View metadata, citation and similar papers at core.ac.uk
brought to you by CORE
provided by University of Queensland eSpace

The Journal of Animal & Plant Sciences, 25(6): 2015, Page: 1675-1684
ISSN: 1018-7081

ECONOMICS OF NITROGEN AND INTEGRATED WEED MANAGEMENT IN DRY SEEDED RICE

S. Ahmed[1, 2] T. H. Awan[1*] M. Salim[2] and B. S. Chauhan[3]

[1]Crop and Environmental Sciences Division, International Rice Research Institute, Los Baños, Manila, Philippines
[2]Agronomy Division, Bangladesh Agricultural University, Mymensingh, Bangladesh
[3]Queensland Alliance for Agriculture and Food Innovation (QAAFI), The University of Queensland, Toowoomba, Queensland, Australia
[*]Corresponding author's email: tahirawanrri@gmail.com

ABSTRACT

Dry-seeded rice (DSR) is an emerging production technology in many Asian countries, whose profitability is higher than puddled transplanted rice. However, weed infestations are severe in the DSR. To increase the competitiveness with weeds and achieve the yield potential of rice, weed management in DSR needs an integration of herbicides and higher nitrogen (N) fertilizer rates. Field experiments were conducted in the aman (wet season) 2012 and 2013 in Bangladesh to evaluate the effect of N rates (0, 80, 120, and 160 kg ha^{-1}) and weed control methods [one hand weeding (HW); pendimethalin 1000 g ai ha^{-1} followed by (fb) ethoxysulfuron 20 g ai ha^{-1}; pendimethalin fb ethoxysulfuron fb one HW; and weed-free] on weed growth and crop yield in DSR. The experiment was arranged in a split-plot design with three replications. The highest grain yield (5.3 to 5.5 t ha^{-1}) was recorded in the season-long manual weed-free treatment when N rate was160 kg ha^{-1}; however, because of the high cost of labor, this method was not profitable. The use of pendimethalin fb ethoxysulfuron fb one HW effectively controlled weeds and produced a similar yield with the weed-free treatment for all levels of N. However, weed management cost was also higher because of the involvement of one HW. Although pendimethalin fb ethoxysulfuron treatment had always lower yielded than the pendimethalin fb ethoxysulfuron fb one HW, grain yield increased and net profit was similar when N rate increased from 120 to 160 kg ha^{-1}. Considering weed control efficiency, yield, and economics, pendimethalin fb ethoxysulfuron fb one HW with 120 kg N ha^{-1} may be recommended to growers. However, if laborers are not available for hand weeding, pendimethalin fb ethoxysulfuron with 160 kg N ha^{-1} is the best option to achieve high yield in DSR.

Keywords: Labor, manual weeding, herbicides, weed suppression, rice yield, resource conservation.

INTRODUCTION

Bangladesh is the fourth largest rice-producing and -consuming country in the world (FAO, 2013). However, because of inadequate water and the high cost of farm labor, rice production is becoming less profitable to farmers in this country (Ahmed and Chauhan, 2014). Puddled transplanted rice is the common traditional rice production method, which is highly labor- and water-intensive (Ahmed *et al*., 2011). Rice growers of Bangladesh are demanding alternate rice production systems, which require less water and labor. Dry-seeded rice (DSR) is becoming popular to growers in many parts of Asia as the production system is conducive to mechanization (Chauhan *et al*., 2012). However, weeds are the major biotic constraint to the sustainability of DSR (Ahmed *et al*., 2014).

Studies with DSR indicated that, if weeds are not controlled in this production system, yield losses are more than that in puddled transplanted rice (Chauhan and Johnson, 2011). However, the extent of weed infestation in DSR depends on several factors such as weed seed bank, tillage practices, cultivar used, planting season, fertilizer, and water management (Mahajan and Chauhan, 2013). Therefore, weed management in DSR is very important and a challenging task. Manual weeding is an effective method of weed control, but, because of the unavailability of labor and high cost involved, herbicides are considered the best tool to manage weeds in DSR (Awan *et al*., 2006). Although using herbicides is considered an economical weed control method, the use of herbicides alone is not enough to provide a season-long weed-free crop (Chauhan and Opeña, 2013a). For example, a single herbicide cannot control all weed species, and weeds escape after application of post-emergence herbicides (Ahmed and Chauhan, 2014). In addition, the continuous use of herbicides having similar modes of action enhances the development of herbicide-resistant weed biotypes (Fischer *et al*., 2000).

