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Efficient Nitrogen Management for Reducing Weed Population and Improving Productivity of *Boro* Rice

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ABSTRACT

Among many causes of weed growth and rice's low yield, improper nitrogen management are thought to be an important issue. To find out the efficient nitrogen management for reducing weed population and improving productivity of *boro* rice an experiment was conducted from December 2021 to June 2022 at the Agronomy Field Laboratory, Bangladesh Agricultural University, Mymensingh. Five different nitrogen management and six different weed control techniques were applied to BRRI dhan29. Four of the thirteen weed species were grasses, three were broadleaf, four were sedges and two were aquatic. Application of 100% N from urea and un-weeded control had the greatest weed density and dry weight (78.67 m^{-2} and 4.80 g m^{-2}) at 20 DAT, whereas 100% N from USG and weed free over the time treatment had the lowest weed density and dry weight (0.00 m^{-2} and 0.00 g m^{-2}). When 100% N from USG was applied coupled with weed-free conditions the maximum numbers of effective tillers $hill^{-1}$, grains $panicle^{-1}$, straw yield, and biological yield were 10.11, 122, 6.23 t ha^{-1}, and 11.07 t ha^{-1}, respectively. The minimum effective tillers $hill^{-1}$, grains $panicle^{-1}$, straw yield and, biological yield was 6, 70.84, 3.13 t ha^{-1} and, 4.95 t ha^{-1}, respectively found at 0 kg N ha^{-1} followed by un-weeded control. The maximum grain yield was 5.84 t ha^{-1} for 100% N from USG and weed-free conditions, while the lowest grain yield was 2.15 t ha^{-1} for 0 kg N ha^{-1} and un-weeded control. However, because of the labor problem and the weeds' tremendous capacity for regeneration, it is impossible to keep the field weed-free over the whole growing season. This study showed that farmers may choose to apply 100% N from USG in combination with either pre-emergence herbicide (Commit 500 EC @ 1 L ha^{-1}) and hand weeding at 30 DAT or early post-emergence herbicide (Acetochlor 14% + Bensulfuron-methyl 4% @ 750g ha^{-1}) and hand weeding at 30 DAT to effectively manage weeds and maximize grain yield in *boro* rice.

1. Introduction

In Bangladesh, rice is the primary food crop. A major contributor to Bangladesh's GDP, job creation, and food supply, rice cultivation is essential to the country's economy. The agriculture sector contributes about 13.31% to the total GDP (BBS, 2022). Bangladesh is now producing 38.14 million tons of rice in total, of which 52.8 percent was *boro* rice, 38.4 percent was *aman* rice and 8.8 percent was *aus* rice (BBS, 2022). Due to a combination of factors including favorable environmental conditions, improved management, government assistance, and the planting of high-yielding cultivars, *boro* rice yield has achieved its greatest level ever (MoA, 2021).

In 2020–2021, the country produced 19.89 million tons of *boro* rice with a yield of 4.15 t ha^{-1}, with an increase in area of 0.52% and production of 1.22% compared to the previous year (BBS, 2022). The rice area in *boro* has decreased during the past ten years (2011 to 2020). With the exception of 2016 and 2017, the production pattern exhibits a consistent increase. In 2017, *boro* rice output decreased to 18.01 million tons because of a flash flood in the *Haor* basins (Jamal et al., 2022). Bangladesh, although being the fourth-largest rice producer, continues to produce at a lower rate than other Asian countries. However, agricultural land is declining at a pace of 1% while population growth is hitting 1.08% (BBS, 2022). The first cause is that agricultural land is changing to non-agricultural land at a rate of 1% annually, according to UNDP in 2003 (Hasan et al., 2013).

The most restrictive nutrient for rice crop growth and output among the primary nutritional elements is nitrogen (N), which is needed at higher concentrations than other

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nutrients (Djaman et al., 2018). Among the three major macronutrients, N affects the organic structure, physiological characteristics and biomass synthesis and distribution of plants, and has the greatest effect on dry matter production (Zhu et al., 2014). Insufficient N supply seriously impairs the structure and function of photosynthesis, thereby reducing crop yields (Zhao et al., 2017).

One of the main reasons for low rice output is weed infestation. Without a question, keeping the crop free from weed infestation allows rice farmers to receive the greatest benefit. The most significant pests that reduce rice harvests are weeds (Paul et al., 2013). The average yield losses in rice due to weed competition are estimated to vary between 40 and 60% which may go up to 94–96% with uncontrolled weed growth (Chauhan and Johnson, 2011). High competition of weed has a profound detrimental impact on crop productivity and results in substantial yield losses (Sardana et al., 2017). Ineffective weed control, the degree of which varies according to the kind of weed flora and the extent of infestation. Weed infestations result in larger yield losses than all other pests and diseases put together. To minimize weed infestation and increase rice yield, farmers must implement the best weeding practices.

Herbicidal weed management techniques are viewed as cost-effective since they provide an advantage to save labor and money (Paul et al., 2024). Traditional management techniques like hand weeding take a lot of time and money to implement. Herbicides can be used alone or in conjunction with hand weeding to effectively manage weeds (Marimuthu et al., 2024). Usage of herbicides in Bangladesh increased annually from 108 M. tons in the years 1986–87 (BBS, 1991) to 7881 M. tons in 2021 (BBS, 2021), an almost exponential increase. Herbicides like Oxadiazone, Pretilachlor, Acetochlor 14%+Bensulfuron-methyl 4%, Butachlor, Ethoxysulfuran, Pyrazosulfuranethyl, Oxadiarzil, Anilphos, 2,4-D, etc. are frequently used in Bangladesh to cultivate rice. As a result, the right herbicide and nitrogen fertilizer dosage are essential for the production of rice as well as for the effective management of weeds. While these elements' impacts on rice were observed independently, there is more information available in Bangladesh on the cumulative impact of nitrogen dosage and weed management on *boro* rice productivity and weed infestation behavior. In light of the aforementioned information, the current study was conducted to determine how nitrogenous fertilizer management and weed control techniques affect weed development and *boro* rice output.

