Journal of Applied Sciences

ISSN 1812-5654

science alert

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OPEN ACCESS Journal of Applied Sciences

ISSN 1812-5654
DOI: 10.3923/jas.2019.654.661

Research Article
Effect of Seeding Depth and Weed Management Options on Weed Control and Yield Performance of Dry Direct Seeded Rice

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Abstract

Background and Objective: Rice cultivation using the conventional puddled transplanted system is no longer sustainable in Bangladesh due to shortage of irrigation water. Dry direct seeding is an alternative system that provides the avenue of rice cultivation using less than 50% irrigation water. However, weed is the major constraint to the adoption of dry direct seeded rice (DDSR) system. Manual weeding is tedious and costly. Herbicidal weed control is very easy and economic. However, reliance on only herbicide creates environmental hazard. In this situation, integration of cultural, mechanical and chemical methods for controlling weed is required to reduce weeding cost and dependency on herbicide. **Materials and Methods:** Three seeding depths viz. 2 cm (D1), 5 cm (D2) and 8cm (D3) and (b) seven weed management options viz., no weeding (M_1), Four hand weeding at 20, 35, 50 and 65 DAS (M_2), Blade weeding plus three hand weeding at 20, 35 and 50 DAS (M_3), Blade and rake plus three hand weeding at 20, 35 and 50 DAS (M_4), Sirius 10 wp (Pyrazosulfuron-ethyl) at 125 g ha^{-1} with one hand weeding at 20 DAS fb Sirius (M_5), Top (Pretilachlor) at 1 L ha^{-1} with one hand weeding at 20 DAS fb Top (M_6), Panida (Pendimethalin) at 2.5 L ha^{-1} with one hand weeding at 20 DAS fb Panida (M_7) were included in a split-plot design with three replications. **Results:** The results revealed that seeding depth and weed management options had significant interaction effect on grain yield and weed density and dry matter. The lowest weed density and dry matter was found with seeding of rice seed at 5 cm and application of Pendimethalin at 1 DAS followed by one hand weeding at 20 DAS plus application of Pendimethalin again just after weeding gave the lowest weed density and matter and resulted in highest rice yield among the treatment combinations. **Conclusion:** It may be concluded that sowing at 5 cm depth and pre-emergence application of Pendimethalin followed by a hand weeding at 20 DAS fb Pendimethalin application could be considered as the best way to control weeds in dry direct seeded rice.

Key words: Seeding depth, pre-emergence herbicides, weed control efficacy, weed index, yield over control

Citation: Md. Moshiur Rahman and Md. Mehedi Masood, 2019. Effect of seeding depth and weed management options on weed control and yield performance of dry direct seeded rice. J. Applied Sci., 19: 654-661.

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Rice (*Oryza sativa* L.) is grown pre-dominantly by transplanting of seedling on puddled soil followed by keeping standing water for easy crop establishment and weed control[1-3]. Currently, shortage of irrigation water both from surface and underground is posing a serious threat to the sustainability of rice production under conventional puddled transplanted system. Dry direct seeding (DDS) is an alternative rice production system which allows production of rice using 50-60% less irrigation water and gives higher economic return[4]. Dry direct seeded rice (DDSR) offers the advantages of faster and easier planting, ensure proper plant population, reduced labour and hence less drudgery, 10-12 earlier crop maturity, more efficient water utilization and often higher profit in areas with assured water supply[5]. The weed pressure in dry seeded rice is higher because soil moisture is maintained at around field capacity at the root zone, such an aerobic soil condition encourages weed growth in this system. Thus development of sustainable weed management approach for DDSR is a great challenge for widespread adoption of the dry seeded rice technology. Weeds cause 39-41% yield reduction in DDSR compared to the weed-free condition[6]. Dry direct seeding of rice is profitable in cases where adequate weed control methods are available to keep the crop free from weeds[7,8], however, in absence of proper weed control, rice yields are reduced by 35-100% in DSR[9,10].

Weed management is generally done using manual and mechanical methods, which are highly labour intensive and costly. At present due unavailability of labour and higher wages, dependency on herbicide use for weed control is increasing. The use of herbicide causes adverse effects on human health and environment. The use of herbicide along with different manual weed control measures could be help to reduce weeding cost and amount of herbicide use towards reducing the adverse effect on environment. Locally available "blade or seniweeder" and 'field rake' can be used as mechanical tools to control weeds in the line sown rice field. Depth of seeding is a cultural practice that may have influence on the crop weed competition and could be used as a tool for weed management. Moreover, the use of pre-emergence herbicide along with mechanical weed control measures and sowing at optimum depth could also help effective and economic weed management with minimal herbicide use. The present study was therefore, initiated to elucidate the effect of integrated use of seeding depth, mechanical and herbicidal measures on weed control in dry direct seeded Boro rice.