Manual weeding is very common in Bangladesh; because of the high price of labor, this method is becoming expensive and, in the near future, it will be difficult to find labor for manual weeding (Ahmed and Chauhan, 2014). Previous results showed that, without herbicide application, manual weeding in DSR systems needed to be performed three to five times to maintain the crop completely weed-free (Chauhan and Opeña, 2013b).

It was also found that, even after the application of pre- and post-emergence herbicides, it was not enough to achieve adequate weed control in DSR (Chauhan *et al*., 2015). Therefore, an integrated weed management approach is needed. One of the components of integrated weed management approach is to increase the competitive ability of crops with weeds by using optimal fertilizer management (Blackshaw *et al.,* 2007).

Nitrogen (N) is the key nutrient for crops, which affects biomass production and partitioning into various plant parts, and plays a significant role in the competitive balance between weeds and crops (Camara *et al*., 2003, Awan *et al*., 2011). In general, higher N favors crop or weeds or both and increases total biomass production in the field; however, such a response depends on crop-weed competitive interaction. Nitrogen increases the competitive ability of some weed species, which are more N-responsive than crops; therefore, the addition of N fertilizer can sometimes reduce crop yield (Andreasen *et al*., 2006). However, studies also reported that N fertilizer application favored crops more than weeds (Abouziena *et al*. 2007). Therefore, it is not always true that, in the presence of weeds, higher N rate will be more beneficial for crops or weeds, and the response depends on several factors such as the size asymmetric difference, population density, and the crop and weed species (Kirkland and Beckie, 1998).

Under limited crop competition, the vegetative growth of weed species may increase more than that of some crops when exposed to high N rates (Blackshaw *et al*., 2003). But, when the crop is more competitive than weeds, the crop canopy will soon close and will generally be denser at high N rates; weeds will get limited light and other resources, which will result in weed suppression by the crop (Olsen *et al*., 2005). A study on DSR in India found that weed density increased significantly with the increase of N rate from 120 to 150 kg ha^{-1}; however, further increases in N rate failed to increase total weed density (Mahajan and Timsina, 2011).

Sowing in dry soil and alternate wetting and drying soil conditions may cause N fertilizer to behave differently in the DSR system compared to the puddled transplanted rice system (Beldar *et al*., 2005). DSR has recently been introduced in Bangladesh and fertilizer recommendations have not yet been made. In our previous study on DSR, results showed that the sequential application of a pre-emergence herbicide pendimethalin fb post-emergence herbicide ethoxysulfuron controlled a range of weeds; however, satisfactory yield was not achieved due to survivors of some of the weed species (Ahmed and Chauhan, 2014). In that study, N fertilizer was applied at 120 kg ha^{-1}, which was based on the recommendation for puddled transplanted rice. From the results of the study, it has been hypothesized that the best weed management in DSR may be achieved by using N fertilizer higher than the currently recommended rate for puddled transplanted rice. Therefore, the objectives of this study were the optimization of N fertilizer rate for DSR, the effect of different N rates on rice-weed competition, and to determine the economical weed control method in DSR.

MATERIALS AND METHODS

Experimental site: Experiments were conducted during the aman (June to October) 2012 and 2013 at the research farm of the Regional Agricultural Research Station (RARS), Bangladesh Agricultural Research Institute (BARI), Jessore, Bangladesh (23°11' N, 89°14' E; 16 m above mean sea level). Historically, the area is known as the High Ganges River Floodplain and is predominantly highland. The climate of the area is subtropical with an average annual rainfall of 1,590 mm, minimum temperatures of 6 to 9 ºC in January, and maximum temperatures of 36 to 44 ºC in April and May. Soil of the experimental fields at the 0 to 15-cm depth is clay loam, having a bulk density of 1.54 Mg m^{-3}, pH of 7.8, organic carbon of 1.5%, sand of 30%, silt of 33%, and clay of 37%. The experimental area was dry-cultivated using a four-wheel tractor before crop sowing. Historically the field is under wheat-fallow-transplanted aman rice cropping systems and previous crop was wheat. The minimum and maximum temperatures and amount of rainfall recorded at the experimental site during the experimental periods are presented in Fig.1.