2. Materials and Methods

2.1. Description of the experimental site

The experiment was conducted at the Bangladesh Agricultural University's Agronomy Field Laboratory in Mymensingh between December 2021 and June 2022 (*boro* season). The study location is located at 18 meters above sea level and lies at 24˚75´ N latitude and 90˚50´E longitude, which is the part of Agroecological Zone-9 (Old Brahmaputra Floodplain). The field is part of the dark-grey, non-calcareous floodplain soil, which has medium fertility and a pH of 6.5. With a silt loam texture and a medium-high land type, the soil had a low organic matter level (1.67%) and was well-drained. In the Kharif season (April–September), this region has high temperatures, high humidity, and significant precipitation with sporadic gusts of wind. In the Rabi season (October–March), there is little rainfall and a somewhat low average air temperature. The humidity stays high for the most of the year, with the exception of Rabi season.

2.2. Experimental treatments and design

The experimental treatments were - Factor A: nitrogenous fertilizer management (5) - 0 kg N ha^{-1} (N_0), 100% N from urea (138 kg N ha^{-1}) (N_1), 100% N from poultry manure (PM) (14.5 t PM ha^{-1}) (N_2), 50% N from poultry manure (7.5 t PM ha^{-1}) + 50% N from urea (69 kg N ha^{-1}) (N_3), 100% N from urea super granule (USG) (2.7 g per 4 hills) (N_4), Factor B: weed management practices (6)-Un-weeded control (W_0), weed free throughout the period (W_1), application of pre-emergence herbicide (Commit 500 EC @ 1 L ha^{-1}) (W_2), application of pre-emergence herbicide followed by one hand weeding at 30 DAT (W_3), application of early post-emergence herbicide (Acetochlor 14% + Bensulfuron-methyl 4% @ 750g ha^{-1}) (W_4), application of early post-emergence herbicide followed by one hand weeding at 40 DAT (W_5). A randomized complete block design (RCBD) with three replications was used to carry out the trial, and each treatment was administered as prescribed.

2.3. Crop husbandry

In the experimental plot, damaged seedlings were replaced with healthy seedlings after one week of transplantation from the same source to maintain plant population.Two times manual weeding were done at 20 and 40 days after transplanting. Water management is very important for *boro* rice. For proper growth of the plant 7 flood irrigations were done. Excess water was drained out from the plot during vegetative stage for top dressing of urea fertilizer. During tillering the field was left to dry out twice for 2 to 4 days. On completion of tillering 5-7 cm of water was allowed to stand in order to depress late tillering. Starting from panicle initiation, a thin layer of water (2-3 cm) was kept on the plots. The bund around individual plot was repaired as and when necessary to prevent water movement between the plots. The crop was infested by rice stem borer (*Sesamia inferens*) and brown planthopper (*Nilaparvata lugens*). These were controlled by using Basudin 10 G @ 16.8 kg ha^{-1}. No disease infestation was observed. The experimental field was observed regularly and the field was looked nice with normal green leaves. The flowering was uniform and also the grains were matured at same time. The crops were harvested on 2 June 2022.

2.4. Data collection procedure

From each plot, five hills were chosen at random to record the essential information on various crop characters. Then, in order to determine the yields of grain and straw, the middle one square meter section of each plot was collected. Weed density data were computed at 20 and 40 DAT using a 1 m^2 quadrate. Each plot had a quadrate positioned at random in three locations. Next, the number of weeds within the quadrate was equated to m^{-2}. Weeds in each quadrate were removed and cleaned once the weed density was established. The sample weeds were initially let to air dry for six to eight hours in order to determine dry matter. Once the brown paper bag was labeled, the weed samples were dried for 72 hours at 80°C, or until their weight didn't change. The samples were precisely measured to ascertain the dry weight of the plant after oven drying, and the weight was subsequently converted to grams per square meter.

2.5. Statistical analysis

Using the computer program MSTAT-C, measurements and analyses were conducted for weed density, dry weight, yield, and yield contributing features. The average of all treatments was calculated, and each character under study underwent "Analysis of Variance" (ANOVA). The differences in treatment means were compared using the Duncan's Multiple Range Test (Gomez and Gomez, 1984).

3. Results

3.1. Weed Composition

Thirteen different types of weeds viz., *Paspalum scrobiculatum, Echinochola crusgalli, Eleocharis atropurpurea, Digitaria setigera, Monochoria vaginanalis, Fimbristylis miliacea, Pontederia crassipes, Marsilea minuta, Pistia stratiotes, Eclipta alba, Cyperus difformis, Alternathera philoxeroides, Cyperus rotundus.* Among them *Paspalum scrobiculatum, Echinochola crusgalli, Eleocharis atropurpurea, Digitaria setigera, Monochoria vaginanalis, Fimbristylis miliacea* were present in the tested field (Table 1). Almost similar research finding was also reported by Sultana et al. (2023) in their finding who observed *Echinochloa crusgalli, Leersia hexandra, Paspalum scrobiculatum, Cyperus difformis* were the most dominating weeds in their research filed in *aman* season at the same location. Many authors reported that *Echinochloa crusgalli* was the most dominating species in the *aman* rice field at the same location (Islam et al., 2018; Afroz et al., 2019; Monira et al., 2020).

