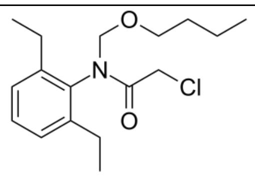
	ditches, lakes, marshes; Golf courses, turfgrass & sod farms
Application rate	25 g ha^{-1}
Time of application	20 days after transplanting

3.11.2 Pendimethalin

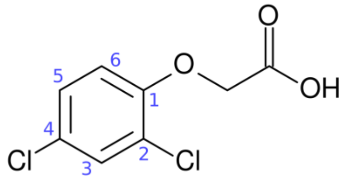
Trade name	CREEZENDO 33 EC
Name of registration holder	UPL Bangladesh Ltd.
IUPAC Name	N-(1-ethylpropyl)-2, 6-dinitro-3, 4-Xylidi
Structural formula	
Molecular weight	281.308
Formulation types	Emulsion Concentrate (33 and 40%),
Mode of actions	Selective, absorbed by roots and leaves and control annual grasses. Inhibition of mitosis and cell division. Microtubule assembly inhibition
Target Weeds	Cereals (wheat, barley, rye, triticale), corn, soybeans, rice, potato, legumes, fruits, vegetables, nuts.
Major crops	Grasses and Broadleaves Weeds
Application rate	2 L ha^{-1}.
Time of application	Pre-emergence, Post-emergence

3.11.3 Butachlor

Trade name	Vitachete 5G
Name of	Semco (Setu Pesticides Ltd.)

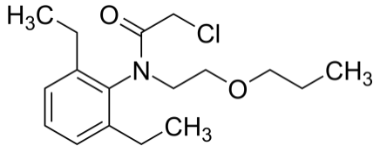
registration holder	
IUPAC Name	N-butoxymethyl- 2 Chloro-2, 6-diethyl acetanilide
Structural formula	
Molecular weight	311.847
Formulation types	Granule 5G
Mode of actions	Selective, systemic absorbed primarily via germinating shoots. Inhibition of VLCFA (inhibition of cell division) control of annual grasses and some broad-leaved weed
Target Weeds	Boro Shama, Holde Mutha, Boro Chucha, Joyna, Pani Katchu, Pani Long, Chechra, Sushni Shak, Zhill Marich, Dubra etc.
Major crops	Rice
Application rate	25 kg ha^{-1}
Time of application	2-3 days after sowing

3.11.4 2, 4-D Amine

Trade name	Filder
Name of registration holder	ACI Formulation Limited
IUPAC Name	2, 4-Dichlorophenoxy acetic acid ethyl ester
Structural formula	
Molecular weight	221.037

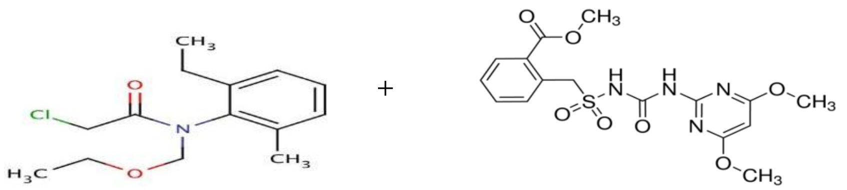
Formulation types	Emulsion Concentrate (38%), Dark amber liquid
Mode of actions	It is penetrate foliage, whereas plant roots absorb the salt forms used on a wide variety of terrestrial and aquatic broadleaf weeds. It has little effect on grasses. Abnormal increases in cell wall plasticity, biosynthesis of proteins, and production of ethylene occur in plant tissues following exposure, and these processes are responsible for uncontrolled cell division.
Target Weeds	Mikania lata, Pig weeds and other dicotyledonus weeds
Major crops	Tea and Rubber
Application rate	2.24 L ha^{-1}.
Time of application	Post-emergence

3.11.5 Pretilachlor

Trade name	Superhit 500 EC
Name of registration holder	ACI Formulations Limited
IUPAC Name	2- Chloro-N- 92.6 diethyl phenyl) –N- (2- propoxyethyl) acetamide
Structural formula	
Molecular weight	311.9
Formulation types	Emulsion Concentrate (50%)
Mode of actions	Selective, systemic action herbicide. Control annual grasses, broad-leaved weeds and sedges in rice and works by inhibiting cell division
Target Weeds	Boro Shama, Choto Shama, Panikachu, Chandmala, Zheel

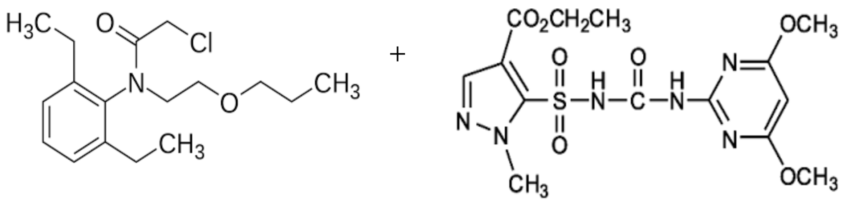
	morich, Panilong, Malancha etc.
Major crops	Rice
Application rate	1 L ha^{-1}
Time of application	Pre-emergence (0-5 DAS)

3.11.6 Acitachlor 14% + Bensulfuron methyl 4%

Trade name	Gail 18WP
Name of registration holder	Fosol Agro Industries Limited
IUPAC Name	2-chloro-N-ethoxymethyl-6-ethylacet-o-toluidide
Structural formula	
Molecular weight	269.77
Formulation types	Wettable powder herbicide
Mode of actions	It is a systemic compound with foliar and soil activity and it works rapidly after it is taken up by the plant. Its mode of action is by inhibiting cell division in the shoots and roots of the plant, and it is biologically active at low use rates
Target Weeds	Grasses and *Echinochloa* spp., sedges and broadleaf weeds,
Major crops	Rice (paddy) field
Application rate	3 kg ha^{-1}

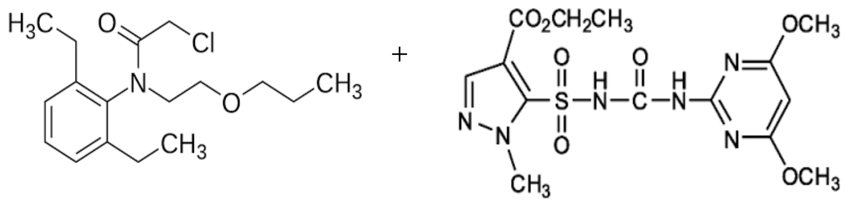
Time of application	07 days after sowing

3.11.7 Pretilachlor 6% + Pyrazosulfuron- ethyl 0.15%

Trade name	EROS
Name of registration holder	ACI Formulations Limited (UPL Bangladesh Ltd)
IUPAC Name	2-chloro-N-(2,6-diethylphenyl)-N-(2-propox yethyl) acetamide +ethyl 5-1-methyl-1H-pyrazole-4-carboxylate
Structural formula	
Molecular weight	386.4
Formulation types	Granular herbicide
Mode of actions	Selective pre-emergence herbicide. Inhibition of acetolactate synthase
Target Weeds	*Echinochloa crusgalli, E. colona, Eclipta alba, Cyperus iria, C. difformis, Fimbristylis miliacea*
Major crops	Rice field
Application rate	2 kg ha^{-1}
Time of application	3 days after sowing

3.11.8 Pretilachlor 30% + Pyrazosulfuron- ethyl 0.75%

Trade name	EROS Gold
Name of registration	ACI Formulations Limited (UPL Bangladesh Ltd)

holder	
IUPAC Name	2-chloro-N-(2,6-diethylphenyl)-N-(2-propox yethyl) acetamide +ethyl 5-1-methyl-1H-pyrazole-4-carboxylate
Structural formula	
Molecular weight	386.4
Formulation types	Granular herbicide
Mode of actions	Selective pre-emergence herbicide. Inhibition of acetolactate synthase
Target Weeds	*Echinochloa crusgalli, E. colona, Eclipta alba, Cyperus iria, C. difformis, Fimbristylis miliacea*
Major crops	Rice field
Application rate	2 kg ha^{-1}
Time of application	3 days after sowing

3.12 Field operation

The different field operations performed during the present investigation are given below in chronological order in list form.

Table 1. List of schedule of field operations done during experimentation

Sl. No.	Field Operation	Date
01	Final land preparation	21 March 2022
02	The layout of the experimental field	21 March 2022
03	Fertilizer Application	21 March 2022
04	Drain making	25 March 2022
05	Seed Sowing and sallow irrigation	29 March 2022
06	Spraying of Butachlor	30 March 2022
07	Spraying of Pendimethalin	30 March 2022
08	Spraying of Pretilachlor 6% + Pyrazosulfuron- ethyl 0.15%	03 April 2022
09	Spraying of Pretilachlor 30% + Pyrazosulfuron- ethyl 0.75%	03 April 2022
10	Spraying of Acitachlor 14% + Bensulfuron methyl 4%	03 April 2022
11	Spraying of Pretilachlor	11 April 2022
12	Spraying of Bispyribac-Sodium	11 April 2022
13	Spraying of 2,4-D Amine	24 April 2022
14	Application of 2nd dose of Urea	22 April 2022
15	Application of 3rd dose of Urea and deep irrigation	22 May 2022
16	1st Weeding of T_1	20 April 2022
17	2nd Weeding of T_1	10 May 2022
18	1st Weeding of T_2	10 April 2022
19	2nd Weeding of T_2	30 April 2022
20	3rd Weeding of T_2	13 May 2022
21	4th Weeding of T_2	5 June 2022
21	Harvesting of Rice	21 July 2022
22	Threshing and winnowing of produce	22 July 2022 05 August 2022

3.13 Intercultural operations

3.13.1 Gap filling

Some hills were replaced by sowing from the same seed source within 7 days of sowing.

3.13.2 Application of irrigation

One sallow irrigation (surface irrigation) was given just after sowing, and and one deep irrigation (5 cm) during the panicle initiation period to each plot.

3.13.3 Method of irrigation

The experimental plots were irrigated through irrigation channels. Centimeter-marked sticks were installed in each plot which was used to measure the depth of irrigation water.

3.13.4 Herbicide application

Herbicide was taken into a knapsack sprayer and mixed with water, then applied according to with par treatment requirement for each plot. For herbicide application, only 1 labor was required.

3.13.5 Weedy check

The weeds were allowed to grow along with the crop throughout the crop season in weedy check plots, and no control measures were adopted to check the weeds. The weed flora present in the weedy check plots was noted.

3.13.6 General observations of the experimental field

Regular observations were made to see the growth and visual differences of the crops due to the application of different treatments were applied in the experimental field.

3.13.7 Harvesting and post-harvest operation

The rice plant was harvested depending upon the maturity of grains, and harvesting was done manually from each plot. The crop's maturity was determined when 80–90% of the grains became golden yellow. Ten (5) pre-selected hills per plot from which different data were collected and 1.00 m^2 areas from the middle portion of each plot were separately harvested and bundled, properly tagged, and then brought to the threshing floor. A pedal thresher did threshing. The grains were cleaned and sun-dried to a moisture content of 12%. The straw was also sun-dried properly. Finally, grain and straw yields plot^{-1} were recorded and converted to t ha^{-1}.

3.14 Data collection

The data were recorded on the following parameters

a) Observation on weeds

i. Weed flora
ii. Weed population in weedy check plot (No.m^{-2})
iii. Relative weed density in weedy check plot (m^{-2})
iv. Weed density (m^{-2})
v. Weed dry weight (g m^{-2})
vi. Weed control efficiency (%)
vii. Weed control index (%)

b) Observation on crop

i) Crop growth characters

viii. Plant height (cm)
ix. Number of tillers hill^{-1}
x. Dry matter accumulation (g plant^{-1})

ii) Yield contributing characters

xi. Number of effective tillers hill^{-1}
xii. Number of non-effective tillers hill^{-1}
xiii. Length of panicle (cm)
xiv. Number of filled grains panicle^{-1}
xv. Number of unfilled grains panicle^{-1}
xvi. Total grains panicle^{-1}
xvii. Weight of 1000- grain (g)

iii) Yield parameters

xviii. Grain yield (t ha^{-1})
xix. Straw yield (t ha^{-1})
xx. Biological yield (t ha^{-1})
xxi. Harvest index (%)

iv) Herbicide efficiency index (HEI)

v) Economic analysis

3.15 Procedure of recording data

i) Weeds flora

During experiments, weeds found in the experiment field were recorded, and determine the weeds flora of direct-seeded *aus* rice.

ii) Weed population in weedy check plot (No.m^{-2})

From the pre-demarcated area of 1 m^2 of the weedy check plot, individual weed species' names and populations were listed at 20, 40 and 60 DAS better to understand the various weed interference of the experimented field.

iii) Relative weed density in weedy check plot

Relative weed density in the weedy check plot was estimated at 20, 40, and 60 DAS. The relative weed density was worked out per the formula Mishra gave (2019).

$$\text{Relative weed density (\%)} = \frac{\text{Number of individuals of same species}}{\text{Number of individual of all species}} \times 100$$

iv)Weed density (m^{-2})

From the pre-demarcated area of 1 m^2 of each plot, the total weeds were uprooted and counted at 20, 40, and 60 DAS in the experimental rice field.

v) Weed dry matter weight (m^{-2})

After counting the fresh weeds, weeds were then oven dried at 80^{0}C until a constant weight was obtained. The sample was then transferred into desiccators and allowed to cool down to room temperature, and then the final weight of the sample was taken at 20, 40, and 60 DAS of rice, respectively.

vi)Weed control efficiency (WCE)

Weed control efficiency was measured by using the following formula given by Mani *et al.* (1973).

$$\text{WCE} = \frac{\text{Weed population in control} - \text{weed population in treated plot}}{\text{Weed population in control}} \times 100$$

vii) Weed control index (WCI)

Weed control efficiency was measured using the following formula by Mishra and Tosh (1979).

$$\text{WCI} = \frac{\text{Weed dry weight in control} - \text{weed dry weight in treated plot}}{\text{Weed dry weight in control}} \times 100$$

viii) Plant height

The height of the randomly selected 10 plants was determined by measuring the distance from the soil surface to the tip of the leaf at 15 DAS intervals and harvest, respectively. The mean plant height of rice plant was calculated and expressed in cm.

ix) Number of tillers

Number of tillers hill^{-1} were counted at 15 days interval up to harvest from pre-selected hills and finally averaged as their number hill^{-1}. Only those tillers having three or more leaves were considered for counting.

x) Dry matter accumulation

Dry matter accumulation plant^{-1} (g) was recorded at 30, 45, 75, and 90 DAS. The sample plants were oven-dried for 72 hours at 70°C, and then data were recorded from plant samples plant^{-1} plot^{-1} selected at random from the outer rows of each plot leaving the borderline and expressed in grams.

xi) Panicle length

Panicle length was measured from the rachis's basal node to each panicle's apex. Panicle length was measured with a meter scale from 10 selected panicles, and the average value was recorded.

xii) Number of effective tillers

The total number of effective tillers on hill^{-1} was counted as the number of panicle-bearing tillers per hill. Data on effective tiller per hill were recorded from 5 randomly selected hills at harvesting time, and the average value was recorded.

xiii) Number of non-effective tillers

The total number of non-effective tillers hill^{-1} was counted as the tillers with no panicle on the head. Data on non-effective tiller per hill were counted from 5 pre-selected (used in effective tiller count) hills at harvesting time, and the average value was recorded.

xiv) Number of filled grains

The total number of filled grains was collected randomly from selected 5 plants of a plot, and then average number of filled grains per panicle was recorded.

xv) Number of unfilled grains

The total number of unfilled grains was collected randomly from selected 5 plants of a plot based on no or partially developed grain in the panicle, and then the average number of unfilled grains per panicle was recorded.

xvi) Number of total grains

The number of fertile grains panicle^{-1} alone with the number of sterile grains panicle^{-1} gave the total number of grains panicle^{-1}.

xvii) Weight of 1000-grain

One thousand cleaned dried seeds were counted randomly from each sample and weighed by using a digital electric balance at the stage the grain retained 12% moisture, and the mean weight was expressed in grams.

xviii) Grain yield

Grain yield was adjusted at 14% moisture. Grains obtained from each unit plot were sun-dried and weighed carefully. The dry weight of grains of the central 1m^2 area was measured, and then recorded the final grain yield of each plot^{-1} and converted to t ha^{-1} in both locations. The grain yield t ha^{-1}was measured by the following formula:

$$\text{Grain yield (t ha}^{-1}\text{)} = \frac{\text{Grain yield per unti plot (kg)} \times 10000}{\text{Area of unit plot in square meter} \times 1000}$$

xix) Straw yield

After separating the grains, the straw yield was determined from each plot's central 1 m^2 area. After threshing, the sub-samples were sun-dried to a constant weight and finally converted to t ha^{-1}. The following formula measured the straw yield t ha^{-1}:

Straw yield (t ha^{-1}) = $\frac{\text{Straw yield per unti plot (kg)} \times 10000}{\text{Area of unit plot in square meter} \times 1000}$

xx) Biological yield

The summation of grain yield and above-ground straw yield was the biological yield. Biological yield =Grain yield + Stover yield.

xxi) Harvest index

The Harvest index was calculated on a dry weight basis with the help of the following formula.

Harvest index (HI %) = $\frac{\text{Grain yield}}{\text{Biological yield}} \times 100$

Here, Biological yield = Grain yield + straw yield

xxii) Herbicide efficiency index

Herbicide efficiency index (HEI) was calculated using the formula suggested by Das, (2013).

$$HEI = \frac{\frac{(Y_T - Y_C)}{Y_T} x100}{\frac{WDM_T}{WDM_C} x100}$$

Where, Y_T is crop yield from the treated plot, Y_C is crop yield from unweeded control plot, WDM_T is weed dry matter weight in the treated plot and WDM_C is weed dry matter in the unweeded control plot.

3.16 Economic analysis of direct-seeded rice cultivation

In this research, from the beginning to the end of the experiment, individual cost data of all the heads of expenditure in each treatment were recorded carefully and classified according to Mian and Bhuiya (1977) and posted under different heads of cost of production.

i. Input cost

Input costs were divided into two parts. These are as follows:

A. Non-material cost

Non-material cost is all the labors cost. Human labor was obtained from adult male laborers. In a day, 8 hours of labor was considered a man's day. The mechanical labor came from the tractor. A period of eight working hours of a tractor was taken to be tractor day. Individual labor wages 400 Tk. day^{-1}.