MATERIALS AND METHODS

The experiment was conducted at the Agronomy Field Laboratory (AFL), Bangladesh Agricultural University (BAU), Mymensingh during the period from December, 2009-June, 2010 and December, 2010-June, 2011. The site is medium low land located at 24°75 N Latitude, 90°5 E Longitude and altitude 18 m) during December, 2009-May, 2010 and December, 2010-May, 2011. The experiment site was a well drained medium low land belonging to non-calcareous dark grey soil under the old brahmaputra flood plain Agro-ecological Zone (AEZ-9). The soil had pH 6.85 and contained 1.50% organic matter, 0.074% total nitrogen, 11.85 ppm phosphorus, 0.18% potassium, 9.5 ppm sulphur and 0.43 ppm zinc. The locality experiences high rainfall, relative humidity, temperature and long days during the Kharif season (April-September) while scarce rainfall, low relative humidity, low temperature and short days in the Rabi season (October-March).

The experiment used three seeding depths: 2 cm (D1), 5 cm (D2) and 8 cm (D3) and 7 integrated weed management options: No weeding (M_1), four hand weeding at 20, 35, 50 and 65 DAS (M_2), seniweeder plus three hand weeding at 20, 35 and 50 DAS (M_3), seniweeder and rake plus three hand weeding at 20, 35 and 50 DAS (M_4), Sirius 10 wp (Pyrazosulfuron-ethyl) at 125 g ha^{-1} at sowing followed by (fb) one hand weeding at 20 DAS fbsirius again (M_5), top (Pretilachlor) at 1 L ha^{-1} fb one hand weeding at 20 DAS fb top again (M_6), Panida (Pendimethalin) at 2.5 L ha^{-1} fb one hand weeding at 20 DAS fb Panida again (M_7), in a randomized complete block design with three replications. The area of each unit plot was 10 m^2 (4.0×2.5 m). The distances between the blocks and unit plots were 2.0 and 1.0 m, respectively. Seed of rice variety BRRI dhan29 was primed and then sown on 25 December, 2009 on dry cultivated land at 25×15 cm spacing allocating 5 seeds per hill at 2, 5 and 8 cm depth as per treatments. Priming of seed was done by soaking in water for 24 h at room temperature followed by incubation for 30 h at 35°C. Fertilizers were applied at the rate of 120,14, 48, 18 and 1 kg ha^{-1} of N, P, K, S and Zn, respectively in the form of urea, triple super phosphate, muriate of potash, gypsum and zinc sulphate[11]. All the fertilizers except urea were applied at the time of final land preparation. Urea was top dressed in four equal installments at 20, 35, 50 and 65 days after sowing. Weed control was done as per treatment specification. Pre-emergence herbicides were applied at 1 and 20 DAS. Application of herbicide at 20 DAS was made after hand

weeding. Irrigation was applied to keep the soil moisture at field capacity until the crop reached maximum tillering stage and then 2-3 cm irrigation water was kept upto flowering stage. The crop was infested by stem borer and rice bug which were controlled by applying mortar at 12.5 mL 10^{-1} L of water and Carate at 12.5 mL 10^{-1} L of water. The crop was harvested at fully maturity (when 80% grains became golden yellow in color) from central 3.15 m^2 areas of each plot. At maturity of the crop, 10 hills were randomly selected to measure plant height, number of tillers m^{-2}, number of panicle m^{-2}, panicle length, number of filled and unfilled grains $panicle^{-1}$. The dry weight of grains of 3.15 m^2 areas was adjusted at 14% moisture content and finally converted to ton per hectare.

Crop and weed samples were collected from two randomly selected spots by placing a 25×25 cm quadrate in each plot at PI stage (65 days after sowing, DAS) to record dry matter of weed and crop. The dry matter of weed and crop was expressed as g m^{-2} after drying those in an oven at 70°C for 72 h or constant weight. The crop was harvested at fully maturity (when 80% grains became golden yellow in color) from central 3.15 m^2 areas of each plot. Before harvesting, five hills were randomly selected from each plot to record data on plant height, number of tillers m^{-2}, number of panicle m^{-2}, panicle length, number of filled and unfilled spikelets $panicle^{-1}$. The grain yield was adjusted at 14% moisture content and finally converted to ton per hectare. Impact of different weed control methods were assessed in term of weed control efficiency (WCE) and weed index (WI), which were calculated by using the following equation[12]:

$$WEC = \frac{DMC - DMT}{DMT} \times 100$$

Where:
DMC = Dry matter of weed in control plot
DMT = Dry matter of weed in a particular treatment:

$$WI = \frac{X - Y}{X} \times 100$$

Where:
X = Yield from weed free plot
Y = Yield from treated plot

The collected data from different experiments were compiled and subjected to analysis following Analysis of Variance (ANOVA) technique for Randomized Complete Block Design with the help of a computer based package programme MSTAT-C. The differences among the treatment means were adjudged by Duncan's Multiple Range Test[13].