3.2. Impact of nitrogen levels and weed management techniques on weed density and dry weight

In both 20 and 40 days after emergence, nitrogen management techniques had a notable impact on weed density and dry weight (Figure 1). For weed density, the interaction impact of nitrogen levels and weed management techniques was found to be significant at 20 DAT but non-significant at 40 DAT; however, for weed dry weight, it was shown to be statistically significant at both 20 and 40 DAT. The treatment100% nitrogen from urea and no weed control, had the greatest weed density (78.67 weeds m^{-2}) and dry weight (4.80 g m^{-2}) at 20 DAT. The treatment where 100% nitrogen was provided by urea super granules and weeds were managed during the trial, showed the no weed density and dry weight at 20 DAT (Table 2). Begum et al. (2009) pronounced the same findings of changing the weed density at different nitrogen levels. Jehangir et al. (2021) also concluded that the weed management methods reduce the weed infestation in the field. In the case of weed dry weight at 30 DAT, 4.25 g m^{-2} was the highest value for weed dry weight obtained from the interaction of 100% N from urea and un-weeded control and the lowest one (0.00 g m^{-2}) was documented in the interaction of 0 kg N ha^{-1} and weed free throughout the rice growing period (Table 2). Kebede and Anbasa (2017) concluded the similar findings that the weed management methods and nitrogen levels collectively lower the weed dry weight.

3.3. The impact of managing nitrogen fertilizer on *boro* rice yield and yield-contributing characteristics

The height of the *boro* rice plants was greatly affected by the various nitrogenous fertilizer management techniques (data not shown). Nitrogen fertilizer increased plant height because it encourages plant development and increases internode length and number, both of which lead to a steady rise in plant height. The conformity of this result was also observed by Malik et al. (2014), Ferdush et al. (2020) and Chhanda et al. (2021) who also recorded a positive effect of nitrogen level on plant height.

Nitrogen fertilizer greatly affected the total number of tillers per hill (Figure 2). The N_0 treatment (0 kg N ha^{-1}) produced the fewest tillers per hill (7.85), whereas the N_1 treatment (100% nitrogen from prilled urea) generated the most (9.76). Plots that had nitrogen fertilizers had more tillering. A crucial characteristic for rice production is tillering (Badshah et al*.,* 2014). The conformity of this result was also observed by Salem et al. (2011) who recorded a positive effect of nitrogenous fertilizer management on number of total tillers hill^{-1}. Managing nitrogenous fertilizer significantly impacted the number of productive tillers per hill and the N_4 treatment (100% nitrogen from USG) had the most (8.99). The number of effective tillers per hill increased as a result of the increased cellular activity during tiller creation and growth brought on by the sufficient nitrogen supply. Increased N absorption had great role in increasing number of tillers (Kheya et al., 2024).

Notably, the N_2 treatment (100% N from poultry manure) produced the longest panicle (23.78 cm). The application of 100% N from urea treatment resulted in the shortest panicle (22.15 cm) . Because nitrogen nutrients were involved in both panicle production and elongation, different nitrogen management strategies resulted in varying panicle lengths. Significantly the highest number of grains panicle^{-1} (111.40) was produced from the N_4 (100% N from USG) treatment. The application of 0 kg N ha^{-1} or N_0 resulted the lowest number of grains panicle^{-1} (94.16) (Figure 2). Additionally, nitrogen aided in the correct filling of grains, resulting in larger, plumper grains and an increase in the number of grains per panicle. Since 1000-grain weight is a hereditary trait, it was unaffected by the various nitrogenous fertilizer treatments.

Grain yield was strongly impacted by different nitrogenous fertilizer amounts (Figure 2). After applying 100% N from USG, the N_4 treatment produced the maximum grain production (4.86 t ha^{-1}), which was statistically comparable to the N_3 treatment (50% N from PM + 50% N from urea). While the highest production under the N_4 treatment was probably caused by the combined impacts of the greatest

Table 1. Infesting weed species found growing in the experimental plots in *boro* rice field

Local name	Scientific name	Family	Morphology	Life cycle
Angta	*Paspalum scrobiculatum* L.	Poaceae	Grass	Perennial
Shama	*Echinochola crusgalli* (L.) P. Beauv	Poaceae	Grass	Annual
Pani chaise	*Eleocharis atropurpurea* (Retz.) J. Presl & C. Pres	Cyperaceae	Sedge	Annual
Sabuj Nakful	*Cyperus difformis* L.	Cyperaceae	Sedge	Annual
Choto Anguli ghash	*Digitaria setigera* Roth	Cyperaceae	Grass	Annual
Panikachu	*Monochoria vaginanalis* (Burm. F.) C. Presl	Pontederiaceae	Broad leaved	Annual
Joina	*Fimbristylis miliacea* L.	Cyperaceae	Sedge	Annual
Kochuripana	*Pontederia crassipes*	Pontederiaceae	Aquatic weed	Perennial
Susni shak	*Marsilea minuta*	Marsileaceae	Grass	Perennial
Topapana	*Pistia stratiotes*	Araceae	Aquatic weed	Perennial
Keshuti	*Eclipta alba* L.	Compositae	Broad Leaved	Annual
Malancha	*Alternathera philoxeroides* L.	Araceae	Broad leaved	Annual
Mutha	*Cyperus rotundus* L.	Cyperaceae	Sedge	Perennial