B. Material cost

It included seeds rate ha^{-1}, fertilizers, pesticide application, irrigation application cost

ii. Overhead cost

Overhead cost is the land cost. The value of the land varies from place to place. In this research,the value of land was taken Tk. 200000 per hectare. The interest on this cost was calculated for 6 months @ Tk. 12.5% per year based on the interest rate of the Bangladesh Krishi Bank.

iii. Miscellaneous cost (common cost)

It was 5% of the total input cost.

iv. Gross return from rice

Gross return from rice (Tk. ha^{-1}) = Value of grain yield (Tk. ha^{-1}) + Value of straw (Tk. ha^{-1})

v. Net returns (NR)

Net return was calculated by using the following formula:

NR (Tk. ha^{-1}) = Gross return (Tk. ha^{-1}) – Total cost of production (Tk. ha^{-1}).

vi. Benefit-cost ratio of rice (BCR)

Benefit-cost ratio indicated whether the cultivation is profitable or not which was calculated as follows:

$$\text{BCR} = \frac{\text{Gross return (Tk/ha)}}{\text{Cost of production (Tk/ha)}}$$

3.17 Data analysis

The collected data were compiled and analyzed statistically using the analysis of variance (ANOVA) technique with the help of a computer package program named Statistix 10 Data analysis software, and the mean differences were adjusted by the Least Significant Difference (LSD) test at 5% level of probability.

CHAPTER IV

RESULTS AND DISCUSSION

Results obtained from the present study have been presented and discussed in this chapter to study the influence of herbicides on growth, yield and controlling weeds in direct-seeded *aus* rice. The data are given in different tables and Figures. The results have been discussed, and possible interpretations are given under the following headings.

4.1 Weed flora in the experimental field

In this experiment, the rice field was infested with different types of weeds. Seventeen different weed species were observed in the experimental field (Table 2). Among the infesting different categories of weed species, seven were grasses, one sedge and nine broadleaves. The weed species belonged to the families of Poaceae, Cyperaceae, Solanaceae, Brassicaceae, Malvaceae, Euphorbiaceae, Fabaceae, Amaranthaceae, Lamiaceae, and Scrophulariaceae. The broad-leaved ones were *Physalis heterophylla, Rorippa indica, corchorus trilocularis, Croton sparsiflorus, Euphorbia hirta, Desmodium trifolium, Amaranthus spinosus, Ocimum tenuiflorum, and Lindernia procumbens;* sedge is *Cyperus strigosus*, and grasses were *Cynodon dactylon, Echinochloa crus-galli*, *Echinochloa colona*, *Digitaria sanguinalis*, *Digitaria ischaemum*, *Eleusine indica*, and *Oplismenus compositus*. Several studies reported infestion with mixed weed flora in the direct-seeded rice system, including grasses, broadleaf, and sedges (Suria *et al*., 2011; Ahmed *et al*., 2014; Singh *et al.*, 2016).

Table 2. Weed flora of the experimental field in direct-seeded *aus* rice

WEED SPECIES					
Local name	**English name**	**Scientific name**	**Family**	**Habitat**	**Weed type**
Durba	Bermuda Grass	*Cynodon dactylon*	Poaceae	Perennial	Grass
Boro Shama	Barnyard grass	*Echinochloa crus-galli*	Poaceae	Annual	Grass
Choto shama	Jungle rice	*Echinochloa colona*	Poaceae	Annual	Grass
Soto anguli	Smooth crabgrass	*Digitaria sanguinalis*	Poaceae	Annual	Grass
Boro anguli	Large crabgrass	*Digitaria ischaemum*	Poaceae	Annual	Grass
Chapra	Goosegrass	*Eleusine indica*	Poaceae	Annual	Grass
Busket	Busket Grass	*Oplismenus compositus*	Poaceae	Perennial	Grass
Cucha	Straw-colored Flatsedge	*Cyperus strigosus*	Cyperaceae	Perennial	Sedge
Fuska begun	Ground Cherry	*Physalis heterophylla*	Solanaceae	Annual	Broadleaf
Bon mula	Indian Field Cress	*Rorippa indica*	Brassicaceae	Annual	Broadleaf
Bon pat	Wild jute	*Corchorus trilocularis*	Malvaceae	Annual	Broadleaf
Ban marich	Croton plant	*Croton sparsiflorus*	Euphorbiaceae	Annual	Broadleaf
Boro dudhia	Garden Spurge	*Euphorbia hirta*	Euphorbiaceae	Annual	Broadleaf
Tripatri shak	Calania	*Desmodium trifolium*	Fabaceae	Perennial	Broadleaf
Kanta note	Spiny Pigweed	*Amaranthus spinosus*	Amaranthaceae	Annual	Broadleaf
Bon tulsi	Wild Holy Basi	*Ocimum tenuiflorum*	Lamiaceae	Perennial	Broadleaf
Khet papri	Lindernia	*Lindernia procumbens*	Scrophulariaceae	Annual	Broadleaf

4.2 Species wise weed population and relative weed density

Data on species-wise weed population (No. m^{-2}) and relative density (%) of weeds recorded in weedy check plots at 20, 40, and 60 DAS are presented in Table 3. It is apparent from the data that there was a predominance of broadleaf and grass weeds in weedy check plots of rice during *aus* season. Among the weeds, *Digitaria ischaemum* was the most dominant weed at 20, 40, and 60 DAS, followed by *Physalis heterophylla and Digitaria sanguinalis* weed species at 20, 40, and 60 DAS. At the same time, the dominancy of *Cyperus strigosus* and *Lindernia procumbens* were the least among all the weed species.

Table 3. Species-wise weed population and relative weeds density in weedy check plots of direct-seeded *aus* rice

Scientific name	Weed population (No. m^{-2})			Relative weeds density (%)		
	20 DAS	40 DAS	60 DAS	20 DAS	40 DAS	60 DAS
Cynodon dactylon	0	0	03	0.00	0.00	0.43
Echinochloa crusgalli	16	79	80	12.40	12.27	11.56
Echinochloa colona	12	72	73	9.30	11.18	10.55
Digitaria sanguinalis	14	100	104	10.85	15.53	15.03
Digitaria ischaemum	53	214	231	41.09	33.23	33.38
Eleusine indica	0	14	14	0.00	2.17	2.02
Oplismenus compositus	0	3	5	0.00	0.47	0.72
Cyperus strigosus	0	0	1	0.00	0.00	0.15
Physalis heterophylla	34	140	154	26.36	21.74	22.25
Rorippa indica	0	7	9	0.00	1.09	1.30
Corchorus trilocularis	0	9	11	0.00	1.40	1.59
Croton sparsiflorus	0	1	1	0.00	0.16	0.15
Euphorbia hirta	0	1	1	0.00	0.16	0.15
Desmodium trifolium	0	1	1	0.00	0.16	0.15
Amaranthus spinosus	0	2	2	0.00	0.31	0.29
Ocimum tenuiflorum	0	1	1	0.00	0.16	0.15
Lindernia procumbens	0	0	1	0.00	0.00	0.15
Total Weed	129	644	692	100	100	100

4.3 Effect of herbicides on distribution of weed species in direct-seeded *aus* rice

Treatment-wise weed species distribution is shown in the Table 4. According to the Table 4 at 20 DAS, *Echinochloa crus-galli* was found in T_0, T_3, $T_{9,}$ and $T_{12.}$ *Echinochloa colona* was observed in T_0, T_3, $T_{5,}$ and T_7 treatments. *Digitaria sanguinalis* was in T_3, T_7, $T_{11,}$ and T_{12} plots. *Digitaria ischaemum* was found in T_0,T_1,T_2,T_3,T_5,T_7,$T_{9,}$ and T_{12} treated plots and *Physalis heterophylla* was recorded from T_0,T_2,T_3,T_5,T_7,T_9,T_{11} and T_{12} plots. However, *Cynodon dactylon*, *Eleusine indica, Oplismenus compositus, Cyperus strigosus, Rorippa indica, Corchorus trilocularis, Croton sparsiflorus, Desmodium trifolium, Euphorbia hirta, Amaranthus spinosus, Ocimum tenuiflorum and Lindernia procumbens* were not found. At 40 DAS, *Cynodon dactylon* was recorded from $T_{1,}$ $T_{8;}$ *Echinochloa crus-galli* was recorded from $T_{0,}$ $T_{1,}$ $T_{2,}$ $T_{3,}$ $T_{5,}$ $T_{6,}$ $T_{9,}$ $T_{10,}$ $T_{11,}$ T_{12} treatments; *Echinochloa colona* was recorded from $T_{0,}$ $T_{1,}$ $T_{2,}$ $T_{3,}$ $T_{5,}$ $T_{6,}$ $T_{7,}$ $T_{8,}$$T_{9,}$ T_{11},T_{12} treatments; *Digitaria sanguinalis* was recorded from $T_{0,}$ $T_{1,}$ $T_{2,}$ $T_{3,}$ $T_{5,}$ $T_{6,}$ $T_{7,}$ $T_{9,}$ T_{11},T_{12} treatments; *Digitaria ischaemum* was recorded from T_0,$T_{1,}$ $T_{2,}$ T_3,$T_{5,}$ $T_{6,}$ $T_{7,}$ $T_{9,}$ $T_{10,}$ $T_{11,}$ T_{12} treatments; *Eleusine indica* was recorded from $T_{1,}$ $T_{3,}$$T_{4,}$ $T_{5,}$ $T_{6,}$ $T_{7,}$ $T_{9,}$ T_{11} treatments; *Oplismenus compositus* was recorded from $T_{1,}$$T_4$ treatments; *Physalis heterophylla* was recorded from $T_{0,}$ T_2,$T_{3,}$ $T_{4,}$$T_{5,}$ $T_{6,}$ $T_{7,}$$T_{9,}$ $T_{10,}$ $T_{11,}$ T_{12} treatments; *Rorippa indica* was found in $T_{0,}$ $T_{3,}$ $T_{10,}$ T_{11} treatments; *Corchorus trilocularis* was found in $T_{0,}$ $T_{3,}$ $T_{4,}$ $T_{5,}$ T_{11}; *Croton sparsiflorus* was found in T_9 treatments; *Euphorbia hirta* was found in $T_{2;}$ *Desmodium trifolium* was recorded from $T_{4;}$ *Amaranthus spinosus* was recorded from T_7, $T_{11;}$ *Ocimum tenuiflorum* was recorded from T_{10} treatments. But *Cyperus strigosus* and *Lindernia procumbens* were not found in any plot at 40 DAS. At 60 DAS, *Cynodon dactylon* was recorded from $T_{1,}$ T_8 plots; *Echinochloa crus-galli* was recorded from $T_{0,}$ $T_{1,}$ $T_{2,}$ $T_{3,}$ $T_{5,}$ $T_{6,}$ $T_{9,}$ $T_{10,}$ $T_{11,}$ T_{12} treatments; *Echinochloa colona* was recorded from $T_{0,}$ $T_{1,}$ $T_{2,}$ $T_{3,}$ $T_{5,}$ $T_{6,}$ $T_{7,}$ $T_{8,}$$T_{9,}$ T_{11},T_{12} treatments; *Digitaria sanguinalis* was recorded from $T_{0,}$ $T_{1,}$ $T_{2,}$ $T_{3,}$ $T_{5,}$ $T_{6,}$ $T_{7,}$ $T_{8,}$ $T_{9,}$ T_{11},T_{12} treatments; *Digitaria ischaemum* was recorded from T_0,$T_{1,}$ $T_{2,}$ T_3,$T_{5,}$ $T_{6,}$ $T_{7,}$ $T_{8,}$ $T_{9,}$ $T_{10,}$ $T_{11,}$ T_{12} treatments; *Eleusine indica* was recorded from $T_{1,}$ $T_{3,}$$T_{4,}$ $T_{5,}$ $T_{6,}$ $T_{7,}$ $T_{9,}$ T_{11} treatments; *Oplismenus compositus* was recorded from $T_{1,}$$T_{4,}$$T_{8;}$ *Cyperus strigosus* was recorded from $T_{0;}$ *Physalis heterophylla* was recorded from $T_{0,}$ $T_{2,}$ $T_{3,}$ $T_{4,}$ $T_{5,}$ $T_{6,}$ $T_{7,}$ $T_{9,}$ $T_{10,}$ $T_{11,}$ $T_{12;}$ *Rorippa indica* was recorded from $T_{0,}$ $T_{3,}$ $T_{10,}$ $T_{11;}$ *Corchorus trilocularis* was recorded from $T_{0,}$ $T_{3,}$ $T_{4,}$ $T_{5,,}$ T_{11} treatments; *Croton sparsiflorus* was recorded from $T_{9;}$

Table 4. Effect of herbicides on occurence of weed species in direct-seeded *aus* rice

Weed species Occurrence					
Local name	**English name**	**Scientific name**	**20 DAS**	**40 DAS**	**60 DAS**
Durba	Bermuda Grass	*Cynodon dactylon*	-	T_1, T_8	T_1, T_8
Boro Shama	Barnyard grass	*Echinochloa crus-galli*	T_0, T_3, T_9,T_{12}	T_0, T_1, T_2, T_3, T_5, T_6, T_9, T_{10}, T_{11}, T_{12}	T_0, T_1, T_2, T_3, T_5, T_6, T_9, T_{10}, T_{11}, T_{12}
Choto shama	Jungle rice	*Echinochloa colona*	T_0,T_3,T_5,T_7	T_0, T_1, T_2, T_3, T_5, T_6, T_7, T_8,T_9, T_{11},T_{12},	T_0, T_1, T_2, T_3, T_5, T_6, T_7, T_8,T_9, T_{11},T_{12},
Soto anguli	Smooth crabgrass	*Digitaria sanguinalis*	T_3,T_7,T_{11},T_{12}	T_0, T_1, T_2, T_3, T_5, T_6, T_7, T_9, T_{11},T_{12},	T_0, T_1, T_2, T_3, T_5, T_6, T_7, T_8, T_9, T_{11},T_{12},
Boro anguli	Large crabgrass	*Digitaria ischaemum*	T_0,T_1,T_2,T_3,T_5,T_7,T_9,T_{12}	T_0,T_1, T_2, T_3,T_5, T_6, T_7, T_9, T_{10}, T_{11}, T_{12}	T_0,T_1, T_2, T_3,T_5, T_6, T_7, T_8, T_9, T_{10}, T_{11}, T_{12}
Chapra	Goosegrass	*Eleusine indica*	-	T_1, T_3,T_4, T_5, T_6, T_7, T_9, T_{11},	T_1, T_3,T_4, T_5, T_6, T_7, T_9, T_{11},
Busket	Busket Grass	*Oplismenus compositus*	-	T_1,T_4,	T_1,T_4,T_8
Cucha	Straw-colored Flatsedge	*Cyperus strigosus*	-	-	T_0
Fuska begun	Ground Cherry	*Physalis heterophylla*	T_0,T_2,T_3,T_5,T_7,T_9, T_{11},T_{12},	T_0, T_2,T_3, T_4,T_5, T_6, T_7,T_9, T_{10}, T_{11}, T_{12}	T_0, T_2, T_3, T_4, T_5, T_6, T_7, T_9, T_{10}, T_{11}, T_{12}
Bon mula	Indian Field Cress	*Rorippa indica*	-	T_0, T_3, T_{10}, T_{11},	T_0, T_3, T_{10}, T_{11},
Bon pat	Wild jute	*Corchorus trilocularis*	-	T_0, T_3, T_4, T_5, T_{11}	T_0, T_3, T_4, T_5,, T_{11}
Ban marich	Croton plant	*Croton sparsiflorus*	-	T_9	T_9
Boro dudhia	Garden Spurge	*Euphorbia hirta*	-	T_2	T_2
Tripatri shak	Calania	*Desmodium trifolium*	-	T_4	T_4
Kanta note	Spiny Pigweed	*Amaranthus spinosus*	-	T_7, T_{11}	T_7, T_{11}
Bon tulsi	Wild Holy Basil	*Ocimum tenuiflorum*	-	T_{10}	T_{10}
Khet papri	Lindernia	*Lindernia procumbens*	-	-	T_4

Euphorbia hirta was recorded from T_2 treatments; *Desmodium trifolium* was recorded from $T_{4;}$ *Amaranthus spinosus* was recorded from T_7, T_{11} treatments; *Ocimum tenuiflorum* was recorded from T_{10} and *Lindernia procumbens* was recorded from T_4 treatments. Therefore, Pendimethalin-applied plots had lesser weed density, particularly grasses, compared with butachlor also reported that the density of *Echinochloa colona* was reduced to a great extent with PRE application of butachlor and pendimethalin. Several authors have reported the effectiveness of pendimethalin PRE in reducing weed density (Moody, 1991; Valverde and Gressel, 2005). The current study has confirmed that the potential herbicide for PRE under DSR was pendimethalin, with its good grass weed control and activity on some broadleaved weeds. However, with sequential application of Pendimethalin PRE fb Bispyribac-Sodium in POST, grassy and broadleaved weed density reduced significantly. Singh *et al.* (2006) also reported similar findings.

4.4 Weed density

The application of different herbicides significantly affects weed density (No. m^{-2}) on direct-seeded *aus* rice (Table 5). Results revealed that maximum weed density (m^{-2}) was recorded in the T_3 (Pre-emergence Butachlor) treatment followed by weedy check plot. In contrast, pre-emergence herbicide Pendimethalin @ 2 L ha^{-1} and post-emergence Bispyribac-Sodium @ 25 g ha^{-1} treated plot was recorded minimum (0.0, 2.33, and 4.00 at 20, 40, and 60 DAS, respectively) weed density m^{-2}. This was due to the sequential application of Pendimethalin and Bispyribac-Sodium herbicides which might have prevented the germination of susceptible weed species and also reduced the growth of germinated weeds by inhibiting the process of photosynthesis comparable to other herbicides treatments. Mahajan *et al.* (2009) also found that sequential application of pendimethalin (1000 g ha^{-1}) PRE fb Bispyribac-Sodium (30 g ha^{-1}) applied 15 DAS provided better control of weeds in DSR. Besides, Mahbub and Bhuiyan (2018) also reported that pre-and-post emergence herbicides gave 80% control of annual and perennial weeds comparable to individual application of herbicides. Reddy *et al*. (2000) and Rekha *et al.* (2003) also found similar results and reported that the weed density was highest in the weed check condition. Weed density was decreased under different weed management treatments.