RESULTS

Weed and crop dry matter: At 65 days after sowing (DAS), weed dry matter varied significantly in response to seeding depth in 2010-11 but not in 2009-10 (Fig. 1). The highest weed dry matter was obtained from the D_3 treatment i.e., 8 cm seeding depth and the lowest from 2 cm seeding depth. On the other hand, the crop dry matter significantly varied in response of seeding depth in both the years (Fig. 1). The highest crop dry matter was obtained from 5 cm seeding depth and the lowest from 8 cm seeding depth (Fig. 1). In case of weed management options, weedy (control) plots produced the highest weed dry matter and the application of Panida (Pendimethalin) at 2.5 L ha^{-1} with one hand weeding at 20 DAS (M_7) followed by again Panida application produced the lowest weed dry matter. On the other hand, this treatment gave the highest crop dry matter in 2009-10 while application of Sirius 10 wp (Pyrazosulfuron-ethyl) at 125 g ha^{-1} with one hand weeding at 20 DAS followed by Sirius 10 wp gave the highest in 2010-11 (Fig. 2). The highest WDM was recorded

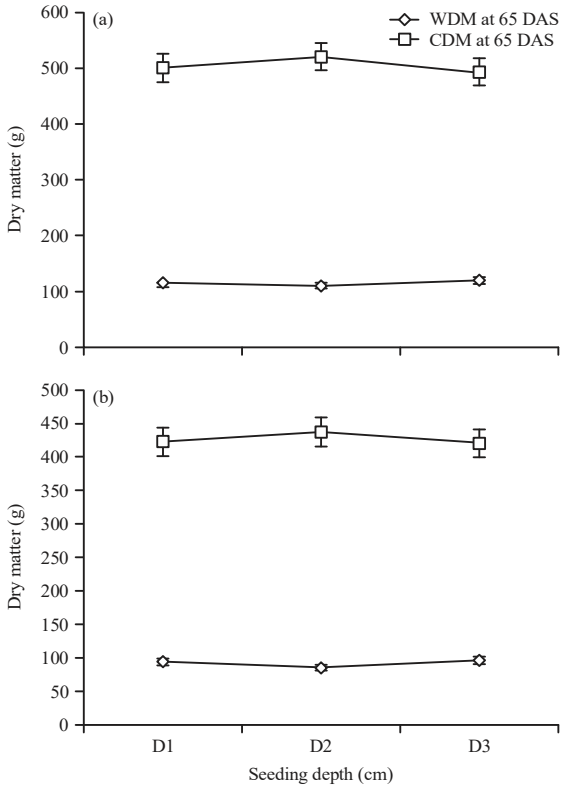

Fig. 1(a-b): Effect of different seeding depth on weed dry matter (WDM) and crop dry matter (CDM) of Boro rice under dry direct seeded system of cultivation during (a) 2009-10 and (b) 2010-11 seasons
Vertical bar indicates the LSD ($p \leq 0.05$)

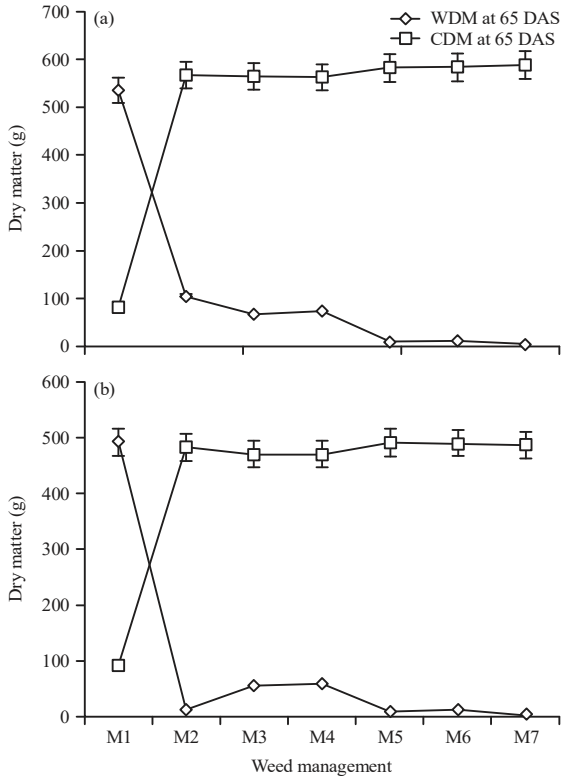

Fig. 2(a-b): Effect of different weed management on weed dry matter (WDM) and crop dry matter (CDM) in (a) 2009-10 and (b) 2010-11
Vertical bar indicates the LSD ($p \leq 0.05$)