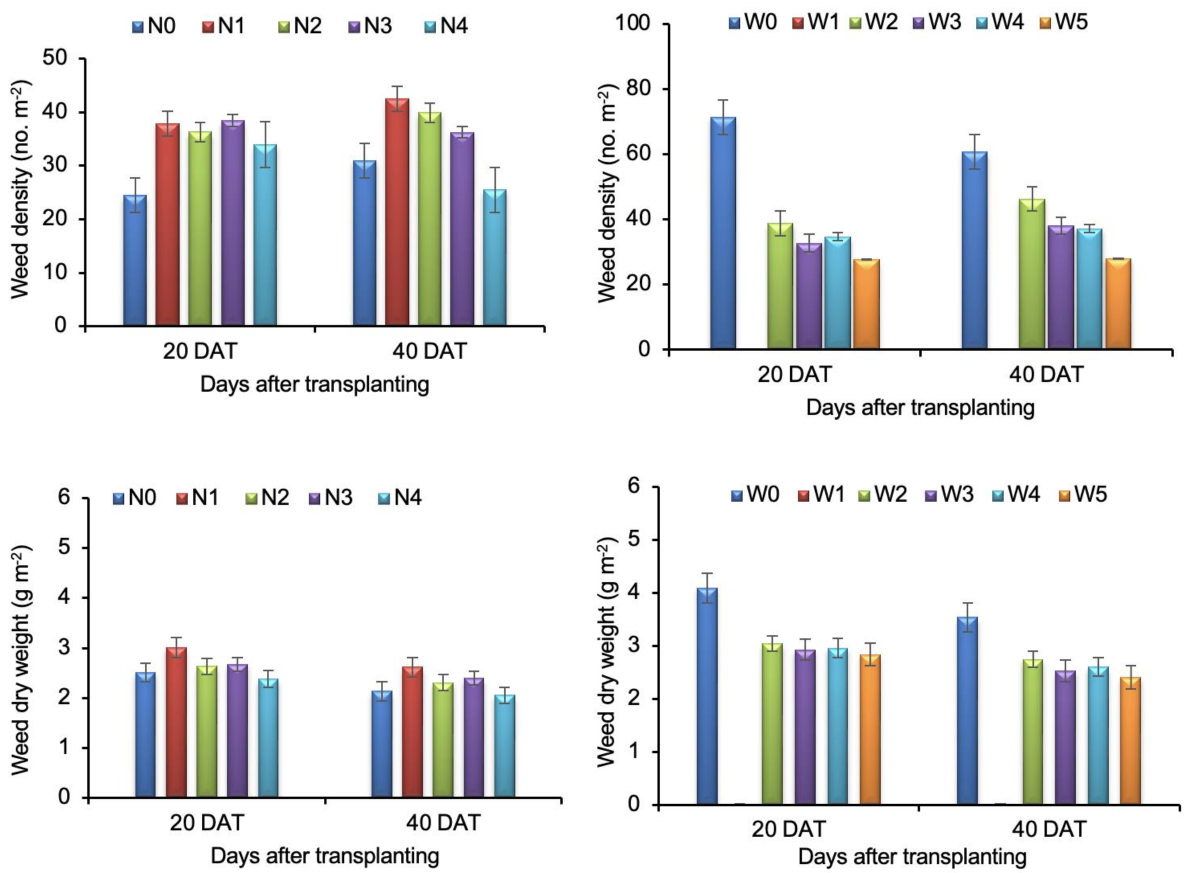

Figure 1 : Effect of nitrogen levels and weed control methods on weed density and dry weight. N_0 = 0 kg N ha^{-1}, N_1 = 100% N from urea, N_2 = 100% N from poultry manure, N_3 = 50% N from PM + 50% N from urea, N_4 = 100% N from USG, W_0 = Un-weeded control, W_1 = Weed free throughout the period, W_2 = Application of Pre-emergence herbicide, W_3 = Application of Pre-emergence herbicide followed by one hand weeding at 40 DAT, W_4 = Application of early post-emergence herbicide, W_5 = Application of early post-emergence herbicide followed by one hand weeding at 40 DAT.

Table 2. Interaction effect of various nitrogen levels and weed management practices on weed density and dry weight of *boro* rice at different days after transplanting

Interaction (N×W)	Weed density (no. m^{-2})		Weed dry weight (g m^{-2})	
	20 DAT	40 DAT	20 DAT	40 DAT
N_0W_0	74.67a*	55.33	3.80bcd	3.20bcd
N_0W_1	0.00i	0.00	0.00g	0.00g
N_0W_2	22.67gh	38.33	2.67ef	2.43def
N_0W_3	18.00h	34.33	3.00c-f	2.40def
N_0W_4	15.33h	35.00	2.76ef	2.41def
N_0W_5	16.00h	22.67	2.83def	2.35def
N_1W_0	78.67a	74.67	4.80a	4.25a
N_1W_1	0.00i	0.00	0.00g	0.00g
N_1W_2	43.33cd	57.00	3.47b-e	3.09b-e
N_1W_3	37.00cde	46.33	3.35b-f	2.83b-f
N_1W_4	44.33cd	44.00	3.42b-f	2.93b-e
N_1W_5	24.00fgh	33.00	3.00c-f	2.60def
N_2W_0	70.00ab	66.33	4.30ab	3.63ab
N_2W_1	0.00i	0.00	0.00g	0.00g
N_2W_2	40.00cde	51.67	3.07c-f	2.77c-f
N_2W_3	35.67c-f	43.33	2.70ef	2.42def
N_2W_4	38.67cde	43.33	2.87def	2.52def
N_2W_5	33.67d-g	35.00	2.83def	2.49def
N_3W_0	73.67a	62.33	3.93abc	3.47bc
N_3W_1	0.00i	0.00	0.00g	0.00g
N_3W_2	47.00c	47.33	3.13c-f	2.93b-e
N_3W_3	37.33cde	40.00	2.90def	2.65c-f
N_3W_4	38.33cde	38.67	2.97c-f	2.74c-f
N_3W_5	34.33def	29.33	3.10c-f	2.57def
N_4W_0	60.00b	45.00	3.59b-e	3.10b-e
N_4W_1	0.00i	0.00	0.00g	0.00g
N_4W_2	41.00cde	36.67	2.83def	2.49def
N_4W_3	35.67c-f	26.33	2.67ef	2.32ef
N_4W_4	36.67cde	25.00	2.77ef	2.39def
N_4W_5	30.33efg	20.00	2.40f	2.01f
Level of significance	**	NS	*	*
CV (%)	18.76	17.16	19.34	18.80