Table 5. Effect of herbicides on weed density in direct-seeded *aus* rice

Treatments	Weed density (No. m^{-2}) at		
	20 DAS	40 DAS	60 DAS
T_0	5.33 b	22.33 ab	23.00 ab
T_1	2.33 c	5.33 c	5.33 c
T_2	-	-	-
T_3	9.33 a	26.33 a	29.33 a
T_4	0.00 d	5.33 c	6.33 c
T_5	2.67 c	21.0 ab	21.67 b
T_6	0.00 d	22.33 ab	23.00 ab
T_7	9.00 a	18.33 b	18.67
T_8	0.00 c	2.33 c	4.00 c
T_9	3.00 c	21.33 ab	22.67 ab
T_{10}	0.00 d	19.33 ab	20.00 b
T_{11}	1.67 c	23.33 ab	25.33 ab
T_{12}	8.67 a	19.33 ab	21.33 b
$LSD_{(0.05)}$	1.52	7.57	7.50
CV (%)	27.82	28.25	26.23

A column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.05 probability level

Notes *viz:*
NS= Non- significant
T_0= Unweeded
T_1= Partial Weeding
T_2= Weed free
T_3= Pre-emergence (Butachlor)
T_4= Pre-emergence (Pendamethyline)
T_5= Post-emergence (Pretilachlor)
T_6= Post-emergence (Bispyribac-Sodium)
T_7= Pre+ Post-emergence (Vichete+Bispyribac-Sodium)
T_8= Pre+ Post-emergence (Pendamethyline+ Bispyribac-Sodium)
T_9= Mixed Herbicide (Pretilachlor 6% + Pyrazosulfuron- ethyl 0.15%)
T_{10}= Mixed Herbicide (Pretilachlor 30% + Pyrazosulfuron- ethyl 0.75%)
T_{11}= Mixed Herbicide (Acitachlor 14% + Bensulfuron methyl 4%)
T_{12}= Late Post-emergence (2, 4-D Amine)

4.5 Weed dry weight

Weed dry weight (m^{-2}), was significantly influenced due to the application of different herbicides at 20, 40, and 60 DAS (Table 6). Results showed that the maximum weed dry weight m^{-2} was recorded (7.67 gm) from Butachlor @ 25 kg ha^{-1}, which was statistically similar (5.33 gm) with Butachlor @ 25 kg ha^{-1} + Bispyribac-Sodium @ 25 g ha^{-1} at 20 DAS. At 40 DAS, the maximum weed dry weight m^{-2} was recorded (133.33 g) from Butachlor @ 25 kg ha^{-1}, which was statistically similar (130.67 g) to the weedy check plot. At 60 DAS, the maximum weed dry weight was recorded

(163.00 g) from the weedy check plot, which was statistically similar (158.00 g) with Butachlor @ 25 kg ha^{-1}. However, the minimum weed dry weight was recorded (0.00, 0.57, and 1.25 g) from Pendimethalin @ 2 L ha^{-1} + Bispyribac-Sodium @ 25 g ha^{-1} at 20, 40, and 60 DAS, respectively.

Table 6. Effect of herbicide on weed dry weight of *aus* rice at 20, 40, and 60 DAS

Treatments	Weed dry weight (g m^{-2}) at		
	20 DAS	40 DAS	60 DAS
T_0	3.00 c	130.67 a	163.00 a
T_1	1.00 de	10.33 f	21.00 d
T_2	-	-	-
T_3	7.67 a	133.33 a	158.00 a
T_4	0.00 e	30.33 ef	41.33 cd
T_5	1.33 d	79.33 b-d	120.33 ab
T_6	0.00 e	51.00 de	97.67 bc
T_7	5.33 b	45.00 e	96.00 bc
T_8	0.00 e	0.57 f	4.33 d
T_9	1.00 de	106.00 ab	150.67 ab
T_{10}	0.00 e	86.33 bc	120.00 ab
T_{11}	0.33 de	60.00 c-e	115.00 ab
T_{12}	2.67 c	80.33 b-d	124.33 ab
$LSD_{(0.05)}$	1.16	34.00	57.65
CV (%)	38.95	31.98	36.29

A column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.05 probability level.

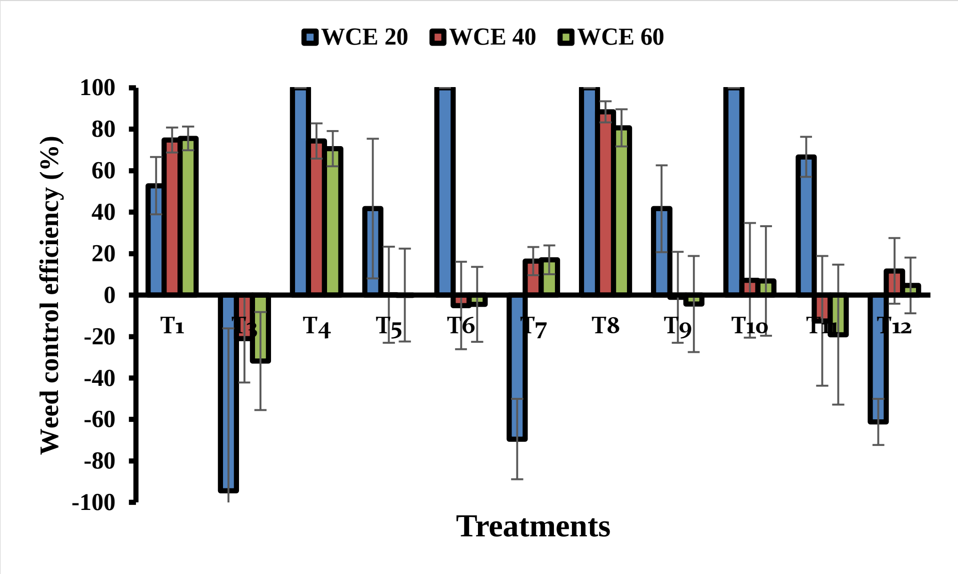
Notes *viz:*

NS= Non- significant
T_0= Unweeded
T_1= Partial Weeding
T_2= Weed free
T_3= Pre-emergence (Butachlor)
T_4= Pre-emergence (Pendamethyline)
T_5= Post-emergence (Pretilachlor)
T_6= Post-emergence (Bispyribac-Sodium)
T_7= Pre+ Post-emergence (Vichete+Bispyribac-Sodium)
T_8= Pre+ Post-emergence (Pendamethyline+ Bispyribac-Sodium)
T_9= Mixed Herbicide (Pretilachlor 6% + Pyrazosulfuron- ethyl 0.15%)
T_{10}= Mixed Herbicide (Pretilachlor 30% + Pyrazosulfuron- ethyl 0.75%)
T_{11}= Mixed Herbicide (Acitachlor 14% + Bensulfuron methyl 4%)
T_{12}= Late Post-emergence (2, 4-D Amine)

The differences in the dry matter accumulation by different weeds m^{-2} were due to the application of an effective mix herbicide that alters the physiological and morphological activities of the weeds. As a result, dry matter accumulation by different weeds m^{-2} was reduced compared to non-treated ones. Mishra (2019) also found a similar result that supported the present finding and reported that untreated weedy check produced the maximum weed dry weight at all the crop growth stages because of higher weed intensity and its dominance in utilizing the sunlight, nutrients, moisture, etc. Suryakala *et al.* (2019) also reported that the differential application of herbicides highly influenced weed dry matter. The overall weed density and dry matter found in this study are higher, reflecting that rice under an aerobic system is subjected to more weed pressure than transplanted systems. Mahajan *et al.* (2009) found almost double weed density and biomass in aerobic rice field than conventional transplanted rice at 35 and 75 days after transplanting. The high weed pressure in the aerobic rice field may be related to dry soil tillage (favorable soil moisture level during sowing) and alternate wetting and drying conditions during the crop growth period conducive to the germination and growth of weeds (Rao *et al*., 2007).

4.6 Weed control efficiency (%)

Application of different herbicides significantly affects weed control efficiency of *aus* rice at 20, 40, and 60 DAS (Fig. 1). Weed-free plots by manual weeding had 100% weed control efficiency, and it was caused due to removal of all weeds whenever they emerged and grew. However, experiment results revealed that higher weed control efficiency was observed in T_8 (Pendimethalin @ 2 L ha^{-1} + Bispyribac-Sodium @ 25 g ha^{-1}), comparable to other treatments and it was (100, 88.46, and 80.66 %) at 20, 40, and 60 DAS among all herbicidal treatments. At the same time, negative results were in T_3, T_6, T_9, and T_{11} treatments. Where stimulated weed population over the weedy check plot due to the respective herbicidal treatment application. The differences in weed control efficiency were due to variations in weed density in the experiment plot, which was attended to through different herbicide applications. Herbicides deteriorate the physiological and morphological features of weeds and thus reduce weed density and increase weed control efficiency. The results found in this experiment agreed with Bhuiyan and Mahbub (2020), who reported that weed control efficiency differed due to the herbicides.



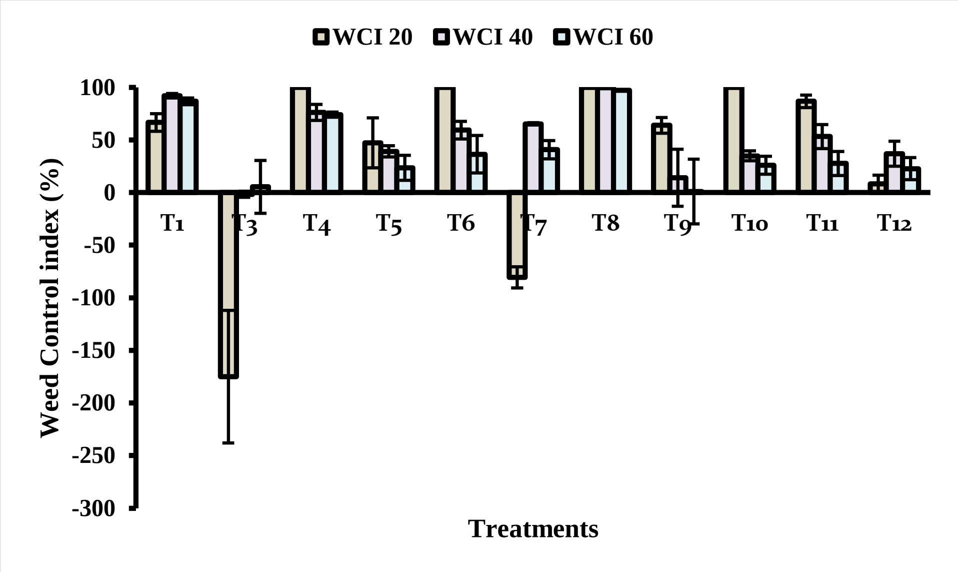
Notes *viz:*

NS= Non- significant
T_0= Unweeded
T_1= Partial Weeding
T_2= Weed free
T_3= Pre-emergence (Butachlor)
T_4= Pre-emergence (Pendamethyline)
T_5= Post-emergence (Pretilachlor)
T_6= Post-emergence (Bispyribac-Sodium)
T_7= Pre+ Post-emergence (Vichete+Bispyribac-Sodium)
T_8= Pre+ Post-emergence (Pendamethyline+ Bispyribac-Sodium)
T_9= Mixed Herbicide (Pretilachlor 6% + Pyrazosulfuron- ethyl 0.15%)
T_{10}= Mixed Herbicide (Pretilachlor 30% + Pyrazosulfuron- ethyl 0.75%)
T_{11}= Mixed Herbicide (Acitachlor 14% + Bensulfuron methyl 4%)
T_{12}= Late Post-emergence (2, 4-D Amine)

Figure 1. Effect of herbicide on weed control efficiency (%) of *aus* rice at 20, 40, and 60 days after sowing. Bars represent ±SE values obtained from three biological replications.

4.7 Weed control index (%)

The weed control index is an ideal parameter to judge the effectiveness of herbicides. Due to herbicide application, the weed control index ranged from -175 to 100% over the weedy check plot (Fig. 2). The experiment result revealed that the highest weed control index was found in fields receiving T_4, T_6, T_8, and T_{10} from Pendimethalin @ 2 L ha^{-1}, Bispyribac-Sodium @ 25 g ha^{-1}, Pendimethalin @ 2 L ha^{-1} + Bispyribac-Sodium @ 25 g ha^{-1} and Pretilachlor 30% + Pyrazosulfuron- ethyl 0.75% @ 2 kg ha^{-1}, respectively at 20 DAS. At 40 and 60 DAS, the highest weed control index (97.31 and 99.16%, respectively) was noticed in T_8 (Pendimethalin @ 2 L ha^{-1} + Bispyribac-Sodium @ 25 g ha^{-1}), followed by T_1 (partial weeding) (92.00 and 86.82%, respectively). In contrast, the lowest weed control index (- 175, -1.64, and 5.43%, respectively, at 20, 40, and 60 DAS) was found in pre-emergence application (Butachlor 25 kg ha^{-1}) (T_3). The differences in weed control index were due to different herbicidal effects on weeds which help to alter the physiological and morphological features of the weeds and reduce solar energy absorption and thus reduction of dry matter accumulation and ultimately causing a reduction of weed density in the crop field. The result obtained from the present study was similar to the findings of Suryakala *et al.* (2019), who reported that the weed control index (WCI) ranged from 78.66-92.32% with various herbicide combinations. Priya and Kubsad (2013) also reported higher weed control efficiency and lower weed index in herbicide treatments than weedy check owing to lower weed dry weight, higher weed control efficiency, and lower weed index due to effective control of complex weed flora. Hussain *et al.* (2008) found that Bispyribac-Sodium gave good control in dry direct seeded rice (about 91% weed control).



Notes *viz:*

NS= Non- significant	T_6= Post-emergence (Bispyribac-Sodium)
T_0= Unweeded	T_7= Pre+ Post-emergence (Vichete+Bispyribac-Sodium)
T_1= Partial Weeding	T_8= Pre+ Post-emergence (Pendamethyline+ Bispyribac-Sodium)
T_2= Weed free	T_9= Mixed Herbicide (Pretilachlor 6% + Pyrazosulfuron- ethyl 0.15%)
T_3= Pre-emergence (Butachlor)	T_{10}= Mixed Herbicide (Pretilachlor 30% + Pyrazosulfuron- ethyl 0.75%)
T_4= Pre-emergence (Pendamethyline)	T_{11}= Mixed Herbicide (Acitachlor 14% + Bensulfuron methyl 4%)
T_5= Post-emergence (Pretilachlor)	T_{12}= Late Post-emergence (2, 4-D Amine)

Figure 2. Effect of herbicide on weed control index (%) of *aus* rice at 20, 40, and 60 days after sowing. Bars represent ±SE values obtained from three biological replications.

4.8 Crop growth characters

4.8.1 Plant height

The plant height of direct-seeded *aus* rice significantly differed due to the effect of herbicides (Table 7). Experiment results showed that the maximum plant height (21.74 cm) was recorded from Pendimethalin @ 2 L ha^{-1} at 15 DAS, and the second maximum plant height (20.67 cm) was recorded from Bispyribac-Sodium @ 25 g ha^{-1} and significantly superior over remaining treatments. At 30 DAS, the maximum plant height (30.64 cm) was recorded from combination pre-emergence herbicide Butachlor 5G @ 25 kg ha^{-1} + post-emergence Bispyribac-Sodium @ 150 g $ha^{-1,}$ which was statistically similar to (30.03 cm) Bispyribac-Sodium 20 WP @ 25 g ha^{-1}. At 45 DAS, the highest plant height (50.66 cm) was recorded from the partial weeding plot, and the second highest height (49.75 cm) was recorded from Pretilachlor 30% + Pyrazosulfuron- ethyl 0.75% @ 2 kg ha^{-1}. At 60 DAS, 56.48 cm was the maximum plant height which was recorded from Pretilachlor 30% + Pyrazosulfuron- ethyl 0.75% @ 2 kg $ha^{-1,}$ and 55.59 cm was the second highest plan height, recorded from the partial weeding plot. At 75 DAS, the maximum plant height (85.56 cm) was recorded from partial weeding treatment, which was statistically similar (79.78 cm) to weed-free treatment. At 90 DAS, the maximum plant height (91.83 cm) was recorded partial weeding plot, and the second one was (88.34 cm) recorded from Bispyribac-Sodium @ 25 g ha^{-1}. At harvest, the maximum plant height (97.67 cm) was recorded from partial weeding treatment, which was statistically similar (94.33 cm) with combination of Pendimethalin @ 2 L ha^{-1} + Bispyribac-Sodium @ 25 g ha^{-1}. In contrast, the minimum plant height (18.69 cm) was recorded from Acitachlor 14%+ Bensulfuron methyl 4% WP @ 3 kg ha^{-1} at 15 DAS, which was statistically similar (18.92 cm) with Butachlor @ 25 kg ha^{-1}. At 30, 45, 60, 75, and 90 DAS, and at harvest, the weedy check plot recorded the minimum (26.55, 37.93, 44.41, 59.79, 65.53, and 65.53 cm, respectively) plant height. Plant height is an important morphological character that acts as a potential indicator of the availability of growth resources in its approach. The experiment showed that plant height showed significant variation due to the effect of different herbicide treatments. At an earlier growth stage, spraying mixed herbicide in plants produced a thin layer in the leaf surface area that hampers photosynthesis. As a result, dry matter accumulation and plant height become short for a while, comparable to no herbicide treatment or weedy check plot.

A similar result was also observed by Das *et al.* (2017), who reported that the application of herbicides did not show any phytotoxic symptoms on rice plants. Teja *et al.* (2017) also reported that the plant height of rice varied significantly among different herbicide treatments.