from the no weeding plots at 8 cm seeding depth ($M_1 \times D_3$) followed by the interaction of $M_1 \times D_1$ and $M_1 \times D_2$. The lowest WDM was recorded with Panida (Pendimethalin) at 2.5 L ha^{-1} with one hand weeding at 20 DAS with 5 cm depth ($M_7 \times D_2$) followed $M_7 \times D_1$ and $M_7 \times D_3$ (Fig. 3). Crop dry matter (CDM) was significantly affected by the interaction effect of seeding depth and weed management in the year 2009-10 but not in 2010-11. In 2009-10, the highest CDM at 65 DAS was recorded from the interaction of Panida (Pendimethalin) at 2.5 L ha^{-1} with one hand weeding at 20 DAS with 5 cm seeding depth ($M_7 \times D_2$) followed by $M_5 \times D_2$ and $M_6 \times D_2$ and the lowest was recorded in weedy plots and 8 cm depth ($M_1 \times D_3$) followed by $M_1 \times D_2$ and $M_1 \times D_2$ (Fig. 3).

Weed control efficiency, weed index and yield increase over control: Weed control efficiency (%WCE), weed index (%WI) and yield increase over control (%YIOC) considerably varied among the treatment combinations in both year 2009-10 and 2010-11. The weeding treatments showed more than 80% weed control efficiency than the non-weeded control (Table 1). The highest weed control efficiency was observed from the interaction $M_7 \times D_2$ followed $M_7 \times D_1$, $M_7 \times D_3$ in both the years. The lowest weed control efficiency was observed from the interaction $M_2 \times D_2$ which was similar with $M_2 \times D_1$ and $M_2 \times D_3$ in the year 209-10. But in the year 2010-11, the lowest weed control efficiency was observed from the interaction $M_3 \times D_3$ followed by $M_3 \times D_2$ and $M_3 \times D_1$. The

Table 1: Effect of interaction between seeding depth and weed management options on the performance of Boro rice under dry bed direct seeded system of cultivation in 2009-10 and 2010-11

	Weed control efficiency (%)		Weed Index (%)		YIOC (%)	
Management×depth	2009-2010	2010-2011	2009-2010	2010-2011	2009-2010	2010-2011
M_1D_1	0.00	0.00	84.67	84.78	0.00	0.00
M_1D_2	0.00	0.00	76.70	76.70	0.00	0.00
M_1D_3	0.00	0.00	81.61	81.61	0.00	0.00
M_2D_1	80.35	94.41	0.00	0.00	552.45	466.02
M_2D_2	79.87	98.73	0.00	0.00	329.14	378.30
M_2D_3	81.33	98.70	0.00	0.00	443.80	508.49
M_3D_1	86.67	88.56	2.67	2.68	535.01	447.25
M_3D_2	87.19	88.46	2.36	2.47	319.01	362.44
M_3D_3	87.96	88.09	7.19	7.29	404.71	493.84
M_4D_1	86.17	88.71	-4.41	-4.35	581.24	442.29
M_4D_2	86.21	88.93	3.04	3.09	316.09	358.25
M_4D_3	86.59	88.90	6.43	6.53	408.84	480.23
M_5D_1	98.27	98.12	-5.75	-5.69	589.97	469.26
M_5D_2	98.52	98.36	0.82	0.93	325.63	381.04
M_5D_3	98.06	97.70	7.14	7.14	404.96	507.33
M_6D_1	97.76	97.17	-3.79	-3.85	577.21	465.26
M_6D_2	97.88	97.83	0.77	0.77	325.83	377.67
M_6D_3	97.64	97.28	7.40	7.45	403.55	500.35
M_7D_1	99.19	99.20	-5.58	-5.52	588.88	475.30
M_7D_2	99.34	99.21	-1.59	-1.54	335.96	386.14
M_7D_3	99.10	99.18	4.97	5.02	416.78	511.63

D_2: 5 cm depth and D_3: 8 cm depth, M_1: No weeding, M_2: Four hand weeding at 20, 35, 50 and 65 DAS, M_3: Blade weeding plus three hand weeding at 20, 35 and 50 DAS, M_4: Blade and Rake plus three hand weeding at 20, 35 and 50 DAS, M_5: Sirius 10 wp (Pyrazosulfuron-ethyl) at 125 g ha^{-1} with one hand weeding at 20 DAS, M_6: Top (Pretilachlor) at 1 L ha^{-1} with one hand weeding at 20 DAS and M_7: Panida (Pendimethalin) at 2.5 L ha^{-1} with one hand weeding at 20 DAS