*In a column, figures with same letters(s) or without letter(s) do not differ significantly whereas figures with dissimilar letters(s) differ significantly as per Duncan's Multiple Range Test (DMRT). **= Significant at 1% level of probability, *= Significant at 5% level of probability, NS = Non-significant; N_0 = 0 kg N ha^{-1}, N_1 = 100% N from urea, N_2 = 100% N from poultry manure, N_3 = 50% N from PM + 50% from urea, N_4 = 100% N from USG; W_0 = Un-weeded control, W_1 = Weed free throughout the period, W_2 = Application of Pre-emergence herbicide, W_3 = Application of Pre-emergence herbicide followed by one hand weeding at 40 DAT, W_4 = Application of early post-emergence herbicide, W_5 = Application of early post-emergence herbicide followed by one hand weeding at 40 DAT.

number of grains per panicle and the highest number of effective tillers per hill, the lowest grain yield (3.76 t ha^{-1}) was seen with the application of 100% nitrogen from poultry manure.

Similarly, Das (2011) and Shah et al. (2013) have documented differences in grain output due to nitrogen fertilizer management. Different nitrogenous fertilizer management strategies were shown to cause variations in straw output (data not shown). The highest straw yield (5.28 t ha^{-1}) was obtained from application of 100% N from USG treatment. Nitrogen availability during the vegetative phase, especially during the initiation of primary, secondary, and tertiary tillers, probably enhanced dry matter accumulation, resulting in the highest straw yield. In contrast, the application of 0 kg N ha^{-1} produced the lowest straw yield (4.49 t ha^{-1}). Additionally, Shah et al. (2013) have observed significant differences in straw yield as a result of nitrogen control. Various nitrogenous fertilizer amounts had no discernible effects on the harvest index (data not shown). It appears that application of 100% N from USG produced the greatest harvest index (42.42%). The lowest harvest index (40.94%) was obtained with the application of 0 kg N ha^{-1}. Ali et al. (2005) reported that N management strategy did not influence the harvest index. On the other hand, Miah et al. (2004) reported that different forms of nitrogenous fertilizer exerted very little variation in harvest index.

3.4. Impact of weed control techniques on *boro* rice yield and yield-contributing traits

Different weed control techniques had no discernible effect on plant height (data not shown). The different weed control techniques had no noticeable impact on the number of total tillers per hill (Figure 2). In terms of numbers, the un-weeded control treatment produced the fewest total tillers $hill^{-1}$ (8.51), while the W_4 treatment (application of early post-emergence herbicide, Acetochlor 14%+ Bensulfuron-methyl 4% at recommended dose) produced the most (9.51). The different weed control techniques had a considerable impact on the number of effective tillers $hill^{-1}$ (Figure 2). The un-weeded control treatment gave the lowest number of effective tillers $hill^{-1}$ (6.89), whereas the weed-free condition during the rice growth period treatment produced the maximum number (8.70). However, weeds were successfully managed in various weed management treatment plots, resulting in robust crop growth and increased tiller output.