Table 7. Effect of herbicide on plant height of direct-seeded *aus* rice

Treatments	Plant height (cm) at						
	15 DAS	**30 DAS**	**45 DAS**	**60 DAS**	**75 DAS**	**90 DAS**	**Harvest**
T_0	20.36 ab	26.55	43.93 a-e	44.41 c	63.41 d	68.79 cd	68.79 ef
T_1	19.09 ab	29.29	50.66 a	55.59 a	85.56 a	91.83 a	97.67 a
T_2	19.11 ab	28.71	45.30 a-e	51.11 a-c	79.78 ab	87.55 ab	93.00 a-c
T_3	18.92 b	28.64	46.03 a-d	46.58 bc	59.79 d	65.53 d	65.53 f
T_4	21.75 a	29.31	46.51 a-c	53.59 ab	71.05 b-d	75.85 b-d	80.85 c-e
T_5	19.41 ab	28.45	42.19 b-e	51.96 a-c	72.79 a-d	76.15 b-d	76.15 d-f
T_6	20.67 ab	30.03	37.93 e	48.57 a-c	72.11 b-d	77.13 b-d	82.13 b-d
T_7	20.27 ab	30.64	40.82 cde	50.92 a-c	65.55 cd	76.01 b-d	81.01 c-e
T_8	20.34 ab	27.46	40.14 c-e	47.95 a-c	69.46 b-d	88.34 ab	94.33 ab
T_9	19.74 ab	27.81	42.63 b-e	45.50 bc	70.88 b-d	76.80 b-d	76.80 d-f
T_{10}	20.45 ab	26.75	49.75 ab	56.48 a	68.60 b-d	76.66 b-d	76.66 d-f
T_{11}	18.69 b	29.15	47.51 a-c	52.47 a-c	77.26 a-c	83.29 ab	83.29 b-d
T_{12}	19.95 ab	29.74	38.45 de	46.03 bc	68.47 b-d	81.30 a-c	86.30 a-d
$LSD_{(0.05)}$	2.70	NS	7.67	8.69	13.10	12.55	12.59
CV (%)	8.05	11.12	10.35	10.30	10.93	9.44	9.14

In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.05 level of probability.

Notes *viz:*

NS= Non- significant
T_0= Unweeded
T_1= Partial Weeding
T_2= Weed free
T_3= Pre-emergence (Butachlor)
T_4= Pre-emergence (Pendamethyline)
T_5= Post-emergence (Pretilachlor)
T_6= Post-emergence (Bispyribac-Sodium)
T_7= Pre+ Post-emergence (Vichete+Bispyribac-Sodium)
T_8= Pre+ Post-emergence (Pendamethyline+ Bispyribac-Sodium)
T_9= Mixed Herbicide (Pretilachlor 6% + Pyrazosulfuron- ethyl 0.15%)
T_{10}= Mixed Herbicide (Pretilachlor 30% + Pyrazosulfuron- ethyl 0.75%)
T_{11}= Mixed Herbicide (Acitachlor 14% + Bensulfuron methyl 4%)
T_{12}= Late Post-emergence (2, 4-D Amine)

4.8.2 Number of leaves

Different weed management practices significantly improved the number of leaves plant^{-1}, which might be due to the increased leaf number due to a reduced weed population in these treatments causing favorable soil moisture and nutrient availability, which helps in rapid cell development.

The number of leaves plant^{-1} of *aus* rice on various days after sowing varied significantly, depending on the different weed management treatments (Table 8). The experimental result revealed that at 15 DAS, the highest number of leaves plant^{-1} was recorded (4.47 cm) from Bispyribac-Sodium @ 25 g ha^{-1}, which was similar (4.33 cm) with Pretilachlor 6% + Pyrazosulfuron- ethyl 0.15% @ 2 kg ha$^{-1.}$ At 30 DAS, the maximum number of leaves plant^{-1} was recorded (15.40 cm) from Acitachlor 14% + Bensulfuron methyl 4% @ 3 kg ha^{-1}, which was similar (14.87 cm) with Bispyribac-Sodium @ 25 g ha^{-1}. At 45 DAS, the maximum number of leaves plant^{-1} was recorded (44.47 cm) from partial weeding treatment, similar to (34.93 cm and 30.13 cm) with weed-free treatment and Pendimethalin @ 2 L ha$^{-1,}$ respectively. At 60 DAS, the highest number of leaves plant^{-1} was recorded (48.40 cm) from weed-free treatment, which was similar (45.07 and 36.93 cm) with partial weeding treatment and the combination of pre-emergence herbicide Pendimethalin @ 2 L ha^{-1} and post-emergence Bispyribac-Sodium @ 25 g ha^{-1}, respectively. At 75 DAS, the highest number of leaves plant^{-1} (55.20 cm) was recorded from weed-free treatment, which was statistically similar (51.47 cm) with partial weeding treatment. However, the lowest number of leaves plant^{-1} was observed (3.80, 10.73, 12.73, 15.13, 20.73 cm) at 15, 30, 45, 60, and 75 DAS from the pre-emergence application (Butachlor) (T_3). .

Table 8. Effect of herbicide on number of leaves of direct seeded *aus* rice

Treatments	No. of Leaves plant^{-1} at				
	15 DAS	30 DAS	45 DAS	60 DAS	75 DAS
T_0	4.00 b-d	10.73 e	12.73 f	15.13 e	20.73 g
T_1	4.13 a-d	12.80 a-e	44.47 a	45.07 a	51.47 ab
T_2	4.20 a-d	11.53 c-e	34.93 ab	48.40 a	55.20 a
T_3	3.80 d	12.80 a-e	15.33 d-f	20.27 de	24.20 e-g
T_4	3.87 cd	12.67 a-e	30.13 bc	44.93 ab	49.60 a-c
T_5	4.13 a-d	14.07 a-d	24.00 c-e	25.33 c-e	24.80 e-g
T_6	4.47 a	14.87 ab	24.87 b-e	26.87 c-e	32.00 d-g
T_7	4.07 a-d	12.93 a-e	18.87 d-f	29.13 cd	35.47 d-f
T_8	4.20 a-d	10.87 de	25.73 b-d	36.93 a-c	38.87 b-d
T_9	4.33 ab	14.73 a-c	21.87 c-f	25.00 c-e	26.53 d-g
T_{10}	4.27 a-c	13.67 a-e	15.73 d-f	23.60 de	29.40 d-g
T_{11}	4.13 a-d	15.40 a	19.00 d-f	31.80 b-d	36.67 c-e
T_{12}	4.07 a-d	11.93 b-e	14.53 ef	19.93 de	22.27 fg
$LSD_{(0.05)}$	0.41	3.21	10.89	13.23	13.76
CV (%)	5.81	14.66	27.80	26.01	23.74

A column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.05 probability level.

Notes *viz:*

NS= Non- significant
$T_{0=}$ Unweeded
T_1= Partial Weeding
T_2= Weed free
T_3= Pre-emergence (Butachlor)
T_4= Pre-emergence (Pendamethyline)
T_5= Post-emergence (Pretilachlor)
T_6= Post-emergence (Bispyribac-Sodium)
T_7= Pre+ Post-emergence (Vichete+Bispyribac-Sodium)
T_8= Pre+ Post-emergence (Pendamethyline+ Bispyribac-Sodium)
T_9= Mixed Herbicide (Pretilachlor 6% + Pyrazosulfuron- ethyl 0.15%)
T_{10}= Mixed Herbicide (Pretilachlor 30% + Pyrazosulfuron- ethyl 0.75%)
T_{11}= Mixed Herbicide (Acitachlor 14% + Bensulfuron methyl 4%)
T_{12}= Late Post-emergence (2, 4-D Amine)

4.8.3 Number of tillers

Tiller number hill^{-1} of direct-seeded *aus* rice significantly differed due to the effect of herbicides (Table 9). Experiment results revealed that, at 15 DAS, the maximum tiller number hill^{-1} (1.25) was recorded from combined pre-emergence herbicide Butachlor @ 25 kg ha^{-1} + post-emergence Bispyribac-Sodium @ 25 g ha^{-1}. At 30 DAS, the maximum tiller number hill^{-1} (4.00) was recorded from mixed herbicide Acitachlor 14% + Bensulfuron methyl 4% @ 3 kg ha^{-1}. At 45 DAS, the highest tiller number hill^{-1} (15.60), was recorded from the partial weeding plot, which was statistically similar to the weed-free plot (12.53). At 60 DAS, the maximum tiller number hill^{-1} (10.80) was recorded from Pendimethalin @ 2 L ha^{-1}, which was statistically similar to partial weeding plot (10.20).

Table 9. Effect of herbicide on number of tillers of direct seeded *aus* rice

Treatments	Number of tillers hill^{-1} at					
	15 DAS	**30 DAS**	**45 DAS**	**60 DAS**	**75 DAS**	**90 DAS**
T_0	0.83 a-c	3.20 bc	3.73 d	4.67 c	5.10 e	4.80 e
T_1	0.42 cd	3.47 a-c	15.60 a	10.20 a	11.43 a-c	9.60 a-c
T_2	0.50 cd	3.47 a-c	12.53 a	9.47 ab	11.93 a	11.13 a
T_3	0.67 b-d	3.67 a-c	4.67 cd	5.27 c	6.27 de	5.80 de
T_4	0.67 b-d	3.87 ab	8.87 b	10.80 a	11.30 ab	10.53 ab
T_5	0.83 a-c	3.33 a-c	6.93 b-d	5.80 c	5.63 e	5.20 e
T_6	0.67 b-d	3.73 ab	7.60 bc	6.87 bc	7.33 c-e	6.87 c-e
T_7	1.25 a	3.93 ab	6.53 b-d	7.07 bc	8.17 c-e	7.60 c-e
T_8	1.08 ab	2.93 c	7.67 bc	9.07 ab	9.27 a-d	8.33 a-d
T_9	0.75 b-d	3.60 a-c	6.07 b-d	6.13 c	6.20 de	5.67 de
T_{10}	0.67 b-d	3.53 a-c	4.87 cd	5.73 c	7.87 c-e	6.93 c-e
T_{11}	0.33 d	4.00 a	5.80 b-d	7.13 bc	9.33 b-d	8.13 b-d
T_{12}	0.42 cd	3.73 ab	4.20 cd	5.07 c	5.53 e	5.00 e
$LSD_{(0.05)}$	0.44	0.77	3.59	2.67	2.67	2.84
CV (%)	37.35	12.82	29.09	22.07	19.60	22.89

A column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.05 probability level.

Notes *viz:*

NS= Non- significant
T_0= Unweeded
T_1= Partial Weeding
T_2= Weed free
T_3= Pre-emergence (Butachlor)
T_4= Pre-emergence (Pendamethyline)
T_5= Post-emergence (Pretilachlor)
T_6= Post-emergence (Bispyribac-Sodium)
T_7= Pre+ Post-emergence (Vichete+Bispyribac-Sodium)
T_8= Pre+ Post-emergence (Pendamethyline+ Bispyribac-Sodium)
T_9= Mixed Herbicide (Pretilachlor 6% + Pyrazosulfuron- ethyl 0.15%)
T_{10}= Mixed Herbicide (Pretilachlor 30% + Pyrazosulfuron- ethyl 0.75%)
T_{11}= Mixed Herbicide (Acitachlor 14% + Bensulfuron methyl 4%)
T_{12}= Late Post-emergence (2, 4-D Amine)

At 75 DAS, the highest tiller number hill^{-1} (11.93) was recorded from complete weeding treatment, which was statistically similar (11.43 and 11.30) with partial weeding treatment and Pendimethalin @ 2 L ha$^{-1,}$ respectively. At 90 DAS, the highest tiller number hill^{-1} (11.13), was recorded from weed-free treatment. In contrast, the minimum tiller number hill^{-1} (0.33) was recorded under post-emergence

2,4-D Amine @ 2.24 L ha^{-1} and mixed herbicides Acitachlor 14% + Bensulfuron methyl 4% @ 3 kg ha^{-1} with BRRI dhan98 cultivation which was statistically similar with (0.42) in the partial weeding plot at 15 DAS. At 30 DAS, the minimum tillers number $hill^{-1}$ (2.93) was recorded from pre-emergence herbicide Pendimethalin @ 2 L ha^{-1} and post-emergence Bispyribac-Sodium @ 25 g ha^{-1}. At 45, 60, 75, and 90 DAS, the minimum tiller number (3.73, 4.67, 5.10, and 4.80, respectively) was recorded from the unweeded plot. Effective herbicide reduces weed density and crop competition, thus helping plants to utilize resources properly, which improves crop growth characteristics and increases tillers number $hill^{-1}$ than weed-infested rice. Similar results were also observed by Paulraj *et al.* (2019), who reported that weed control through herbicide application positively affects tiller production in rice. Lodhi (2016) also reported that different weed control treatments caused remarkable variations in the tillers m^{-2} on different days after sowing. Weedy check plots have the minimum number of tillers m^{-2}, which increased appreciably at all the growth intervals when the plants received herbicidal treatments.

4.8.4 SPAD Value (Leaf chlorophyll content)

SPAD (Soil Plant Analysis Development) value determines the chlorophyll content in the leaf. Different herbicide treatments significantly affected the SPAD value of direct-seeded rice leaves on various days after sowing (Table 10). The experimental results revealed that, at 30 DAS, the highest value of SPAD was recorded (34.90 and 34.45) from the combination of pre-emergence herbicide Butachlor 5G @ 25 kg ha^{-1} + post-emergence Bispyribac-Sodium @ 25 g ha^{-1} and Pendimethalin @ 2 L ha^{-1} respectively, which was statistically similar with (33.50) Pretilachlor @ 1 L ha^{-1}. At 60 DAS, the highest value of SPAD was recorded (42.05 and 41.31) from Acitachlor 14% + Bensulfuron methyl 4% @ 3 kg ha^{-1} and Pretilachlor 6% + Pyrazosulfuron-ethyl 0.15% @ 2 kg ha^{-1}, respectively, which was statistically similar (39.32 and 38.92) with Pendimethalin @ 2 L ha^{-1} and Butachlor @ 25 kg ha^{-1} accordingly. At 90 DAS, the maximum value of SPAD was recorded (38.93) from Pendimethalin @ 2 L ha^{-1}, which was statistically similar (35.71 and 35.57) with Pretilachlor 6% + Pyrazosulfuron- ethyl 0.15% @ 2 kg ha^{-1} and partial weeding treatment, respectively. At the same time, the minimum value of SPAD was (31.10, 34.87, and 32.43) at 30, 60, and 90 DAS, respectively. The SPAD value obtained in the weed free plots was statistically similar to those obtained for herbicide treated plots. The results are similar to the findings of the Suria *et al*. (2011). The field was checked 7 and 14 days after each herbicide treatment to note any phytotoxicity symptoms on the herbicide-treated plants, but none were seen in any of the herbicide-treated plots. (data not shown).

Table 10. Effect of herbicide on SPAD Value of direct-seeded *aus* rice on different days after sowing

Treatments	Value of SPAD		
	30 DAS	**60 DAS**	**90 DAS**
T_0	32.83 a-c	36.49 d-g	34.43 ab
T_1	33.31 a-c	38.59 cde	35.57 ab
T_2	33.12 a-c	34.94 g	32.74 b
T_3	31.89 bc	38.92 b-d	34.11 ab
T_4	34.45 ab	39.32 bc	38.93 a
T_5	33.50 a-c	34.87 g	34.61 ab
T_6	32.34 a-c	34.39 g	32.43 b
T_7	34.90 a	37.75 c-f	32.67 b
T_8	31.10 c	35.11 fg	33.55 b
T_9	31.57 c	41.31 ab	35.71 ab
T_{10}	32.71 a-c	36.19 e-g	33.79 ab
T_{11}	31.19 c	42.05 a	33.79 ab
T_{12}	32.58 a-c	36.03 e-g	35.31 ab
$LSD_{(0.05)}$	2.81	2.7140	5.27
CV (%)	5.09	4.31	9.08

A column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.05 probability level.

Notes *viz:*
NS= Non- significant
T_0= Unweeded
T_1= Partial Weeding
T_2= Weed free
T_3= Pre-emergence (Butachlor)
T_4= Pre-emergence (Pendamethyline)
T_5= Post-emergence (Pretilachlor)
T_6= Post-emergence (Bispyribac-Sodium)
T_7= Pre+ Post-emergence (Vichete+Bispyribac-Sodium)
T_8= Pre+ Post-emergence (Pendamethyline+ Bispyribac-Sodium)
T_9= Mixed Herbicide (Pretilachlor 6% + Pyrazosulfuron- ethyl 0.15%)
T_{10}= Mixed Herbicide (Pretilachlor 30% + Pyrazosulfuron- ethyl 0.75%)
T_{11}= Mixed Herbicide (Acitachlor 14% + Bensulfuron methyl 4%)
T_{12}= Late Post-emergence (2, 4-D Amine)

4.8.5 Dry matter accumulation

The dry matter accumulation (g $plant^{-1}$) consists of all its constituents, excluding water. Different herbicides significantly affect dry matter accumulation (g $plant^{-1}$) of aus rice on different days after sowing (Table 11). Dry matter accumulation (g $plant^{-1}$) significantly varied due to the combined effect of herbicide and rice variety at different DAS. The experiment showed that in both T_3 (0.89 g) treatments, Butachlor @ 25 kg ha^{-1} and T_4 (0.89 g) treatments Pendimethalin @ 2 L ha^{-1} was recorded the maximum dry matter accumulation (2.67 g $plant^{-1}$) at 30 DAS. At 60 and 90 DAS, partial weeding treatment recorded the maximum dry matter accumulation of 5.11 and 20.78 g, respectively.

Table 11. Effect of herbicide on total dry matter accumulation in direct-seeded *aus* rice

Treatments	Weight of dry matter (g $plant^{-1}$) at		
	30 DAS	60 DAS	90 DAS
T_0	0.23 d	1.33 d	8.22 ef
T_1	0.67 a-c	5.11 a	20.78 a
T_2	0.78 ab	2.89 bc	19.67 ab
T_3	0.89 a	2.11 cd	3.78 g
T_4	0.89 a	3.11 bc	15.78 bc
T_5	0.28 cd	1.33 d	10.00 de
T_6	0.44 b-d	1.89 cd	11.33 de
T_7	0.77 ab	3.44 b	14.11 cd
T_8	0.67 a-c	2.78 bc	17.22 a-c
T_9	0.27 cd	1.33 d	5.44 fg
T_{10}	0.56 a-d	1.89 cd	7.56 e-g
T_{11}	0.40 b-d	1.44 d	8.22 ef
T_{12}	0.78 ab	3.89 ab	5.44 fg
$LSD_{(0.05)}$	0.40	1.24	4.20
CV (%)	40.78	29.26	21.97

A column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.05 probability level.