Treatments and design: The experiment in each year was arranged in a split-plot design with four N rates (0, 80, 120, and 160 kg ha^{-1}) assigned on the main plots and N applied in four equal splits—at 14 days after sowing (DAS), at the start of tillering (32 DAS), at maximum tillering (50 DAS), and at panicle initiation stage (72 DAS). Main plots were separated by soil bunds to prevent N fertilizer movement. The treatments in subplots were four weed control methods: (i) one HW (HW was done at 32 DAS and weeds were allowed to grow before and after hand weeding); (ii) pendimethalin (1000 g ai ha^{-1}) was applied at 2 DAS followed by (fb) ethoxysulfuron (20 g ai ha^{-1}) at 20 DAS; (iii) pendimethalin (1000 g ai ha^{-1}) fb ethoxysulfuron (20 g ai ha^{-1}) fb one HW (45 DAS); and (iv) weed-free (plots were kept completely weed-free using manual weeding four times at 15, 30, 45, and 60 DAS). The herbicides were applied using a knapsack sprayer attached with three flat-fan nozzles on a boom that delivered 450 L ha^{-1}. Each treatment was replicated three times. The area of each subplot was 24 m^2 (6 m x 4 m).

Crop management: The rice cultivar BRRI dhan49 (135-d duration) was used during both the seasons. A power tiller seed drill (2BG-6A model, China) was used to plant dry rice seeds at a row spacing of 20 cm and seed rate of 40 kg ha^{-1}. Seeds were sown on 27 and 19 June in

2012 and 2013, respectively. Immediately before sowing, all fertilizers (except N) were applied at 15, 48, 12, and 2.2 kg ha^{-1} of P, K, S, and Zn in the form of triple superphosphate (TSP), muriate of potash (MoP), gypsum, and zinc sulphate, respectively. The field was irrigated immediately after sowing and thereafter irrigation was based on tensiometer readings using a threshold value of 15 kPa at 15 cm soil depth. At each irrigation time, water was applied until its height on the soil surface reached 5 cm. Total number of irrigation were 13 and 9, respectively, aman 2012 and 2013. At 40 DAS, 300 g ai ha^{-1} of fipronil (Regent 3GR, BASF Bangladesh Ltd.), was applied to control stem borers (*Scirpophaga incertulas* Walker).

Observations: Weed density and weed biomass were measured at 32 DAS (before the second application of N), at 70 DAS (before the fourth application of N), and at 50% crop anthesis. At each sampling time, two quadrats of 40 cm × 40 cm were placed randomly on each plot and weeds were collected from each quadrat. Collected weeds were clustered by groups (i.e., grass, broadleaf, and sedge) and counted. Weed biomass was measured group-wise after the samples were oven-dried at 70 °C until biomass was constant. The number of rice tillers and rice dry biomass were determined on the same dates from the same quadrats used for weed sampling. At harvest, rice panicles were counted from four randomly placed 1-m row lengths on each plot. The number of spiklets per panicle (filled and unfilled) was counted by randomly sampling 20 panicles per plot. Rice grain yield was determined from a harvested area of 8.8 m^2 (4.0 × 2.2 m). Grain yield was converted to t ha^{-1} at 14% moisture content.

Economic analysis: Economic analysis was performed to determine the efficiency of different treatments. In the economic analysis, only N fertilizer and weeding cost, which were variable, were considered. Other management costs, which were the same for all treatments were not included. The amount of N fertilizer and commercial product of herbicides required for one hectare was calculated and the cost was estimated based on their market price. The number of laborers for fertilizer application, herbicide spraying, and hand weeding were counted and labor wage was based on an 8-hour work-day. The market price of paddy was determined during the year of experiment and used for calculation of the gross income. The net profit per hectare for each treatment was calculated after deducting the total cost (N fertilizer cost plus weeding cost) from the gross income.

Statistical analysis: Data were analyzed using ANOVA to evaluate differences between treatments, and the means were separated using least significant differences (LSD) at the 5% level of significance (Crop Stat 7.2; International Rice Research Institute, Philippines). Weed density and biomass data were transformed using square-root transformation [$\sqrt{(x + 0.5)}$] before analyses. Transformation, however, did not improve homogeneity. Therefore, the original values were used for analysis and presentation. Because of a nonsignificant interaction between years for economics, the data on economics were pooled over the two years.