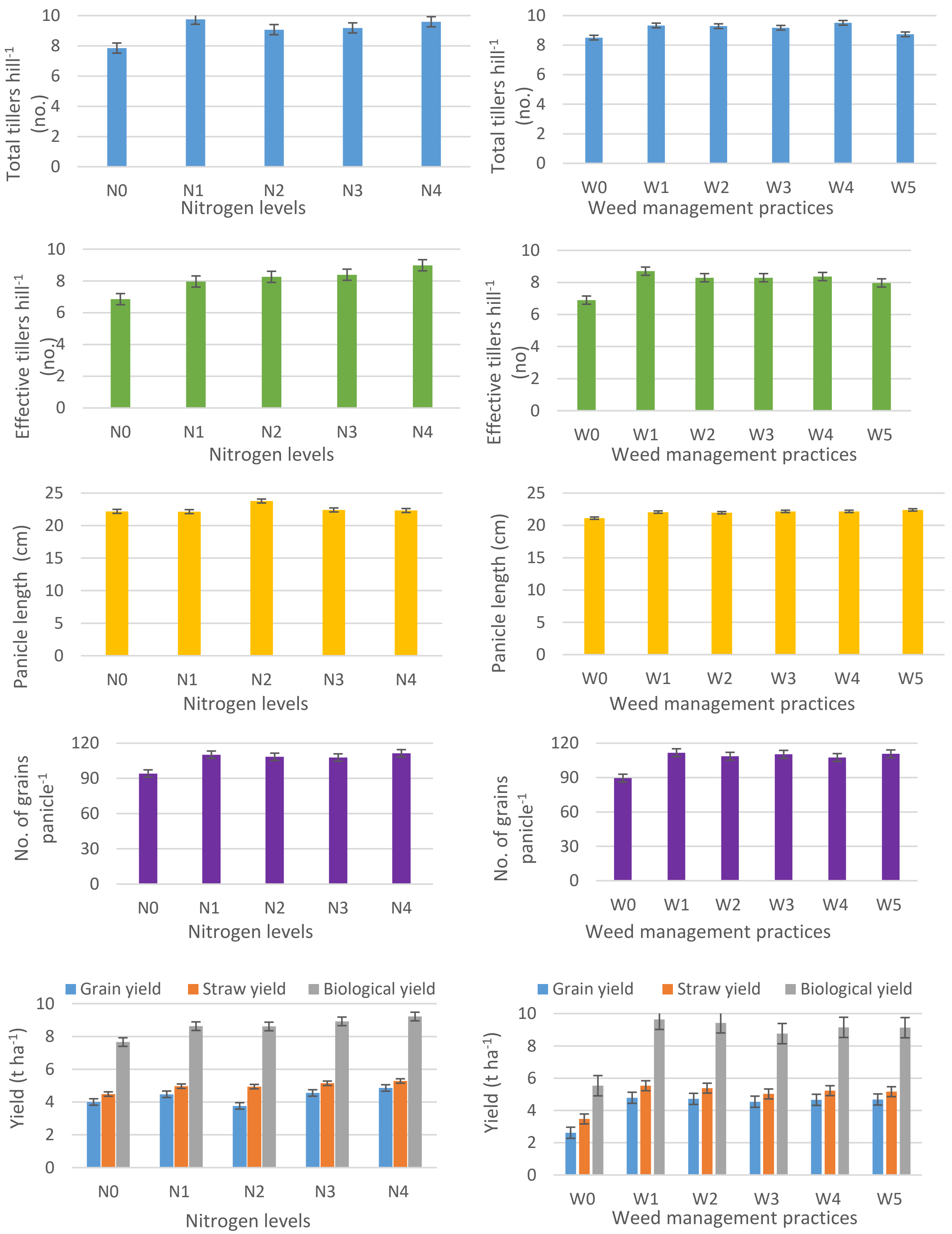

Figure 2: Effect of nitrogen fertilizer and weed control methods on yield contributing parameters . N_0 = 0 kg N ha^{-1}, N_1 = 100% N from urea, N_2 = 100% N from poultry manure, N_3 = 50% N from PM + 50% N from urea, N_4 = 100% N from USG; W_0 = Un-weeded control, W_1 = Weed free throughout the period, W_2 = Application of Pre-emergence herbicide, W_3 = Application of Pre-emergence herbicide followed by one hand weeding at 30 DAT, W_4 = Application of early post-emergence herbicide, W_5 = Application of early post-emergence herbicide followed by one hand weeding at 30 DAT.

Table 3. Interaction effects of nitrogen level and weed management practices on yield and yield contributing characters of *boro* rice

Interaction (N×W)	Plant height (cm)	Total tillers hill^{-1} (no.)	Effective tillers hill^{-1} (no.)	Grains panicle^{-1} (no.)	Length of panicle (cm)	1000-grain weight (g)	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Harvest index (%)
N_0W_0	89.78abc*	7.56bcd	6.00f	70.84f	20.20b	20.89	2.15h	3.13i	36.51
N_0W_1	84.55bc	8.44a-d	7.22b-f	92.22de	21.57ab	20.97	3.89def	4.30fgh	40.14
N_0W_2	87.78abc	7.22d	6.45ef	96.31cde	22.93a	20.89	4.69bcd	5.06b-f	42.19
N_0W_3	89.11abc	7.44cd	6.67def	100.40b-e	21.81ab	20.74	4.41b-f	4.50e-h	42.72
N_0W_4	89.44abc	8.89a-d	8.11a-f	98.79b-e	21.65ab	20.89	4.26c-f	4.53e-h	41.87
N_0W_5	81.56c	7.56bcd	6.67def	106.40a-e	21.83ab	20.74	4.61b-e	5.39a-e	42.25
N_1W_0	84.67bc	10.22abc	7.45b-f	89.50e	21.32ab	21.20	2.69gh	3.70ghi	36.80
N_1W_1	91.33ab	8.89a-d	7.45b-f	118.00ab	21.93ab	20.76	4.39b-f	5.68a-d	41.60
N_1W_2	91.11ab	9.11a-d	8.00a-f	114.60abc	22.05a	20.43	4.76bcd	5.17b-f	42.15
N_1W_3	90.11abc	10.22abc	8.33a-e	114.10abc	22.44a	20.62	4.37c-f	4.67d-g	41.82
N_1W_4	93.11ab	10.00a-d	8.33a-e	111.10a-d	22.27a	20.59	5.23abc	5.30a-f	44.18
N_1W_5	95.89a	10.11abc	8.22a-e	113.80abc	22.49a	20.73	5.40ab	5.27a-f	45.50
N_2W_0	88.00abc	7.89a-d	6.78def	92.59de	21.20ab	20.52	2.71gh	3.63hi	37.16
N_2W_1	92.78ab	9.33a-d	9.45ab	110.50a-d	21.58ab	21.31	4.59b-e	5.83abc	43.84
N_2W_2	94.67a	10.33a-d	8.87a-d	112.00a-d	21.22ab	21.08	4.32c-f	5.43a-e	44.36
N_2W_3	96.11a	9.33a-d	8.67a-e	113.30abc	22.11a	20.89	3.85def	5.17b-f	42.72
N_2W_4	88.89abc	9.56a-d	8.33a-e	112.30a-d	21.22a	21.40	3.43fg	4.67d-g	42.28
N_2W_5	87.34abc	8.00a-d	7.45b-f	109.60a-d	22.45a	20.56	3.68ef	4.90b-f	42.81
N_3W_0	89.33abc	8.44a-d	6.82c-f	97.60cde	21.35ab	20.90	2.79gh	3.70ghi	36.43
N_3W_1	89.56abc	9.34a-d	9.29ab	115.70abc	22.68a	20.65	5.21abc	5.60a-d	42.94
N_3W_2	96.56a	9.34a-d	8.78a-d	110.00a-d	21.42ab	21.09	4.95abc	5.87ab	43.92
N_3W_3	84.67bc	9.11a-d	8.78a-d	106.90a-e	21.71ab	20.49	4.80bcd	5.13b-f	42.86
N_3W_4	94.55a	10.00a-d	8.00a-f	105.80a-e	22.24a	20.85	5.13abc	5.78abc	43.50
N_3W_5	92.44ab	8.89a-d	8.67a-e	110.70a-d	22.78a	20.85	4.44b-e	4.79c-f	41.61
N_4W_0	95.89a	8.44a-d	7.44b-f	97.10cde	21.52ab	20.77	2.73gh	3.187i	39.67
N_4W_1	93.67ab	10.67a	10.11a	122.00a	22.55a	20.78	5.84a	6.23a	43.69
N_4W_2	91.89ab	10.43a	9.39ab	109.90a-d	22.19a	20.78	4.84bcd	5.37a-e	41.71
N_4W_3	92.67ab	9.78a-d	9.07abc	116.50abc	22.76a	20.31	5.27abc	5.63a-d	43.06
N_4W_4	88.11abc	9.11a-d	9.07abc	109.70a-d	22.47a	20.77	5.22abc	5.83abc	41.96
N_4W_5	93.00ab	9.13a-d	8.84a-d	113.10abc	22.47a	20.77	5.26abc	5.45a-e	44.48
Sig. level	*	**	*	**	*	NS	**	**	NS
CV (%)	5.17	15.28	13.88	9.49	4.21	1.97	11.89	10.78	4.86