Notes *viz:*

NS= Non- significant
T_0= Unweeded
T_1= Partial Weeding
T_2= Weed free
T_3= Pre-emergence (Butachlor)
T_4= Pre-emergence (Pendamethyline)
T_5= Post-emergence (Pretilachlor)
T_6= Post-emergence (Bispyribac-Sodium)
T_7= Pre+ Post-emergence (Vichete+Bispyribac-Sodium)
T_8= Pre+ Post-emergence (Pendamethyline+ Bispyribac-Sodium)
T_9= Mixed Herbicide (Pretilachlor 6% + Pyrazosulfuron- ethyl 0.15%)
T_{10}= Mixed Herbicide (Pretilachlor 30% + Pyrazosulfuron- ethyl 0.75%)
T_{11}= Mixed Herbicide (Acitachlor 14% + Bensulfuron methyl 4%)
T_{12}= Late Post-emergence (2, 4-D Amine)

The dry matter accumulation (g $plant^{-1}$) differences over weedy check treatment were due to the application of herbicide reduced weed density which ultimately helped undisturbed plant growth by utilizing its surrounding resources. A similar result was also observed by Lodhi (2016), who reported that different weed control treatments caused remarkable variations in the quantity of dry matter accumulation on different days after sowing. Weedy check plots have the minimum quantity of dry matter production, which increased appreciably at all the growth intervals as the plots received weed control treatments.

4.9 Yield contributing characters

4.9.1 Number of effective tillers

It is observed from the data that number of effective tillers $hill^{-1}$ varied significantly under different herbicide treatments (Table 12). Among all the treatments, the minimum number of effective tillers $hill^{-1}$ (0.00) was recorded under the weedy check plot, which enhanced significantly with different herbicide applications. The maximum number of effective tillers $hill^{-1}$ (11.20) was recorded under the combination of pre-emergence herbicide Pendimethalin @ 2 L ha^{-1} and post-emergence herbicide Bispyribac-Sodium @ 25 g ha^{-1}, which was appreciably superior over all the other herbicide weed control treatments and was statistically similar with partial weeding treatment (10.93) and weed-free treatment (10.53). While along with weedy check treatment, the minimum number of effective tillers $hill^{-1}$ (0.00) was recorded with Butachlor @ 25 kg ha^{-1}, Pretilachlor @ 1 L ha^{-1}, Pretilachlor 6% + Pyrazosulfuron- ethyl 0.15% @ 2 kg ha^{-1}, Pretilachlor 30% + Pyrazosulfuron- ethyl 0.75% @ 2 kg ha^{-1} and Acitachlor 14% + Bensulfuron methyl 4% @ 3 kg ha^{-1}. Yadav *et al.* (2018) also observed a similar result, who reported that herbicide application improved the number of effective tillers m^{-2} in treated plots comparable to weedy check plots. Jabran *et al.* (2012) also reported that the herbicides' application effectively improved the yield and yield-related traits of DPR (Direct planted rice) over the control (weedy check). Singh *et al.* (2016) also found that the maximum number of effective tillers $hill^{-1}$ from the combination of pre-emergence herbicide Pendimethalin and post-emergence herbicide Bispyribac-Sodium than other herbicide applications.

4.9.2 Number of non-effective tillers

Different herbicide treatment significantly affects the number of non-effective tillers hill^{-1} of direct-seeded *aus* rice (Table 12). However, no test crop plants were found in T_0, T_5, T_9, T_{10}, and T_{11} treatments due to the heavy weed infestation (Plate 3). The experiment showed the maximum number of non-effective tillers hill^{-1} (7.47) produced by Pre+ Post-emergence (Butachlor + +Bispyribac-Sodium) treatment.

4.9.3 Length of panicle

Panicle is a vital yield contributing character as its bear grains and significantly influenced due to different herbicide treatments (Table 12). Results revealed that the maximum panicle length (20.95 cm) was recorded from the combination of Pendimethalin @ 2 L ha^{-1} $^{+}$ Bispyribac-Sodium @ 25 g ha^{-1} among all the herbicidal treatments, which was statistically similar with partial weeding treatments (21.21 cm) and weed-free treatments (20.90 cm). The results vary due to herbicide's effectiveness on weed diversity in crop fields. Mahajan *et al.* (2003) and Jabran *et al.* (2012) from their study concluded that weed management through herbicide application results in the highest panicle length comparable to weedy check (control).

4.9.4 Number of filled grains

Herbicide application significantly influenced the number of filled grains panicle^{-1} of direct-seeded *aus* rice (Table 12). The differences of filled grains panicle^{-1} among different treatments might favor the vigorous growth of seeding without crop weed competition and sustained nutrient availability. The experiment result revealed that, the highest number of filled grains panicle^{-1} was obtained (50.73) from the sequential application of pre-emergence herbicide Pendimethalin @ 2 L ha^{-1} and post-emergence Bispyribac-Sodium @ 25 g ha^{-1}, which was effective among all chemical weed control treatments; which was statistically comparable to weed free treatments(62.00) and partial weeding treatments(56.33). Teja *et al.* (2017) reported that effective and timely management of weeds through effective herbicide application facilitated the crop plants to have sufficient space, light, nutrients, and moisture, and thus the yield components like the number of filled grains panicle^{-1} increased.

4.9.5 Number of unfilled grains

Among the undesirable traits, the number of unfilled grains panicel^{-1} was important and played a vital role in yield reduction. Different herbicide applications significantly influenced the filled grains panicle^{-1} of direct-seeded *aus* rice (Table 12). The experiment result showed that among all the herbicidal treatments, the maximum number of unfilled grains panicle^{-1} was recorded (66.40) from the combination of Butachlor @ 25 kg ha^{-1} + Bispyribac-Sodium @ 25 g ha^{-1} treatments and the minimum number of unfilled grains panicle^{-1} (35.20) was obtained from the combination of Pendimethalin @ 1 L ha^{-1} and Bispyribac-Sodium @ 25 g ha^{-1}.

4.9.6 Total grains

Total grains panicle^{-1} was varied using different chemical treatments of direct-seeded *aus* rice (Table 12). The examined result showed that among different herbicide treatments, the highest number of total grains panicle^{-1} (85.93 g) was recorded from Pendimethalin @ 2 L ha^{-1} and Bispyribac-Sodium @ 25 g ha^{-1}, which was superior over all the herbicides treatment. Weed-free treatment (102.07g) and partial weeding treatment (91.80 g) were statistically comparable. Hossain (2015) also observed a similar result, who reported that herbicide-treated plots increased total grains panicle^{-1} over a weedy check or control plots.

4.9.7 1000-grain weight

It is obvious from the experiment result that the 1000-grain weight significantly varied due to different herbicide treatments (Table 12). Among all the treatments, the maximum 1000-grain weight (23.33 g) was recorded under partial weeding treatment, and thoroughly weeding treatments, and application of Butachlor @ 25 kg ha^{-1} + Bispyribac-Sodium @ 25 g ha$^{-1,}$ which was statistically similar with 2,4-D Amine @ 2.24 L ha^{-1} herbicide-treated plot. There were no grains in the weedy check plot. Jabran *et al.* (2012) also found similar results to the present study and reported that the highest 1000-grain weight of rice was observed in weed-free conditions, and the lowest 1000-grain weight was observed in weedy check.

Table 12. Effect of herbicides on yield contributing characters of *aus* rice

Treatments	No. of effective tiller	No. of non-effective tiller	Panicle length (cm)	Filled grains panicle^{-1} (Nos.)	Unfiiled grains panicle^{-1} (Nos.)	Total grains panicle^{-1}	1000-grain Wt. (g)
T_0	0.00 e	0.00 e	0.00 e	0.00 f	0.00 d	0.00 e	0.00 c
T_1	10.93 a	1.60 d	21.21 a	56.33 b	35.47 c	91.80 b	23.33 a
T_2	10.53 a	2.20 d	20.90 a	62.00 a	40.07 c	102.07 a	23.33 a
T_3	0.00 e	0.00 e	0.00 e	0.00 f	0.00 d	0.00 e	0.00 c
T_4	1.53 d	4.13 c	16.92 cd	8.87 e	60.87 a	69.73 c	20.00 b
T_5	0.00 e	0.00 e	0.00 e	0.00 f	0.00 d	0.00 e	0.00 c
T_6	2.87 c	5.40 b	15.93 d	9.00 e	49.87 b	58.87 d	20.00 b
T_7	6.20 b	7.47 a	17.87 bc	18.33 d	66.40 a	84.73 b	23.33 a
T_8	11.20 a	4.47 c	20.95 a	50.73 c	35.20 c	85.93 b	20.00 b
T_9	0.00 e	0.00 e	0.00 e	0.00 f	0.00 d	0.00 e	0.00 c
T_{10}	0.00 e	0.00 e	0.00 e	0.00 f	0.00 d	0.00 e	0.00 c
T_{11}	0.00 e	0.00 e	0.00 e	0.00 f	0.00 d	0.00 e	0.00 c
T_{12}	2.93 c	4.63 bc	18.14 b	9.40 e	50.73 b	60.13 d	21.67 ab
$LSD_{(0.05)}$	1.00	0.92	1.20	3.81	7.57	8.79	2.61
CV (%)	16.70	23.85	7.01	13.71	17.24	12.26	13.29

In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.05 level of probability.

Notes *viz:*

NS= Non- significant
T_0= Unweeded
T_1= Partial Weeding
T_2= Weed free
T_3= Pre-emergence (Butachlor)
T_4= Pre-emergence (Pendamethyline)
T_5= Post-emergence (Pretilachlor)
T_6= Post-emergence (Bispyribac-Sodium)
T_7= Pre+ Post-emergence (Vichete+Bispyribac-Sodium)
T_8= Pre+ Post-emergence (Pendamethyline+ Bispyribac-Sodium)
T_9= Mixed Herbicide (Pretilachlor 6% + Pyrazosulfuron- ethyl 0.15%)
T_{10}= Mixed Herbicide (Pretilachlor 30% + Pyrazosulfuron- ethyl 0.75%)
T_{11}= Mixed Herbicide (Acitachlor 14% + Bensulfuron methyl 4%)
T_{12}= Late Post-emergence (2, 4-D Amine)

4.10 Yield

4.10.1 Grain yield

The grain yield of rice was significantly influenced due to different herbicide applications in direct-seeded *aus* rice (Table 13). It is clear from the result that different herbicide treatments caused marked variations in the grain yield of rice. Although the maximum grain yield (3.93 t ha^{-1}) was obtained from weed-free treatment, the sequential application of pre-emergence herbicide Pendimethalin @ 2 L ha^{-1} and post-emergence herbicide Bispyribac-Sodium @ 25 g ha^{-1} herbicide treated plot gave the highest (20.96 t ha^{-1}) grain yield among all the chemical treatments. This variation might be related to variations in weed dominance and efficacy of herbicides relative to soil moisture regimes (Juraimi *et al.*, 2009). Singh *et al.* (2016) reported that the sequential application of pre-and-post-emergence treatments gave a yield similar to weed-free control plots in an aerobic rice system. Higher rice grain yield with POST application of Bispyribac-Sodium was also reported by Khaliq and Matloob (2012). A similar result was observed by Suryakala *et al.* (2019), who reported that grain yield production was lower in unweeded, respectively indicating the importance of weed management in the critical growth period of the crop by herbicide application, which facilitated the efficient use of resources.

4.10.2 Straw yield

After removing grains from the panicle, the rest part was considered as straw. It is evident from the data that weed control through different herbicide treatments caused significant variation in the straw yield of rice (Table 13). The maximum straw yield (4.25 t ha^{-1}) was recorded from the partial weeding treatment, which was statistically similar to weed-free (4.11 t ha^{-1}) and pre-emergence herbicide Pendimethalin @ 2 L ha^{-1} and post-emergence herbicide Bispyribac-Sodium @ 25 g ha^{-1} herbicide treated plot (4.02 t ha^{-1}). Hossain (2015) also found similar result which supported the present finding and reported that the straw yield of rice differ, due to application of different herbicides comparable to weedy check.

4.10.3 Biological yield

Weed control through different herbicide treatments caused a significantly varied biological yield of rice (Table 13). The maximum biological yield (8.04 t ha^{-1}) was obtained from the weed-free treatment, which was statistically similar to partial weeding (7.99). However, among herbicidal treatments, the maximum (6.98 t ha^{-1}) biological yield was obtained from the sequential application of pre-emergence herbicide Pendimethalin @ 2 L ha^{-1} and post-emergence herbicide Bispyribac-Sodium @ 25 g ha^{-1}. The result obtained from the present study was similar to the findings of Hasanuzzaman *et al.* (2008), who observed that the biological yield was influenced by the effectiveness of the herbicidal treatments.

Table 13. Effect of herbicide on grain, straw, and biological yield and harvest index of *aus* rice

Treatments	Grain yield ($t\ ha^{-1}$)	Straw yield ($t\ ha^{-1}$)	Biological yield ($t\ ha^{-1}$)	Harvest index (%)
T_0	0.00 f	0.00 d	0.00 e	0.00 e
T_1	3.73 b	4.25 a	7.99 a	46.75 a
T_2	3.93 a	4.11 a	8.04 a	48.92 a
T_3	0.00 f	0.00 d	0.00 e	0.00 e
T_4	0.08 ef	0.59 c	0.66 d	15.54 d
T_5	0.00 f	0.00 d	0.00 e	0.00 e
T_6	0.12 ef	0.58 c	0.70 d	17.61 cd
T_7	0.71 d	1.17 b	1.88 c	38.07 b
T_8	2.96 c	4.02 a	6.98 b	42.36 ab
T_9	0.00 f	0.00 d	0.00 e	0.00 e
T_{10}	0.00 f	0.00 d	0.00 e	0.00 e
T_{11}	0.00 f	0.00 d	0.00 e	0.00 e
T_{12}	0.17 e	0.52 c	0.69 d	24.22 c
$LSD_{(0.05)}$	0.15	0.32	0.38	6.82
CV (%)	9.97	16.32	10.89	22.54

In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.05 level of probability.

Notes *viz:*

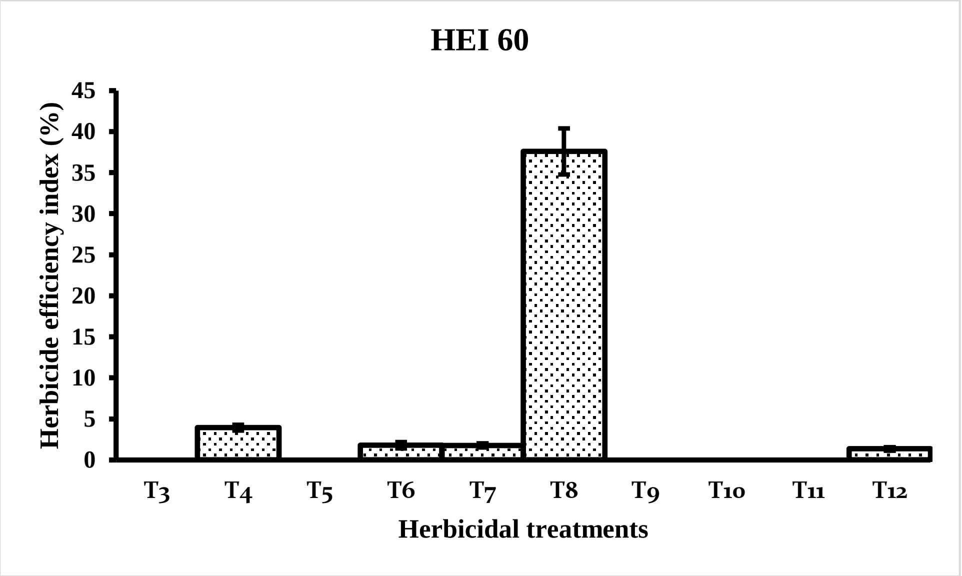
NS= Non- significant
T_0= Unweeded
T_1= Partial Weeding
T_2= Weed free
T_3= Pre-emergence (Butachlor)
T_4= Pre-emergence (Pendamethyline)
T_5= Post-emergence (Pretilachlor)
T_6= Post-emergence (Bispyribac-Sodium)
T_7= Pre+ Post-emergence (Vichete+Bispyribac-Sodium)
T_8= Pre+ Post-emergence (Pendamethyline+ Bispyribac-Sodium)
T_9= Mixed Herbicide (Pretilachlor 6% + Pyrazosulfuron- ethyl 0.15%)
T_{10}= Mixed Herbicide (Pretilachlor 30% + Pyrazosulfuron- ethyl 0.75%)
T_{11}= Mixed Herbicide (Acitachlor 14% + Bensulfuron methyl 4%)
T_{12}= Late Post-emergence (2, 4-D Amine)

4.10.4 Harvest index (%)

Harvest index was influenced by using different herbicidal treatments significantly of direct-seeded *aus* rice (Table 13). Computed data showed that the maximum harvest index (48.92%) was obtained from the weed-free treatment, which was statistically similar to partial weeding (46.72%). However, among herbicidal treatments, the maximum (42.36 t ha^{-1}) harvest index was obtained from the sequential application of pre-emergence herbicide Pendimethalin @ 2 L ha^{-1} and post-emergence herbicide Bispyribac-Sodium @ 25 g ha^{-1}. The variation of harvest index which was due to reason that the effective weed control in weed-free, partial weeding, and the sequential application of pre-emergence herbicide Pendimethalin @ 2 L ha^{-1} and post-emergence herbicide Bispyribac-Sodium @ 25 g ha^{-1} increased number of productive tillers, crop dry matter, and the plants produced longer panicles which ultimately improve grain yield buy reducing the crop weed competition as compared to weedy check. Hossain (2015) also found similar results which supported the present finding.

4.11 Herbicide efficiency index (%)

The data on herbicide efficiency index at 60 DAS are furnished in Fig. 3. Among the treatments, a maximum herbicide efficiency index of 37.58(%) was observed under the sequential application of pre-emergence herbicide Pendimethalin @ 2 L ha^{-1} and post-emergence herbicide Bispyribac-Sodium @ 25 g ha^{-1}. This was followed by pre-emergence (Pendamethyline @ 2 L ha^{-1}). The lowest herbicide efficiency index was observed from T_3, T_5, T_9, T_{10}, and T_{11} treatments. A higher herbicide efficiency index value indicated the treatment's superiority in higher weed suppression magnitude. These results corroborate the findings of Sarita *et al*. (2022). The lower herbicide efficiency index was also registered under butachlor 1.25 kg ha^{-1} by Prasath *et al.* (2022). .