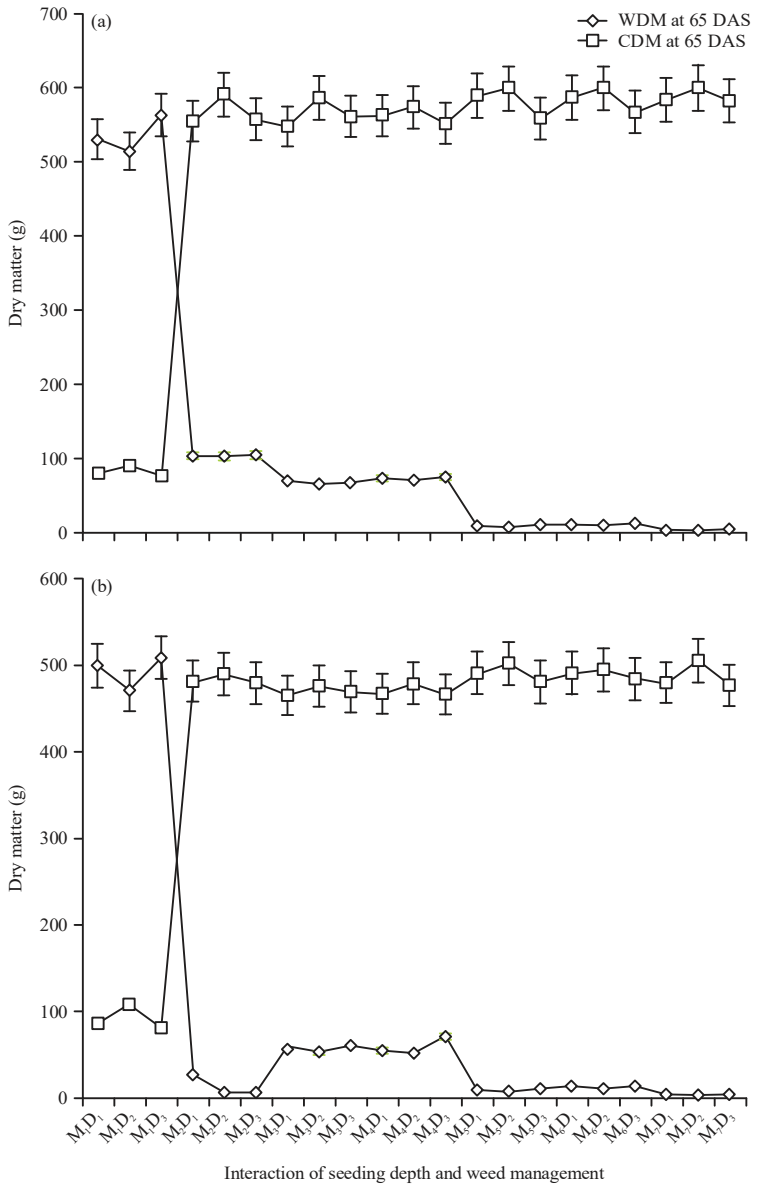

Fig. 3(a-b): Interaction effect of seeding depth and weed management on weed dry matter (WDM) and crop dry matter (CDM) in (a) 2009-10 and (b) 2010-11. D_1: 2 cm depth, D_2: 5 cm depth and D_3: 8 cm depth, M_1: No weeding, M_2: Four hand weeding at 20, 35, 50 and 65 DAS, M_3: Blade weeding plus three hand weeding at 20, 35 and 50 DAS, M_4: Blade and Rake plus three hand weeding at 20, 35 and 50 DAS, M_5: Sirius 10 wp (Pyrazosulfuron-ethyl) at 125 g ha^{-1} with one hand weeding at 20 DAS, M_6: Top (Pretilachlor) at 1 L ha^{-1} with one hand weeding at 20 DAS and M_7: Panida (Pendimethalin) at 2.5 L ha^{-1} with one hand weeding at 20 DAS)

highest weed index was observed with interaction $M_1 \times D_1$ followed $M_1 \times D_3$ and $M_1 \times D_2$. The lowest weed index was observed from the interaction $M_5 \times D_1$ followed by $M_7 \times D_1$ and $M_4 \times D_1$. In the year 209-10, the highest grain yield increase over control was found from the interaction between $M_5 \times D_1$ followed by $M_7 \times D_1$ and $M_4 \times D_1$ and lowest yield increased over control was found from the interaction between $M_4 \times D_2$ followed by $M_3 \times D_2$ and $M_6 \times D_2$ (Table 1). In 2010-11, the highest yield increase over control was found with $M_7 \times D_3$ followed by $M_2 \times D_3$ and $M_5 \times D_3$ and lowest was found in $M_4 \times D_2$ followed by $M_3 \times D_2$ and $M_6 \times D_2$. In the year 2009-10, the yield increase over control among the interaction ranged between 316.09-589.97% and in the year 2010-11, the yield increase over control (YIOC%) among the interaction ranged between 358.25-511.63% (Table 1).