*In a column, figures with same letters(s) or without letter(s) do not differ significantly whereas figures with dissimilar letters(s) differ significantly as per Duncan's Multiple Range Test (DMRT); **= Significant at 1% level of probability, *= Significant at 5% level of probability, NS = Non significant; N_0 = 0 kg N ha^{-1}, N_1 = 100% N from urea, N_2 = 100% N from poultry manure, N_3 = 50% N from PM + 50% N from urea, N_4 = 100% N from USG and W_0 = Un-weeded control, W_1 = Weed free throughout the period, W_2 = Application of Pre-emergence herbicide, W_3 = Application of Pre-emergence herbicide followed by one hand weeding at 30 DAT, W_4 = Application of early-post-emergence herbicide, W_5 = Application of early post-emergence herbicide followed by one hand weeding at 30 DAT

Afroz et al. (2019), Mou et al. (2017), and Parvez et al. (2013) also revealed similar research findings. Notably, treatment early post-emergence herbicide application followed by one hand weeding at 30 DAT produced the longest panicle (22.40 cm), whereas treatment no herbicide application produced the smallest panicle (21.12 cm) (Figure 2). Significant effects of different weed control techniques on panicle length were also noted by Salam (2020). The application of early post-emergence herbicide application followed by one hand weeding at 40 DAT treatment had the most grains panicle^{-1} (110.70), which was statistically equal to all other weeding treatments except the un-weeded control (W_0). In contrast, the W_0 (un-weeded control) treatment had the fewest grains panicle^{-1} (89.53). This result supports the findings of Parvez et al. (2013), who discovered that the application of Pretilachlor herbicide, followed by one-hand weeding at 30 DAT, produced the greatest number of grains panicle^{-1}. Since 1000-grain weight is a hereditary trait, it was unaffected by various weeding techniques (data not shown). Grain yield is the ultimate product and it varied significantly due various weed management practices (Figure 2).

The W_1 treatment (weed-free conditions during the rice growing season) produced the maximum grain yield (4.78 t ha^{-1}), which was statistically equivalent to all other weed management treatments except the unweeded control. The unweeded control treatment had the lowest grain yield (2.61 t ha^{-1}). The findings of Parvez et al. (2013), who used Pretilachlor herbicide and then hand-weeded once at 30 DAT to achieve the maximum grain of transplant *aman* rice, corroborated this outcome. Straw yield was significantly influenced by the various weed management practices (data not shown). The un-weeded control treatment produced the lowest straw production (3.47 t ha^{-1}), whereas the weed-free condition during the rice growth period treatment produced the maximum straw yield (5.53 t ha^{-1}). A considerable impact of the different weed control techniques was seen in the harvest index (data not shown). Application of early post-emergence herbicide Acetochlor 14% + Bensulfuron-methyl 4% @ 750 g ha^{-1}) followed by one hand weeding at 30 DAT had the greatest harvest index (43.33%). The unweeded treatment (control; W_0) had the lowest harvest index (37.31%).

3.5. Interaction effect of nitrogenous fertilizer and weed control techniques on *boro* rice yield and yield-contributing traits

When considering the interaction effect, plant height was significantly impacted by both nitrogen levels and weed management techniques (Table 3). The highest plant height (96.56 cm) was obtained from 50% N from PM + 50% N from urea with the application of pre-emergence herbicide, Commit 500EC @ 1 L ha^{-1}) treatment and the lowest one (81.56 cm) was recorded in 0 kg N ha^{-1} with the application of early post-emergence herbicide followed by one hand weeding at 30 DAT treatment (Table 3), this result was comparable with the result of Chhanda et al. (2021).