Notes *viz:* T_3= Pre-emergence (Butachlor), T_4= Pre-emergence (Pendamethyline), T_5= Post-emergence (Pretilachlor), T_6= Post-emergence (Bispyribac-Sodium), T_7= Pre+ Post-emergence (Vichete+Bispyribac-Sodium), T_8= Pre+ Post-emergence (Pendamethyline+ Bispyribac-Sodium), T_9= Mixed Herbicide (Pretilachlor 6% + Pyrazosulfuron- ethyl 0.15%), T_{10}= Mixed Herbicide (Pretilachlor 30% + Pyrazosulfuron- ethyl 0.75%), T_{11}= Mixed Herbicide (Acitachlor 14% + Bensulfuron methyl 4%), T_{12}= Late Post-emergence (2, 4-D Amine)

Figure 3. Effect of weed management treatments on herbicide efficiency index of direct seeded *aus* rice. Bars represent ±SE values obtained from three biological replications.

4.12 Economic viability of different treatments

The economic performance of different treatments combination were determined per hectare area basis, including total cost of production, gross returns, net returns, and benefit-cost ratio (profit over per taka investment) under treatments imposed**.**

4.12.1 Total cost of production

Cost of production varied due to different weed management applied to direct-seeded *aus* rice cultivation (Table 14). The cost of production varied mainly for hand weeding, weed-free condition, and herbicide application. In the case of weedy check, there was no involvement of cost for weed management. In this experiment, the highest total cost of production was required in weed-free treatment and the lowest in weed check control treatment.

4.12.2 Gross return

Different herbicide treatments influenced gross return (Table 14). The highest gross return (102,360 and 97,500 Tk. respectively) was recorded under weed-free treatment and partial weeding treatment, followed by (78,020 Tk.) with Pendimethalin @ 2 L ha^{-1} + Bispyribac-Sodium @ 25 g ha^{-1}.

4.12.3 Net returns

Different herbicide treatments varied net return (Table 14). The highest net return (26108 Tk.) was recorded from partial weeding treatment, followed by sequential application of Pendimethalin @ 2 L ha^{-1} + Bispyribac-Sodium @ 25 g ha^{-1} (186423 Tk.).

4.12.4 Benefit-cost ratio

The benefit-cost ratio varied in different weed management treatments (Table 14). The highest benefit-cost ratio (1.37) was recorded in the partial weeding treatment, followed by sequential application of pre-emergence herbicide Pendimethalin @ 2 L ha^{-1} and post-emergence herbicide Bispyribac-Sodium @ 25 g ha^{-1} (1.31). While there is no benefit-cost ratio (0.00) obtained from T_{0}, T_{3}, T_{5}, T_{9}, T_{10}, and T_{11} treatments. This result confirmed that manual weeding is costly and uneconomical than herbicide application in the weed control of aerobic rice. Higher rice grain yield and economic returns with sequential application of pendimethalin PRE fb Bispyribac-Sodium POST was reported earlier by Singh *et al.* (2016). A number of reports supported this study and concluded that herbicide application could give a significantly higher net benefit than manual weeding in rice (Islam *et al*., 2000; Hussain *et al*., 2008; Suria *et al*., 2011).

Table 14. Cost of production, net return, and benefit-cost of ratio (BCR) of direct-seeded *aus* rice

Treatment	Total Cost for Weed Management	Total Cost of Production	Gross Return (Tk.)	Net Return (Tk.)	BCR
T_0	0	53592.13	0.00	-53592.1	0.00
T_1	16,000	71392.13	97,500	26107.87	1.37
T_2	32,000	89192.13	1,02,360	13167.87	1.15
T_3	2,000	55817.13	0.00	-55817.1	0.00
T_4	2,000	55817.13	2,590	-53227.1	0.05
T_5	3,200	57152.13	0.00	-57152.1	0.00
T_6	3,200	57152.13	3,580	-53572.1	0.06
T_7	5,200	59377.13	18,920	-40457.1	0.32
T_8	5,200	59377.13	78,020	18642.87	1.31
T_9	3,000	56929.63	0.00	-56929.6	0.00
T_{10}	3,000	56929.63	0.00	-56929.6	0.00
T_{11}	3,000	56929.63	0.00	-56929.6	0.00
T_{12}	3,200	57152.13	4,770	-52382.1	0.08

In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.05 level of probability.

Notes *viz:*

NS= Non- significant
$T_{0=}$ Unweeded
T_1= Partial Weeding
T_2= Weed free
T_3= Pre-emergence (Butachlor)
T_4= Pre-emergence (Pendamethyline)
T_5= Post-emergence (Pretilachlor)
T_6= Post-emergence (Bispyribac-Sodium)
T_7= Pre+ Post-emergence (Vichete+Bispyribac-Sodium)
T_8= Pre+ Post-emergence (Pendamethyline+ Bispyribac-Sodium)
T_9= Mixed Herbicide (Pretilachlor 6% + Pyrazosulfuron- ethyl 0.15%)
T_{10}= Mixed Herbicide (Pretilachlor 30% + Pyrazosulfuron- ethyl 0.75%)
T_{11}= Mixed Herbicide (Acitachlor 14% + Bensulfuron methyl 4%)
T_{12}= Late Post-emergence (2, 4-D Amine)

CHAPTER V

SUMMARY AND CONCLUSION

The present work was carried out at the Agronomy field of Sher-e-Bangla Agricultural University, Dhaka, Bangladesh, from March to July, 2022 to investigate the influence of herbicides on growth, yield and controlling weeds in direct-seeded *aus* rice. The experimental field belongs to the Agro-ecological zone (AEZ) of "The Modhupur Tract", AEZ-28. The soil of the experimental field belongs to the General soil type, Deep Red Brown Terrace Soils, under Tejgaon soil series. The experiment consisted of 13 treatments viz., T_0 = Unweeded, T_1 = Partial Weeding, T_2 = Weed Free, T_3 = Pre-emergence herbicide (Butachlor), T_4 = Pre-emergence herbicide (Pendamethyline), T_5 = Post-emergence herbicide (Pretilachlor), T_6 = Post-emergence herbicide (Bispyribac-Sodium), T_7 = Pre+ Post-emergence herbicide (Butachlor +Bispyribac-Sodium), T_8 = Pre+ Post-emergence herbicide (Pendamethyline+ Bispyribac-Sodium), T_9 = Mixed Herbicide (Pretilachlor 6% + Pyrazosulfuron- ethyl 0.15%), T_{10} = Mixed Herbicide (Pretilachlor 30% + Pyrazosulfuron- ethyl 0.75%), T_{11} = Mixed Herbicide (Acitachlor 14% + Bensulfuron methyl 4%), T_{12} =Late Post-emergence (2, 4-D Amine), which were applied according to the recommended doses for rice. The test rice variety was BRRIdhan 98. The total numbers of unit plots were 39. The unit plot size was 4.5 m^2 (3 m × 1.5 m). The experiment was laid out in a randomized complete block design having three replications. Seeds are sown directly on 29 March 2022. Pre-emergence herbicides were applied one day after sowing, mixed herbicides three days after sowing, and post-emergence herbicides were applied 15 and 20 days after sowing.

The data on weed parameters were collected at 20, 40, and 60 DAS. Weed parameters such as total weed population in weedy check plot (no. m^{-2}), relative weed density (RWD %), weed density (no. m^{-2}), weed biomass (g m^{-2}), weed control efficiency (%) and weed control index were examined at different intervals. The data on growth characters *viz*. plant height, total tillers $hill^{-1}$, total number of leaves $plant^{-1}$, and total dry matter accumulation $plant^{-1}$ were recorded at different intervals. At harvest yield and yield contributing characters like effective tillers $hill^{-1}$, non-effective tillers $hill^{-1}$, total grains $panicle^{-1}$, filled grains $panicle^{-1}$, unfilled grains $panile^{-1}$, 1000-grain weight, grain yield, straw yield, biological yield and harvest index were recorded.

Finally herbicide efficiency index was calculated. The total cost of production, gross return, and net return were calculated to determine the benefit-cost ratio for determining the economic viability of different herbicide treatments to control weeds on direct-seeded *aus* rice.

Seventeen weed species infested the experimental plots belonging to 10 families, where the most dominating were broadleaf and grass weed species. Among the weeds, *Digitaria ischaemum* was the most dominant weed at 20, 40, and 60 DAS, followed by *Physalis heterophylla and Digitaria sanguinalis* weed species at 20, 40, and 60 DAS. At the same time, the dominancy of *Cyperus strigosus* and *Lindernia procumbens* were the least among all the weed species. Pendimethalin-applied plots had lesser weed density, particularly grasses, compared with butachlor also reported that the density of *Echinochloa colona* was reduced to a great extent with PRE application of butachlor and pendimethalin. However, with sequential application of Pendimethalin PRE fb Bispyribac-Sodium in POST, grassy and broadleaved weed density reduced significantly. This was due to the sequential application of Pendimethalin (2 L ha^{-1}) and Bispyribac-Sodium (25 g ha^{-1}) herbicide treated plots recorded minimum (0.0, 2.33, and 4.00 at 20, 40, and 60 DAS, respectively) weed density m^{-2}. Also, the minimum weed dry weight was recorded (0.00, 0.57, and 1.25 g) at 20, 40, and 60 DAS, respectively, from the same treatment. Therefore, experiment results revealed that higher weed control efficiency was observed in T_8 (Pendimethalin @ 2 L ha^{-1} + Bispyribac-Sodium @ 25 g ha^{-1}), comparable to other treatments, and it was (100, 88.46, and 80.66 %) at 20, 40, and 60 DAS among all herbicidal treatments. At 40 and 60 DAS, also the highest weed control index was noticed in T_8 (97.31 and 99.16%, respectively) from Pendimethalin @ 2 L ha^{-1} + Bispyribac-Sodium @ 25 g ha^{-1}.

Different herbicide treatments significantly affect weeds and influence crop growth, yield, and yield-contributing characteristics. At harvest, the maximum plant height (97.67 cm) was recorded from partial weeding treatment, which was statistically similar (94.33 cm) with combination of Pendimethalin @ 2 L ha^{-1} + Bispyribac-Sodium @ 25 g ha^{-1}. The highest number of leaves $plant^{-1}$ (55.20 cm) was recorded from weed-free treatment, which was statistically similar (51.47 cm) with partial weeding treatment. However, the lowest number of leaves $plant^{-1}$ was observed (3.80, 10.73, 12.73, 15.13, 20.73 cm) at 15, 30, 45, 60, and 75 DAS from the pre-emergence application (Butachlor 25 kg ha^{-1}) (T_3). At 90 DAS, the highest tiller number $hill^{-1}$ (11.13), was recorded from weed-free treatment. In contrast, At 45, 60, 75, and 90 DAS, the minimum tiller number (3.73, 4.67, 5.10, and 4.80, respectively) was recorded from the unweeded plot. At 90 DAS, the maximum value of SPAD was recorded (38.93) from Pendimethalin @ 2 L ha^{-1}, which was statistically similar (35.71 and 35.57) with Pretilachlor 6% + Pyrazosulfuron-ethyl 0.15% @ 2 kg ha^{-1} and partial weeding treatment, respectively. At the same time, the minimum value of SPAD was (31.10, 34.87, and 32.43) at 30, 60, and 90 DAS, respectively. The experiment showed that in both T_3 (0.89 g) treatments, Butachlor @ 25 kg ha^{-1} and T_4 (0.89 g) treatments Pendimethalin @ 2 L ha^{-1} was recorded the maximum dry matter accumulation (2.67 g $plant^{-1}$) at 30 DAS. At 60 and 90 DAS, partial weeding treatment recorded the maximum dry matter accumulation of 5.11 and 20.78 g, respectively.

Among all the treatments, the minimum number of effective tillers $hill^{-1}$ (0.00) was recorded under the weedy check plot, which enhanced significantly with different herbicide applications. The maximum number of effective tillers $hill^{-1}$ (11.20) was recorded under the combination of pre-emergence herbicide Pendimethalin @ 2 L ha^{-1} and post-emergence herbicide Bispyribac-Sodium @ 25 g ha^{-1}, which was appreciably superior over all the other herbicide weed control treatments and was statistically similar with partial weeding treatment (10.93) and weed-free treatment (10.53). However, no test crop plants were found in T_0, T_5, T_9, T_{10}, and T_{11} treatments due to the heavy weed infestation. The experiment showed the maximum number of non-effective tillers $hill^{-1}$ (7.47) produced by Pre+ Post-emergence (Butachlor + +Bispyribac-Sodium) treatment. Results revealed that the maximum panicle length (20.95 cm) was recorded from the combination of Pendimethalin @ 2 L $ha^{-1\ +}$ Bispyribac-Sodium @ 25 g ha^{-1} among all the herbicidal treatments, which was statistically similar with partial weeding treatments (21.21 cm) and weed-free treatments (20.90 cm). The highest number of filled grains $panicle^{-1}$ was obtained (50.73) from the sequential application of pre-emergence herbicide Pendimethalin @ 2 L ha^{-1} and post-emergence Bispyribac-Sodium @ 25 g ha^{-1}, which was effective among all chemical weed control treatments; which was statistically comparable to weed free treatments(62.00) and partial weeding treatments(56.33). The maximum number of unfilled grains panicle^{-1} (66.40), and the minimum number of unfilled grains panicle^{-1}(35.20), and the highest number of total grains panicle^{-1} (85.93 g) was recorded from Pendimethalin @ 2 Lha^{-1} and Bispyribac Sodium @ 25 g ha^{-1}, which was superior over all the herbicides treatments. Weed-free treatment (102.07g) and partial weeding treatment (91.80 g) were statistically comparable. Among all the treatments, the maximum 1000-grain weight (23.33 g) was recorded under partial weeding treatment, thoroughly weeding treatments, and application of Butachlor @ 25 kg ha^{-1} + Bispyribac-Sodium @ 25 g ha$^{-1,}$ which was statistically similar with 2,4-D Amine @ 2.24 L ha^{-1} herbicide-treated plot.

Although the maximum grain yield (3.93 t ha^{-1}) was obtained from weed-free treatment, the sequential application of pre-emergence herbicide Pendimethalin @ 2 L ha^{-1} and post-emergence herbicide Bispyribac-Sodium @ 25 g ha^{-1} herbicide treated plot gave the highest (20.96 t ha^{-1}) grain yield among all the chemical treatments. The maximum straw yield (4.25 t ha^{-1}) was recorded from the partial weeding treatment, which was statistically similar to weed-free (4.11 t ha^{-1}) and pre-emergence herbicide Pendimethalin @ 2 L ha^{-1} and post-emergence herbicide Bispyribac-Sodium @ 25 g ha^{-1} herbicide treated plot (4.02 t ha^{-1}). The maximum biological yield (8.04 t ha^{-1}) was obtained from the weed-free treatment, which was statistically similar to partial weeding (7.99). However, among herbicidal treatments, the maximum (6.98 t ha^{-1}) biological yield was obtained from the combination of pre-emergence herbicide Pendimethalin @ 2 L ha^{-1} and post-emergence herbicide Bispyribac-Sodium @ 25 g ha^{-1}. Computed data showed that the maximum harvest index (48.92%) was obtained from the weed-free treatment, which was statistically similar to partial weeding (46.72%). However, among herbicidal treatments, the maximum (42.36 t ha^{-1}) harvest index was obtained from the sequential application of pre-emergence herbicide Pendimethalin @ 2 L ha^{-1} and post-emergence herbicide Bispyribac-Sodium @ 25 g ha^{-1}.

Among the treatments, a maximum herbicide efficiency index of 37.58(%) was observed under the sequential application of pre-emergence herbicide Pendimethalin @ 2 L ha^{-1} and post-emergence herbicide Bispyribac-Sodium @ 25 g ha^{-1}. This was followed by pre-emergence (Pendamethyline @ 2 L ha^{-1}). The lowest herbicide efficiency index was observed from T_3, T_5, T_9, T_{10}, and T_{11} treatments.

Finally, although the highest benefit-cost ratio (1.37) was recorded in the partial weeding treatment, the sequential application of pre-emergence herbicide Pendimethalin @ 2 L ha^{-1} and post-emergence herbicide Bispyribac-Sodium @ 25 g ha^{-1} gave the second maximum return (1.31).

Hand weeding is time consuming, expensive, and tedious though much effective. Under the present situation of unavailability of labourers and high wages, manual weed control is not possible. Hence, chemical weed control appears to hold a great promise in dealing with effective, timely, and economical weed suppression. Weed control efficiency cannot be considered as the only criterion to determine the suitability of an herbicide rather cost-effectiveness should also be taken into consideration while making any decision. Generally, the growers prefer an effective herbicide with acceptable cost. The efficacy of herbicides tested in this study was evaluated in terms of weed control efficiency (%), weed control index (%), and herbicide efficiency index (%). Based on the weed control index and herbicide efficiency index values and the net benefit from economic analysis, it appeared that the sequential application of pre-emergence herbicide Pendimethalin @ 2 L ha^{-1} and post-emergence herbicide Bispyribac-Sodium @ 25 g ha^{-1} could be the possible alternative options for effective and economic weed control as well as avoiding the risk of developing resistant weed biotypes in rice under the aerobic system. Manual weeding is not at all cost-effective, and therefore, weed management by applying the aforementioned herbicide combinations in rotation may be practiced to run the aerobic rice system as a profitable business venture. Besides, returns over variable costs will be a driving force for farmers in adopting DSR and achieving better weed control in the future. Therefore, the present study's emphasis on economics and evaluating herbicide options will give the growers and extension agents more information for sustainable direct-seeded *aus* rice production. However, the yield of the aerobic rice variety used in the trial was very low, and therefore, varietal improvement is also necessary for sustaining rice production in aerobic soil conditions. Moreover, further investigations on the different doses of the sequential application of pre-emergence herbicide Pendimethalin and post-emergence herbicide Bispyribac-Sodium for the other soil types under different AEZ in Bangladesh are necessary.

REFERENCES

Abbas, T., Zahir, Z.A., Naveed, M. and Kremer, R.J, (2018). Limitations of existing weed control practices necessitate development of alternative techniques based on biological approaches. *Adv. Agron*.**147**: 239-280.

Ahmed, S., Salim, M. and Chauhan, B.S. (2014). Effect of weed management and seed rate on crop growth under direct dry seeded rice systems in Bangladesh. *PLoS One*. **9**(7): *e*101919.