Table 2: Effect of seeding depth, weed management options and their interaction on yield and yield attributes of Boro rice under DDSR-AWD of cultivation in 2009-10 and 2010-11 seasons

Seeding depth × weed management	Plant height (cm)		Number of tillers m^{-2}		Number of panicle m^{-2}	
	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11
M_1D_1	57.22^{f}	52.10^{i}	136.33^{f}	145.66	105.66	79.33^{j}
M_1D_2	60.15^{f}	57.99^{h}	186.33^{d}	171.33	119.00	94.66^{i}
M_1D_3	59.65^{f}	50.72^{j}	158.66^{e}	140.00	91.33	74.66^{k}
M_2D_1	92.45^{de}	88.53^{f}	344.00^{c}	306.00	273.33	245.00^{c}
M_2D_2	95.53^{d}	91.18^{e}	363.66^{ab}	314.33	292.00	242.00^{d}
M_2D_3	91.44^{e}	87.50^{g}	348.66^{bc}	303.66	282.00	245.33^{c}
M_3D_1	89.44^{e}	97.53^{cd}	345.33c	303.33	276.66	251.33^{b}
M_3D_2	91.04^{e}	98.76^{b}	365.66^{ab}	308.66	323.66	251.00^{b}
M_3D_3	90.89^{e}	97.03^{d}	357.66b	299.66	312.00	249.00^{b}
M_4D_1	89.81	97.39^{cd}	369.00^{a}	301.00	297.33	254.66^{a}
M_4D_2	97.11^{cd}	97.83^{cd}	363.00^{ab}	312.00	292.00	251.33^{b}
M_4D_3	94.98^{d}	97.24^{d}	354.00^{b}	331.00	282.00	252.00^{ab}
M_5D_1	93.44^{de}	97.76^{cd}	362.00^{ab}	306.00	291.33	237.00^{ef}
M_5D_2	97.75^{cd}	99.53^{b}	355.00^{b}	315.00	289.33	235.00^{f}
M_5D_3	91.44e	97.90^{cd}	345.66^{c}	302.33	272.00	233.00^{f}
M_6D_1	100.01^{c}	98.33^{c}	352.66^{b}	305.33	275.66	240.66^{d}
M_6D_2	103.70^{ab}	98.60^{b}	366.00^{ab}	315.00	278.00	240.33^{d}
M_6D_3	98.09^{cd}	97.55^{cd}	346.33^{c}	302.66	269.33	239.00^{de}
M_7D_1	98.42^{cd}	98.56^{b}	349.66^{bc}	309.66	299.00	230.00^{fg}
M_7D_2	105.14^{a}	100.66^{a}	362.00^{ab}	321.33	267.66	247.66^{c}
M_7D_3	101.42^{bc}	97.30^{d}	364.33^{ab}	305.66	270.33	226.66^{h}
Level of significance	***	***	***	NS	NS	***
Sx						
CV%	1.93	2.63	3.81	6.46	8.20	4.59

In a column, with the same letter(s) or without letter(s) do not differ significantly whereas, figures with dissimilar letter differ significantly (as per DMRT) at 5% level of probability, NS: Not significant, *Significant at 5% level of probability, **Significant at 1% level of probability, ***Significant at 0.1% level. D_1: 2 cm depth, D_2: 5 cm depth and D_3: 8 cm depth, M_1: No weeding, M_2: Four hand weeding at 20, 35, 50 and 65 DAS, M_3: Blade weeding plus three hand weeding at 20, 35 and 50 DAS, M_4: Blade and Rake plus three hand weeding at 20, 35 and 50 DAS, M_5: Sirius 10 wp (Pyrazosulfuron-ethyl) at 125 g ha^{-1} with one hand weeding at 20 DAS, M_6: Top (Pretilachlor) at 1 L ha^{-1} with one hand weeding at 20 DAS and M_7: Panida (Pendimethalin) at 2.5 L ha^{-1} with one hand weeding at 20 DAS

Yield and related attributes: Seeding depth and weed management practices had significant interaction effect on plant height, tiller density, grains panicle^{-1}, 1000-grain weight, grain and straw yield. The combination effect of 5 cm sowing depth and weed management with Pendimethalin at 2.5 L ha^{-1} followed by one hand weeding at 20 DAS plus pendimethalin (M_7) gave the highest grain yield (6.25 and 5.26 t ha^{-1}). This treatment combination (M_7D_2) also produced the tallest plant (105 and 101 cm), highest grains/panicle (102 and 99), 1000-grain weight (24.09 and 24.08 g) and straw yield (8.93 and 7.97 t ha^{-1}) in 2009-10 and 2010-11. The combination of seeding depth 8 cm and no weeding plot gave the lowest values for all the yield and related characters (Table 2, 3).