The number of total tillers per hill varied significantly as a result of the interaction between weed control techniques and varying nitrogenous fertilizer levels. The combination of 100% N from USG with weed-free conditions during the rice growing period and the treatment of no nitrogen fertilizer or 0 kg N ha^{-1} with application of pre-emergence herbicide produced the greatest number of total tillers hill^{-1} (10.67), while the N_0W_2 treatment produced the lowest number (7.22) (Table 3). Because of the plant's progressive growth-promoting mechanism, the combination of nitrogen fertilizer management and weed control techniques results in less crop weed competition and an increase in the total number of tillers hill^{-1}. Similar findings were reported by Hasanuzzaman et al. (2009), who demonstrated that nitrogen levels and weed management techniques had a favorable effect on the overall number of tillers hill^{-1}. The combination of nitrogenous fertilizer and weed control techniques resulted in notable variations in the number of productive tillers hill^{-1} (Table 3).

Application of 100% N from USG with weed-free throughout the growing period produced the most effective tillers hill^{-1} (10.11), whereas no nitrogen fertilizer or 0 kg N ha^{-1} with un-weeded control produced the fewest effective tillers hill^{-1} (6.00). Together, weed management techniques and nitrogen levels raised the effective tiller hill^{-1}. It might due to the acceleration of cellular activity of nitrogen during the growth and development stages which was supported by Kheya et al. (2024). Again, weed control methods suppress the growth of the weed plants favoring the vigorous growth of the crop plants leading to the increase in number of effective tillers per hill^{-1}. This finding corroborates the finding of Parvez et al. (2013). The interaction effect of varying nitrogenous fertilizer doses and weed control techniques resulted in a significant variation in panicle length (Table 3). Application of 0 kg N ha^{-1} with pre-emergence herbicide Pretilachlor had the longest panicle (22.93 cm) (Commit). The treatment no nitrogen fertilizer with unweeded control had the shortest panicle (20.20 cm) (Table 3).

The physiological mechanisms that increase cell division during panicle development may be favored by nitrogen levels, which would result in longer panicles. The combination of various nitrogenous fertilizer levels with weed control techniques had a substantial impact on the number of grain panicles^{-1} (Table 3). Application of 100% N from USG with weed free throughout the rice growing period produced the most grains panicle^{-1} (122.00), while the no nitrogen fertilizer or 0 kg N ha^{-1} with un-weeded control treatment produced the fewest grains panicle^{-1} (70.84). In comparison to no nitrogen fertilizer with un-weeded control, it was found that 100% N from USG with weed free throughout the growth season of rice generated 72.21% more grains panicle^{-1}.

Nitrogen helped in proper filling of grains which produced higher plump grains and thus the number of grain panicle^{-1} was increased. Similar research finding was also reported by Parvez et al. (2013) supported that the weed control methods have positive impact on increasing the number of grains panicle^{-1}. The interaction between weed management methods and varying nitrogenous fertilizer amounts had a major impact on grain yield (Table 3). 100% N from USG with weed free throughout the rice growing period treatment exhibited the highest grain yield (5.84 t ha^{-1}), which was statistically comparable to 100% N from urea with application of early post-emergence herbicide, 100% N from USG with application of early post-emergence herbicide (Acetochlor 14% + Bensulfuron-methyl 4% @ 750 g ha^{-1}), 50% N from PM + 50% N from urea with weed free throughout the rice growing period, and 50% N from PM + 50% N from urea with application of early post-emergence herbicide followed by one hand weeding at 30 DAT. The lowest grain yield (2.15 t ha^{-1}) was recorded from no nitrogen fertilizer used or 0 kg N ha^{-1} with un-weeded control treatment (Table 3).

Application of 100% N from USG with weed free treatment with application of herbicide followed by one hand weeding at 40 DAT provided adequate supply of N continuously without the crop-weed competition, resulted in highest grain yield in these treatments and this was supported by Shah et al. (2013). Weed management practices reduce the competition of nutrients between the crops and weed species leading to the production of higher number of effective tillers and grain yield and this finding showed compatibility with the findings of Parvez et al. (2013). The combination of weed control and nitrogen management strategies affected straw yield (Table 3). 100% N from USG with weed free condition generated the best straw yield (6.23 t ha^{-1}), whereas no nitrogen fertilizer or 0 kg N ha^{-1} with un-weeded control gave the lowest straw yield (3.13 t ha^{-1}) (Table 3). The same findings were made by Adhikari et al. (2018), who discovered that weed management techniques and nitrogen levels enhanced straw yield. The reason for this might be because the availability of nitrogen during the vegetative period, when primary, secondary, and tertiary tillers were beginning to form, led to a greater number of tillers and a significant buildup of dry matter. There was no discernible change in the harvest index when nitrogenous fertilizer and weed control techniques interacted (Table 3).

4. Conclusion

The treatment that yielded the maximum grain yield (5.84 t ha^{-1}) and the lowest weed density and dry weight was 100% N from USG with weed free conditions throughout the time. However, due to a lack of labor, farmers are unable to maintain weed-free conditions during the rice-growing season. Thus, it can be said that in order to effectively manage weeds and maximize grain yield, either 100% N from USG applied with pre-emergence herbicide (Commit 500 EC @ 1 L ha^{-1}) and then hand weeding at 40 DAT or application of USG with early post-emergence herbicide (Acetochlor 14% + Bensulfuron-methyl 4% @ 750g ha^{-1}) and then hand weeding at 30 DAT may be used. However, further research in other places is required to get a firm conclusion.

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Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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