APCAS (Asia and pacific commission on agricultural statistics). (2016). Agriculture Market Information System (AMIS) in Bangladesh. *In*: Twenty-sixth session on Asia and Pacific Commission Agriculture Statistics. 15-19 February, Thimpu, Bhutan. pp. 15–19.

Bari, M.N., Mamun, A.A. and Anwar, S.M.S. (1995). Weed infestation in transplant Aman rice as affected by land topography and time of transplanting. *Bangladesh J. Agril. Sci*. **22**(2): 227-235.

Barla, S. and Upasani, R.R. (2018). Effect of upland rice varieties on relative composition of weeds in Jharkhand.Int. J. Biores. Stress Manag. **9**(2):214-219.

BBS (Bangladesh Bureau of Statistics). (2021). Statistical Monthly Bulletin of Bangladesh, Bureau of Statistics, Statistics Division, Ministry of Planning, Government of People's Republic. Bangladesh, Dhaka. pp. 140–144.

Bhuiyan, M.K.A. and Mahbub, M.M. (2020). Performance of Bensulfuron Methyl 1.1% + Metsulfuron Methyl 0.2%+ Acetochlor 14% WP against wide range of weed control in transplanted rice of Bangladesh. *American-Eurasian J. Agric. Environ. Sci.* **20**(5): 358-366.

BRRI (Bangladesh Rice Research Institute). (2008). Annual Report for 2007. Bangladesh Rice Research Institute, Joydevpur, Bangladesh. pp. 28–35.

Budhar, M.N. and Tamilselven, N. (2002). Effect of stand establishment techniques on yield and economical low land irrigated rice. *Indian J. Agron.* **47**(1): 57-60.

Chauhan, B.S. and Johnson, D.E. (2010). The role of seed ecology in improving weed management strategies in the tropics. *Adv. Agron.* **105**: 221–262.

Chauhan, B.S. and Johnson, D.E. (2011). Row spacing and weed control timing affect yield of aerobic rice. *Field Crops Res*. **121**(2): 226–231.

Chowdhury, I.F. (2012). Influence of weed control methods on the growth and yield of aromatic aman rice varieties. M.S. Thesis, Sher-e-Bangla Agricultural University, Dhaka, Bangladesh.

Daniel, P.S.J., Poonguzhalan, R., Mohan, R. and Suburayalu, E. (2012). Weed management for enhanced production of aerobic rice. *Indian J. Weed Sci*. **22**(4): 270-273.

Das, T., Banerjee, M., Malik, G.C. and Mandal, B. (2017). Efficacy of herbicides against weeds in transplanted wet season rice (*Oryza Sativa* L.). *J. Agric. Vet. Sci.* **10**(5): 1-3.

Edris, K.M.,Islam, A.M.T., Chowdhury, M.S. and Haque, A.K.M.M. (1979).Detailed Soil Survey of Bangladesh, Dept. Soil Survey, BAU and Govt. Peoples Republic of Bangladesh. p. 118

Hasan, M.N., Sarker, U.K. Uddin, M.R. Hasan, A.K. and Kaysar, M.S. (2016). Comparison of weed control methods on infestation and crop productivity in transplant aman rice. *Prog. Agric.* **27**(4): 418-427.

Hasanuzzaman, M., Islam, O. and Bapari, S. (2008). Efficacy of different herbicides over manual weeding in controlling weeds in transplanted rice. *Australian J. Crop Sci*. **2**(1): 18–24.

Hossain, A. and Mondal, D.C. (2014). Weed management by herbicide combinations in transplanted rice. *Indian J. Weed Sci.* **46**(3): 220–23.

Hossain, M.H. (2015). Efficacy and residual activity of herbicide on growth and yield of transplanted aus rice. M. S. Thesis, Department of Agronomy, Sher-e-Bangla Agricultural University, Dhaka−1207, Bangladesh.

Hossain, M.H. (2015). Efficacy and residual activity of herbicide on growth and yield of transplanted aus rice.M. S. Thesis, Department of Agronomy, Sher-e-Bangla Agricultural University, Dhaka−1207, Bangladesh.

Hossain, M.M., Begum, M. Rahman, M.M. and Akanda, M.M. (2016). Weed management on direct-seeded rice system - a review. *Prog. Agric*. **27**: 1-8.

Hussain, S, Ramzan, M, Akhter, M. and Aslam, M. (2008). Weed management in direct seeded rice. *J. Anim. Plant Sci.* **18**(2-3): 86-88.

Iqbal, S., Iram, A. and Akhter, M. (2017). Effective weed management in dry direct seeded rice for sustainable productivity. *Appl. Sci. Bus. Econ*. **4**(1): 1-8.

Islam, T., Bhowmic, M.K., Ghosh, R.K. and Sounda, G. (2000). Effect of pretilachlor on weed control and yield of transplanted rice. *Environ. Ecol.* **19**(2): 265-268.

Jabran, K., Ehsanullah, Hussain, M., Farooq, M., Babar, M., Doğan, M. and Lee, D. (2012). Application of bispyribac-sodium provides effective weed control in direct-planted rice on a sandy loam soil. *Weed Bio. Manag*. **12**(3): 136-145.

Juraimi, A.S., Najib, M.M.Y., Begum, M., Anuar, A.R., Azmi, M. and Puteh, A. (2009). Critical period of weed competition in direct seeded rice under saturated and flooded conditions. *Pertanika J. Trop. Agric. Sci*. **32**(2): 305-316.

Khaliq, A. and Matloob, A. (2012). Germination and growth response of rice and weeds to herbicides under aerobic conditions. *Int. J. Agric. Biol.* **14**: 775-780.

Kumar, R.S., Durairaj, S.N., Daisy, M. and Archana, H.A. (2014). Studies on weed management practices in transplanted rice. *Trend. Bio.* **7**(23): 3882-3885.

Kumar, V. and Ladha, J.K. (2011). Direct-seeding of rice: Recent developments and future research needs. *Advances in Agron*. **111**: 297-413.

Lodhi, R. (2016). Efficacy of Bensulfuron methyl + Pretilachlor against weeds in transplanted Rice. M. S. Thesis, Department of Agronomy,Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur.

MacLaren, C., Storkey, J. and Menegat, A. (2020). An ecological future for weed science to sustain crop production and the environment. A review. *Agron. Sustain. Dev*. **40**: 24.

Mahajan, G., Boparai, B.S., Bra, L.S. and Sardana, V. (2003). Effect of pretilachlor on weeds in direct seeded puddled rice. *Indian J. Weed Sci.* **35**(1-2):128-130.

Mahajan, G., Chauhan, B.S. and Johnson, D.E. (2009). Weed management in aerobic rice in north western Indo-Gangetic Plains. *J. Crop Improv.* 23: 366-382.

Mani, V.S., Malla, M.L., Gautham, K.C., and Bhagwndas. (1973). Weed killing chemicals in potato cultivation. *Indian Farming.* **22**: 17-18.

Maniruzzaman, M., Alam, M.R., Islam, M.S., Islam, M.Z., Molla, M.S.H. and Islam, M.A. (2018). Effect of fertilizer packages on broadcast aus rice in lentil- B. aus-blackgram cropping pattern in the char land of Pabna in Bangladesh. *Bangladesh Agron. J.* **21**(1): 83-88.

Manisankar, Ramesh, G.T., Rathika, S., Janaki, P. and Balasubramanian, P. (2019). Evaluation of sequential herbicide application on transplanted rice under sodic soil. *Pharma Inn. J.* **8**(5): 633-638.

Mian, A.L. and Bhuiya, M. S.U. (1977). Cost, output and return in crop production. Bangladesh J. Agron. **1**(1-2): 8.

Mishra, A. and Tosh, G.C. (1979). Chemical weed control studies on dwarf wheat. *J. Res. Ouatt.* **10**: 1-6.

Mishra, K. (2019). Effect of herbicide bensulfuron methyl plus pretilachlor in weed management of transplanted kharif rice (*Oryza sativa* L.). *J. Pharma. Phytochem*. **8**(5): 378-382.

Mojid, M.A., Parvez, M.F., Mainuddin, M. and Hodgson, G. (2019). Water table trend— a sustainability status of groundwater development in north-west Bangladesh. *Water*. **11**: 1182.

Moody, K. (1991). Weed control in upland rice with emphasis on grassy weeds. *In*: F.W.G., Terry, P.J. (Eds.), Tropical Grass Weeds Baker. CAB Intl., Wallingford, UK. pp. 164-178.

Paulraj, S, Murugan, G., Stalin, P., Saravanaperumal, M. and Suseendran, K. (2019). Effect of pre and post emergence herbicides on weed flora and yield of transplanted rice. *Plant Arc*. **19**(2): 3093-3096.

Priya, H.R. and Kubsad, V.S. (2013). Integrated weed management in rainy season sorghum (*Sorghum bicolour*). *Indian J. Agron*. **58**(4): 548-553.

Rajkhowa, D.J., Borah, N., Barua, I.C. and Deka, N.C. (2006). Effect of pyrazosulfuron-ethyl on weeds and productivity of transplanted rice during rainy season. *Indian J. Weed Sci.* **38**: 25–28.

Raju, A., Pandian, B.J., Thukkaiyannan, P. and Thavaprakash, N. (2003). Effect of weed management practices on the yield attributes and yield of wet seeded rice. *Acta. Agron. Hungarica.* **51**(4):461-464.

Ramana, A.V., Reddy, D.S. and Ramakumar, K. (2014). Influence of sowing time and nitrogen levels on growth, yield and N uptake of rainfed upland rice varieties. *Andhra. Agric. J.* **54**(3&4): 114–120.

Rao, A.N., Johnson, D.E., Sivaprasad, B., Ladha, J.K. and Mortimer, A.M. (2007). Weed management in direct seeded rice. *Adv. Agron*. **93**: 153-255.

Rao, V.S. (1999). Principles of Weed Science. 2nd edn. Oxford & IBH Publishing Co. Pvt. Ltd. pp. 277.

Rashid, M.H., Alam, M.M., Khan, M.A.H. and Ladha, J.K. (2009). Productivity and resource use of direct (drum)-seeded and transplanted rice in puddled soils in rice-rice and rice-wheat ecosystem. *Field Crops Res*. **113**: 274-281.

Reddy, M.D., Reddy, C.N., Reddy, N.V. and Devi. M.P. (2000). Effect of herbicides on weed growth and crop performance in rice–blackgram cropping system. *Intl. J. Weed Sci.* **32**(3&4): 169-172.

Rekha, K.B., Razu, M.S. and Reddy, M.D. (2003). Effect of herbicides in transplanted rice. *Indian J. Weed Sci.* **34**:123-125.

Salam, M. A., Sarker, S. and Sultana, A. (2020). Effect of weed management on the growth and yield performances of boro rice cultivars. *J. Agric. Food Environ*. **1**(4): 19- 26.

Sarita, Singh, I., Mehriya, M.L. and Samota, M.K. (2022). A study of wheat-weed response and economic analysis to fertilization and post-emergence herbicides under arid climatic conditions. *Front. Agron*. **4**: 914091.

Sarkar, M.A.R., Paul, S.K. and Paul, U. (2017). Effect of water and weed management in boro rice (cv. BRRI dhan28) in Bangladesh. *Archive. Agric. Environ. Sci.* **2**(4): 325–329.

Sarwar, A.K.M.G. and Biswas, J.K. (2021).Cereal grains of Bangladesh – Present status, constraints and prospects. *In*: Cereal Grains Goyal, A.K. (Ed.). IntechOpen, London, UK. pp. 1-20.

Singh, K.L., Devi, K.N., Athokpam, H.S., Singh, N.B., Sagolshem, K.S., Meetei, W.H. and Mangang, C. A. (2014). Effect of cultivars and planting geometry on weed infestation, growth and yield in transplanted rice. *Int. Quart. J. Environ. Sci.* **8**(1&2): 01-05.

Singh, S., Bhushan, L., Ladha, J.K., Gupta, R.K., Rao, A.N. and Sivaprasad, B. (2006). Weed management in dry-seeded rice (*Oryza sativa* L.) cultivated on furrow irrigated raised bed planting system. *Crop Prot.* **25**: 487-495.

Singh, V., Jat, M.L., Ganie, Z.A., Chauhan, B.S. and Gupta, R.K. (2016). Herbicide options for effective weed management in dry direct seeded rice under scented rice-wheat rotation of western Indo-Gangetic Plains. *Crop Prot.* **81**:168-176.

Singh, V.P., Singh, S.P., Dhyani, V.C., Tripathi, N., Banga, A. and Yadav, V.R. (2013). Effect of establishment methods on shifting of weed flora in rice-wheat cropping system. *In*: Proc. 24th Asian-Pacific Weed Science Society Conference" October 22- 25, 2013, Bandung, Indonesia, p. 494.

Sunil, C.M., Shekara, B.G., Kalyanamurthy, K.N. and Shankaralingappa, B.C. (2010). Growth and yield of aerobic rice as influenced by integrated weed management practices. *Indian J. Weed Sci.* **42**(3&4): 180-183.

Suria, A.S.M.J., Juraimi, A.S., Rahman, M.M., Man, A.B. and Selamat, A. (2011). Efficacy and economics of different herbicides in aerobic rice system. *African J. Biotech.* **10**(41): 8007-8022.

Suryakala, P., Murugan, G., Saravanaperumal, M., Suseendran, K. and Stalin, P. (2019). Effect of weed management practices with new generation herbicides in transplanted rice. *J. Pharma. Phytochem*. **8**(3): 3913-3915.

Teja, K.C., Duary, B., Kumar, M. and Bhowmick, M.K. (2017). Effect of bensulfuron methyl+pretilachlor and other herbicides on mixed weed flora of wet season transplanted rice. *Int. J. Agric. Environ. Biotech*. **8**(2): 323-329.

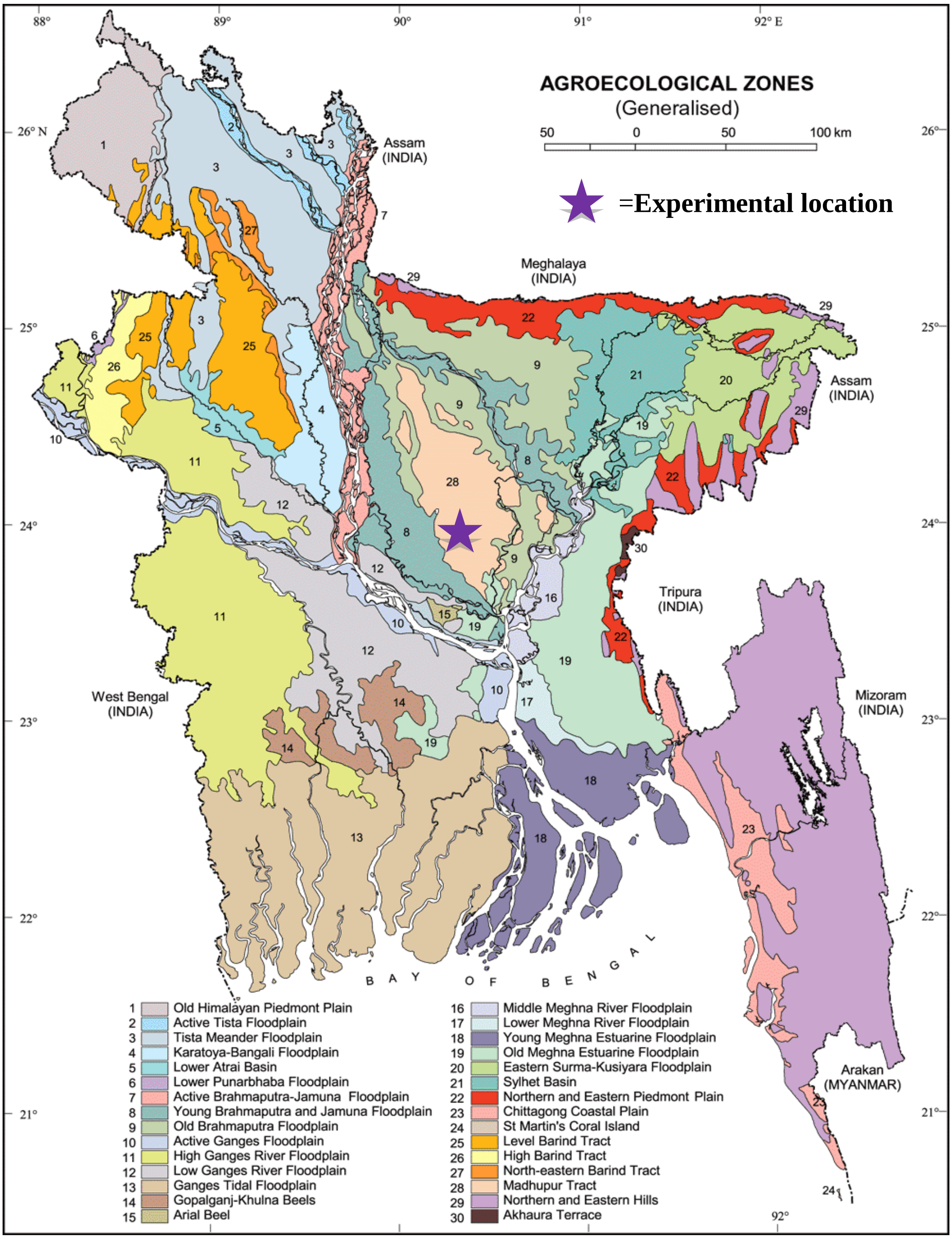
Valverde, B.E. and Gressel, J. (2005). Implication and containment of gene flow from herbicide resistant rice (*Oryza sativa).* In: Proc. 20th Asian PacificWeed Sciences Society, pp. 63-84 (Ho Chi Minh City, Vietnam).

Walker, S.R., Medd, R.W., Robinson, G.R. and Cullis, B.R. (2002). Improved management of Avena ludoviciana and Phalaris paradoxa with more densely sown wheat and less herbicide. *Weed Res*. **42**: 257-270.

Yadav, D.B., Yadav, A., Punia, S.S., Singh, N. and Duhan, A. (2018). Pretilachlor + pyrazosulfuron-ethyl (ready-mix) against complex weed flora in transplanted rice and its residual effects. *Indian J. Weed Sci.* **50**(3): 257–261.