DISCUSSION

Seeding at 5 cm showed the highest crop dry matter and the lowest weed dry matter among the seeding rates. The crop sown at this depth also produced the highest tiller and panicle density and highest yield. This may be attributed to the optimum depth that provides adequate root zone area which helped in providing sufficient moisture level for germination and enhanced early growth of seedling. This ultimately enhanced better establishment and above ground biomass production compared to the seed planted at shallow (0 -1 cm) depth. At deeper root zone, due to low temperature, the availability of nutrient element becomes decreased and development of root system and tillers become restricted[14]. Sowing at deeper depth adversely affects the dynamics of seed germination due to weak coleoptiles while sowing at shallow depth causes rapid drying of the soil surface in peak summers[15].

Application of pre-emergence herbicide such as pendimethalin and others followed by a hand weeding and again application of a pre-emergence herbicide appeared as the best weed management practice for dry direct seeded rice. This treatment showed the highest weed control efficiency and the lowest weed index at all levels of seeding depth. Pre-emergence application of pendimethalin 1.0 kg ha^{-1} or pretilachlor 0.75 kg ha^{-1}, both supplemented with one hoeing at 30 days after sowing, recorded effective

Table 3: Effect of seeding depth, weed management options and their interaction on yield and yield attributes of Boro rice under DDSR-AWD of cultivation in 2009-10 and 2010-11 seasons

Seeding depth × weed management	No. of filled grains/panicle		1000 grain wt. (g)		Grain yield (t ha^{-1})		Straw yield (t ha^{-1})	
	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11
M_1D_1	55.86^{i}	50.6^{l}	22.72^{d}	23.08^{b}	0.91^{e}	0.92^{f}	1.93^{i}	1.81^{g}
M_1D_2	58.60^{h}	54.7^{k}	21.65^{e}	23.12^{b}	1.51^{d}	1.19^{e}	2.95^{g}	2.72^{f}
M_1D_3	57.73^{h}	49.9^{l}	22.88^{d}	23.07^{b}	1.21^{d}	0.86^{f}	2.35^{h}	1.79^{g}
M_2D_1	95.50^{cd}	92.1^{d}	22.93^{cd}	23.19^{b}	5.98^{c}	5.24^{bc}	7.63^{e}	6.67^{e}
M_2D_2	95.76^{cd}	94.2^{cd}	23.16^{c}	23.29^{b}	6.48^{a}	5.33^{bc}	8.68^{b}	7.54^{b}
M_2D_3	95.83^{cd}	91.8^{e}	23.47^{bc}	23.18^{b}	6.58^{a}	5.23^{bc}	8.37^{c}	6.85^{d}
M_3D_1	91.36^{e}	87.7^{h}	23.04^{c}	22.98^{b}	5.82^{c}	5.07^{cd}	7.27^{f}	6.47^{e}
M_3D_2	89.53^{g}	89.2^{g}	23.52^{bc}	23.11^{b}	6.32^{ab}	5.17^{c}	8.53^{b}	7.27^{c}
M_3D_3	90.30^{ef}	87.1^{h}	23.37^{bc}	22.99^{b}	6.10^{b}	5.01^{cd}	7.80^{de}	6.42^{e}
M_4D_1	90.36^{ef}	83.3^{j}	23.23^{bc}	23.56^{ab}	6.24^{ab}	5.02^{cc}	8.04^{d}	6.69^{e}
M_4D_2	91.53^{e}	85.6^{i}	23.51^{bc}	23.85^{a}	6.28^{ab}	5.14^{c}	8.15^{d}	7.83^{a}
M_4D_3	93.13^{de}	83.1^{j}	23.43^{bc}	23.60^{ab}	6.15^{b}	4.99^{d}	7.86^{de}	6.68^{e}
M_5D_1	94.66^{d}	93.5^{d}	22.96^{cd}	23.88^{a}	6.32^{ab}	5.27^{bc}	8.13^{d}	7.15^{c}
M_5D_2	95.03^{cd}	95.1^{c}	23.42^{bc}	24.03^{a}	6.42^{ab}	5.39^{b}	8.62^{b}	7.52^{b}
M_5D_3	95.40^{cd}	93.1^{d}	23.53^{bc}	24.00^{a}	6.11^{b}	5.22c	7.80^{de}	6.98^{d}
M_6D_1	96.13^{c}	91.1^{e}	23.42^{bc}	23.92^{a}	6.21^{ab}	5.24^{bc}	7.89^{de}	7.21^{c}
M_6D_2	96.70^{c}	91.8^{e}	23.89^{ab}	23.93^{a}	6.43^{ab}	5.29^{bc}	8.12^{d}	7.04^{cd}
M_6D_3	95.43^{cd}	90.2^{f}	23.70^{b}	23.96^{a}	6.09^{b}	5.16^{c}	7.67^{e}	6.88^{d}
M_7D_1	100.66^{b}	97.2^{b}	23.61^{b}	23.94^{a}	6.31^{ab}	5.33^{bc}	8.02^{d}	7.01^{cd}
M_7D_2	102.00^{a}	99.6^{a}	24.09^{a}	24.08^{a}	6.58^{a}	5.89^{a}	8.93^{a}	7.97^{a}
M_7D_3	96.76c	97.1^{b}	23.98^{ab}	23.94^{a}	6.25^{ab}	5.26^{bc}	7.95^{de}	6.99^{d}
Level of significance	***	***	***	***	*	***	***	***
CV%	2.10	3.29	0.27	0.13	3.86	5.52	2.41	3.11

In a column, with the same letter(s) or without letter(s) do not differ significantly whereas figures with dissimilar letter differ significantly (as per DMRT) at 5% level of probability, NS: Not significant, *Significant at 5% level of probability, **Significant at 1% level of probability, ***Significant at 0.1% level, D_1: 2 cm depth, D_2: 5 cm depth and D_3: 8 cm depth, M_1: No weeding, M_2: Four hand weeding at 20, 35, 50 and 65 DAS, M_3: Blade weeding plus three hand weeding at 20, 35 and 50 DAS, M_4: Blade and Rake plus three hand weeding at 20, 35 and 50 DAS, M_5: Sirius 10 wp (Pyrazosulfuron-ethyl) at 125 g ha^{-1} with one hand weeding at 20 DAS, M_6: Top (Pretilachlor) at 1 L ha^{-1} with one hand weeding at 20 DAS and M_7: Panida (Pendimethalin) at 2.5 L ha^{-1} with one hand weeding at 20 DAS

control of weeds. Pendimethalin at 1.5 kg ha^{-1} plus one hand weeding showed the highest weed control efficiency than any other weed control treatments in the present study. Higher weed control efficiencies resulted for application of pendimethalin followed by one or two hand weeding[16]. Sequential spray of pre-emergence application of pendimethalin (1 kg ha^{-1}) followed by bispyribac sodium (30 g ha^{-1}) at 15 days after sowing gave best control of weeds in Dry DSR[17]. It was found that pre emergence application of pendimethalin alone gave significantly lesser number of effective tillers m^{-2} as compared to integration of pre-emergence application of pendimethalin with post emergence application of bispyribac/azimsulfuron/2,4-D treatments[18]. Weed control played a key role in improving the yield of rice because of 18% increase of panicle m^{-2} due to weed control over its lower level[19]. Weed management practices and weed-free check gave significantly higher yield attributing characters and yield compared to the weedy check[20]. It was reported that pre-emergence application of pendimethalin 1.0 kg ha^{-1} as well as pretilachlor 0.75 kg ha^{-1}, both supplemented with one hoeing at 30 days after sowing, recorded effective control of weeds[7].

The present study shows that the weed free plot and weed control treatment imposed plots recorded crop dry matter of 500-600 g m^{-2} at panicle initiation stage which resulted in very promising yield and it was possible due to good control of weeds due to these treatments. The weedy plots produced above 500 g m^{-2} of weed dry matter that reduced the crop dry matter to only 80-90 g m^{-2} and contributed to about 77-85% yield loss. The greater (95%) yield loss with weed biomass of 458 and 692 g m^{-2} in wet and dry seasons was reported[21]. The higher weed index was found from no weeding with 2 cm seeding depth and lower weed index was observed in other weed management treatment. The present study showed that among the weed management approaches, application of herbicide with one hand weeding at 20 DAS was better than other weed management options. Application of Penoxsulam or bispyribac-sodium alone was effective to reduce weed density compared with the non-treated control[22]. However, more effective weed control was evident in the present study when pre-emergence application of pendimethalin was followed by one hand weeding at 20 DAS followed by application of pendimethalin on the same day compared with two hand weeding.

CONCLUSION

The result revealed that seeding at 5 cm and application of Panida followed by one hand weeding at 20 DAS plus application of Panida gave the best weed control and highest rice yield. Therefore, it may be concluded sowing at 5 cm depth and pre-emergence application of Panida followed by a hand weeding at 20 DAS fb Panida application could be considered as the best way to control weeds in dry direct seeded rice instead of four hand weeding.

SIGNIFICANCE STATEMENT

The study focuses on the development of weed control technique in dry direct seeded rice integrating sowing depth, hand or mechanical weeding as well as manual weed to formulate a sustainable weed management strategy.

ACKNOWLEDGMENTS

We thank the Programme for Agriculture and Life Science (PALS) of Bangladesh Academy of Science (BAS) and the United States Department of Agriculture (USDA) for proving fund for this research under the project # CR-21.

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