APPENDICES

Appendix I. Map showing the experimental location under study



Appendix II. Soil characteristics of the experimental field

A. Morphological features of the experimental field

Morphological features	Characteristics
Location	Sher-e-Bangla Agricultural University Agronomy research field, Dhaka
AEZ	AEZ-28, Modhupur Tract
General Soil Type	Shallow Red Brown Terrace Soil
Land type	High land
Soil series	Tejgaon
Topography	Fairly leveled

B. The initial physical and chemical characteristics of soil of the experimental site (0 - 15 cm depth)

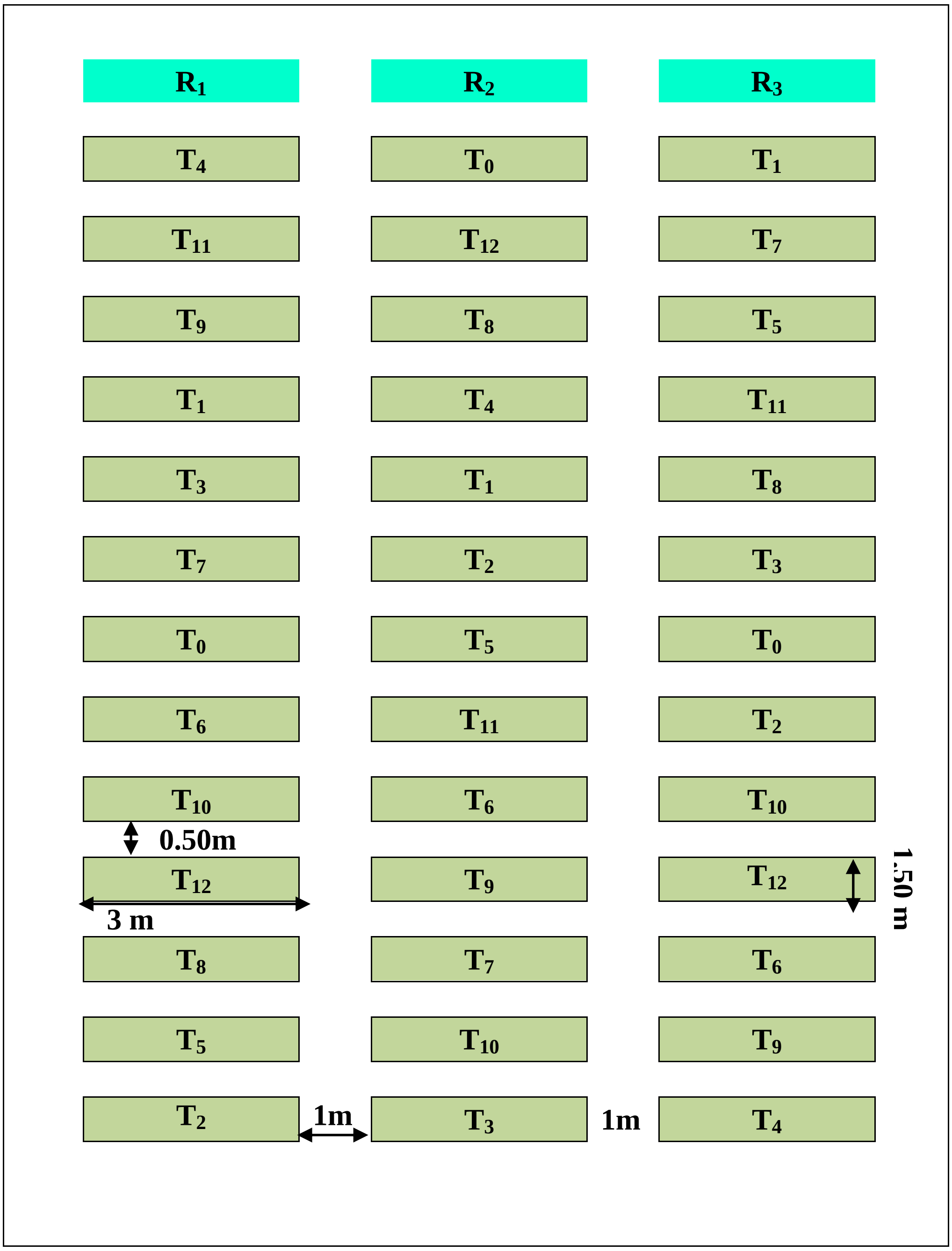
Physical characteristics	
Constituents	**Percent**
Sand	26 %
Silt	45 %
Clay	29 %
Textural class	Silty clay
Chemical characteristics	
Soil characteristics	**Value**
pH	5.6
Organic carbon (%)	0.45
Organic matter (%)	0.78
Total nitrogen (%)	0.03
Available P (ppm)	20.54
Exchangeable K (mg/100 g soil)	0.10

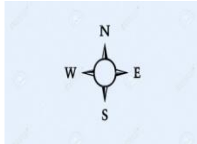
Appendix III. Monthly meteorological information during the period from March, 2022 to August, 2022

Year	Month	Air Temperature (^0C)			Relative Humidity (%)	Rainfall (mm)
		Maximum	Minimum	Mean		
2022	March	32.43	18.10	25.27	51.9	17
	April	34.17	23.00	28.59	64.9	301
	May	32.02	24.25	28.14	77	2537
	June	31.46	25.20	28.33	83.3	3907
	July	32.17	25.92	29.05	82.1	2908
	August	32.90	25.97	29.44	83	1959

Source: Bangladesh Meteorological Department, Dhaka

Appendix IV. Layout of the experimental field





Appendix V. Analysis of variance of the data of plant height of *aus* rice at different DAS

Mean Square of Plant Height at								
Source	Df	15 DAS	30 DAS	45 DAS	60 DAS	75 DAS	90 DAS	At Harvest
Replication (R)	2	8.00	4.10	32.02	1.52	0.77	58.43	52.94
Treatment (T)	12	2.21	4.59	49.93*	45.84	139.96*	168.81*	268.97**
Error (R x T)	24	2.57	10.15	20.73	26.60	60.41	55.48	55.78
Total	38							

**: Significant at 0.01 level of probability
*: Significant at 0.05 level of probability

Appendix VI. Analysis of variance of the data of number of tillers hill^{-1} of *aus* rice at different DAS

Mean Square of Number of Tillers Hill^{-1} at							
Source	Df	15 DAS	30 DAS	45 DAS	60 DAS	75 DAS	90 DAS
Replication (R)	2	0.08	0.37	20.41	9.69	10.62	17.08
Treatment (T)	12	0.21**	0.27	34.66**	12.67**	17.05**	13.36**
Error (R x T)	24	0.07	0.21	4.53	2.51	2.52	2.83
Total	38						

**: Significant at 0.01 level of probability
*: Significant at 0.05 level of probability

Appendix VII. Analysis of variance of the data of dry matter accumulation plant^{-1} of *aus* rice at different DAS

Mean Square of Dry Matter Accumulation Plant^{-1} at				
Source	Df	30 DAS	60 DAS	90 DAS
Replication (R)	2	0.01	0.59	10.54
Treatment (T)	12	0.17*	4.08**	95.66**
Error (R x T)	24	0.06	0.54	6.22
Total	38			

**: Significant at 0.01 level of probability
*: Significant at 0.05 level of probability

Appendix VIII. Analysis of variance of the data of effective tillers hill^{-1}, non-effective tillers hill^{-1} and Panicle length of *aus* rice

Mean square of				
Source	Df	Effective tillers hill^{-1}	Non-effective tillers hill^{-1}	Panicle length
Replication (R)	2	1.48	0.29	0.45
Treatment (T)	12	62.34**	20.51**	293.81**
Error (R x T)	24	0.35	0.30	0.51
Total	38			

**: Significant at 0.01 level of probability
*: Significant at 0.05 level of probability

Appendix IX. Analysis of variance of the data of filled, unfilled, total grains panicle^{-1} and 1000-grain weight of *aus* rice

Source	Df	Mean Square of			
		Filled Grains	Unfilled Grains	Total Grains Panicle^{-1}	1000- Grain Weight
Replication (R)	2	6.76	2.30	4.18	4.49
Treatment (T)	12	1657.66**	2114.33**	5451.67**	383.33**
Error (R x T)	24	5.12	20.16	27.21	2.40
Total	38				

**: Significant at 0.01 level of probability
*: Significant at 0.05 level of probability

Appendix X. Analysis of variance of the data of on grain, straw, biological yield and harvest index of *aus* rice

Source	Df	Mean Square of			
		Grain Yield	Straw Yield	Biological Yield	Harvest Index
Replication (R)	2	0.01	0.01	0.03	0.84
Treatment (T)	12	7.04**	8.90**	31.55**	1191.95**
Error (R x T)	24	0.01	0.04	0.05	16.39
Total	38				

**: Significant at 0.01 level of probability
*: Significant at 0.05 level of probability

Appendix XI. Wages and price of different items used in the experiment

A. Non-Material Cost

Items	No. of Labor Required	Amount Taka
Tractor Operation	1	400
Layout Making	10	4000
Drain Making	8	3200
Seed Sowing	20	8000
Harvesting & Others Works	20	8000
	Grand Total =	23,600

(Individual labor wages 400 taka day^{-1}).

B. Material Cost

Sl. No.	Quantity (kg/ha)/times	Items Cost (Tk)	Cost (Tk/ha)
Seed rate ha^{-1}	50	25	1250
Fertilizers			
Urea	125	16	2000
TSP	50	22	1100
MOP	60	15	900
Gypsum	60	8	480
Irrigation	2 times	2000	4000
Tractor	1	3000	3000
(Excluding herbicide application)		Grand Total =12,730	

Overhead cost

Land value ha^{-1} was 200000 taka. Land cost at 12.5 % interest for 6 month was 12500 taka.

Miscellaneous cost (common cost)

It was 5% of total input cost

Cost of different weed managements according with par treatment requirement

Treatments	No Weding	Partial Wedding(2 times)	Weed Free (4 times)	Pre-emergence	Pre-emergence	Post-emergence	Post-emergence	Pre+post-emergence	Pre+post-emergence	Mixed Herbicide	Mixed Herbicide	Mixed Herbicide	Late Post-emergence	Total cost for weed management
T_0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
T_1	0	16000	0	0	0	0	0	0	0	0	0	0	0	16000
T_2	0	0	32000	0	0	0	0	0	0	0	0	0	0	32000
T_3	0	0	0	2000	0	0	0	0	0	0	0	0	0	2000
T_4	0	0	0	0	2000	0	0	0	0	0	0	0	0	2000
T_5	0	0	0	0	0	3200	0	0	0	0	0	0	0	3200
T_6	0	0	0	0	0	0	3200	0	0	0	0	0	0	3200
T_7	0	0	0	0	0	0	0	5200	0	0	0	0	0	5200
T_8	0	0	0	0	0	0	0	0	5200	0	0	0	0	5200
T_9	0	0	0	0	0	0	0	0	0	3000	0	0	0	3000
T_{10}	0	0	0	0	0	0	0	0	0	0	3000	0	0	3000
T_{11}	0	0	0	0	0	0	0	0	0	0	0	3000	0	3000
T_{12}	0	0	0	0	0	0	0	0	0	0	0	0	3200	3200
	Grand Total =81,000													

Appendix XII. Total cost of production of *aus* rice varieties cultivations

Total cost of production of Direct-Seeded Aus rice (BRRI dhan 98) cultivations

Total cost of production

Treatments	Non-material cost (i)	Material cost (Excluding herbicide) (ii. a)	Total cost for weed management (ii. b)	Total input cost (A = i+ ii) Here, ii= a+b	Interest on input cost @ 12.5% for 6 month (B)	Miscellaneous cost is 5% of total input cost (C)	Overhead cost (D)	Total cost of production (A+B+C+D)
T_0	23,600	12,730	0	36330	2645.63	2116.5	12500	53592.13
T_1	23,600	12,730	16000	52330	3645.63	2916.5	12500	71392.13
T_2	23,600	12,730	32000	68330	4645.63	3716.5	12500	89192.13
T_3	23,600	12,730	2000	38330	2770.63	2216.5	12500	55817.13
T_4	23,600	12,730	2000	38330	2770.63	2216.5	12500	55817.13
T_5	23,600	12,730	3200	39530	2845.63	2276.5	12500	57152.13
T_6	23,600	12,730	3200	39530	2845.63	2276.5	12500	57152.13
T_7	23,600	12,730	5200	41530	2970.63	2376.5	12500	59377.13
T_8	23,600	12,730	5200	41530	2970.63	2376.5	12500	59377.13
T_9	23,600	12,730	3000	39330	2833.13	2266.5	12500	56929.63
T_{10}	23,600	12,730	3000	39330	2833.13	2266.5	12500	56929.63
T_{11}	23,600	12,730	3000	39330	2833.13	2266.5	12500	56929.63
T_{12}	23,600	12,730	3200	39530	2845.63	2276.5	12500	57152.13

(Note: Fixed cost is total cost of production - Herbicide application cost)

Appendix XIII. Gross return from *aus* rice cultivation

Gross return from rice cultivation

Rice value (With husk) = 1 kg 25 taka so 1 ton = 25000 taka

Straw value= 1 kg 1 taka so 1 ton = 1000 taka

Treatment	Grain yield (t/ha)	Value (TK)	Straw yield (t/ha)	Value (TK)	Gross retrun (Tk)
T_0	0.00	0.00	0.00	0.00	0.00
T_1	3.73	93,250	4.25	4,250	97,500
T_2	3.93	98,250	4.11	4,110	102,360
T_3	0.00	0.00	0.00	0.00	0.00
T_4	0.08	2,000	0.59	590	2,590
T_5	0.00	0.00	0.00	0.00	0.00
T_6	0.12	3,000	0.58	580	3,580
T_7	0.71	17,750	1.17	1,170	18,920
T_8	2.96	74,000	4.02	4,020	78,020
T_9	0.00	0.00	0.00	0.00	0.00
T_{10}	0.00	0.00	0.00	0.00	0.00
T_{11}	0.00	0.00	0.00	0.00	0.00
T_{12}	0.17	4,250	0.52	520	4,770

PLATES

Plate 1. Field view just after sowing of aus rice seeds.

Plate 2. Unweeded (weedy check) plot at 20 days after sowing.

Plate 3. Weed infestation in the non-effective herbicidal treatments for direct seeded *aus* rice.

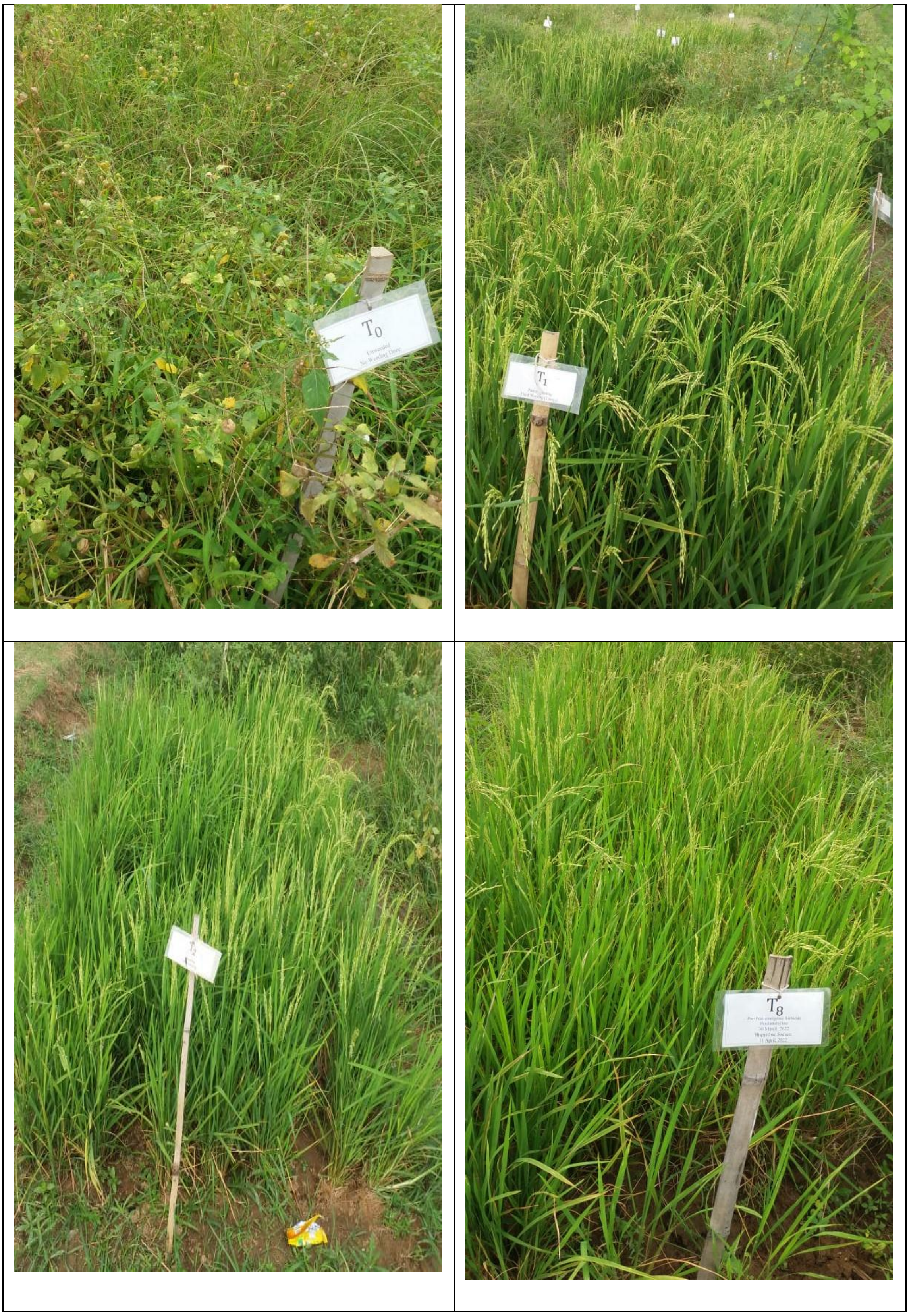


Plate 4. Comparison of crop growth for unweeded, partial weeding, weed-free and the sequential application of Pendimethalin @ 2 L ha^{-1} + Bispyribac-Sodium @ 25 g ha^{-1} treated plots (clockwise).

Plate 5. Field visit by respective Supervisor and Co-Supervisor.