RESULTS

Effect of nitrogen rate and weed control methods on weed and crop: The common weed species found at the experimental site were scarlet pimpernel (*Anagalis arvensis* L.), fringed spider-flower (*Cleome rutidosperma* D.C.), celosia (*Celosia argentea* L.), bermudagrass [*Cynodon dactylon* (L.) Pers.], purple nutsedge (*Cyperus rotundus* L.), southern crabgrass [*Digitaria ciliaris* (Retz.) Koel.], junglerice [*Echinochloa colona* (L.) Link], globe fringerush [*Fimbristylis miliacea* (L.) Vahl], fringed quickweed [*Galinsoga ciliata* (Raf.) Blake], doveweed [*Murdannia nudiflora* (L.) Brenan], and niruri (*Phyllanthus niruri* L.). Results are presented for each weed group (i.e., grass, broadleaf, and sedge).

There was no interaction between N rates and weed control methods on weed density and weed biomass at any observation; however, their individual effect was significant. At 32 DAS (before the application of second N split), total weed density was influenced (P<0.05) by N rate during 2012, but not in 2013 (Table 1). Among individual weed groups, only sedge density was influenced by N rate in 2012. Among weed control methods, herbicide-treated plots always had lower weed density than nontreated plots (one HW plots at this stage were completely weedy because hand weeding was done after this sampling at 32 DAS). Weed biomass at 32 DAS was individually influenced by N rate and weed control methods, but the interaction between these two factors was not significant (Table 2). Nitrogen rate increased weed biomass (two-year average) by 41, 14, and 7% when N rate increased from 0 to 80, 80 to 120, and 120 to 160 kg ha^{-1}, respectively. Among the weed control methods, herbicide-treated plots had 62 to 73% lower weed biomass than the nontreated plots.

Similar to earlier observations, total weed density at anthesis was influenced (P<0.05) by the N rate during 2012, but not in 2013 (Table 3). Among the weed groups, only broadleaf weeds were influenced by N rate at this stage which was for both the seasons. Among weed control methods, the highest total weed density was recorded in the one HW plots (296 to 314 plants m^{-2}), which was higher than in the herbicide-treated plots. Plots treated with pendimethalin fb ethoxysulfuron had 26 to 39% lower weed density than the one HW plots. This was the same for the plots treated with pendimethalin fb ethoxysulfuron fb one HW, which had 46 to 58% lower weed density.

The effect of N rate on total biomass was significant at anthesis and biomass increased (two-year average) by 42, 22, and 2% with increases in N rate from 0 to 80, 80 to 120, and 120 to 160 kg ha^{-1}, respectively (Table 4). Considering individual weed groups, grass and broadleaf weeds were influenced by increasing N rate, but not sedges. Among weed control methods, pendimethalin fb ethoxysulfuron reduced total weed biomass by 31 to 33% and pendimethalin fb ethoxysulfuron fb one HW reduced total weed biomass by 70 to 73%, compared with weedy treatments.

Tiller density and biomass of rice consistently increased with increases in N rate from 0 to 160 kg ha^{-1} (Table 5). At 30 DAS, tiller density increased by 12, 13, and 7%, and rice biomass increased by 31, 17, and 9% when N increased from 0 to 80, 80 to 120, and 120 to 160 kg ha^{-1}, respectively. At anthesis, the corresponding values were 18, 18, and 6% for tiller density and 34, 35, and 16% for rice biomass, respectively.

Effect of N rate and weed control methods on yield components and yield of rice: There was a significant interaction between N rate and weed control method on number of rice panicles in both seasons (Fig. 2). In all weed control treatments, except for weed-free, the panicle number increased significantly with increase in N from 0 to 160 kg ha^{-1}. In the weed-free treatment, panicle number increased up to N rate of 120 kg ha^{-1}, but further increase in N did not influence the number of panicles. The plots treated with pendimethalin fb ethoxysulfuron fb one HW had similar panicle density with the weed-free treatments at all N levels. Plots treated with pendimethalin fb ethoxysulfuron had 15 to 29% lower number of panicles than the weed-free treatment, but 17 to 27% higher panicles than the one HW treatment.

The number of rice grains per panicle was influenced by individual factor of N rate and weed control method. The number of grains $panicle^{-1}$ (110 to 115) was higher at N rate of 160 kg ha^{-1}, and 120 kg N ha^{-1} had similar grains $panicle^{-1}$ (105 to 110) than that at 160 kg ha^{-1} (data not shown). Averaged over years, compared with the highest N rate, 12 to 14% and 7 to 8% lower grains $panicle^{-1}$ were recorded at 0 and 80 kg N ha^{-1}, respectively. Among weed control methods, the weed-free treatment always had the highest number of grains $panicle^{-1}$ (105 to 110), which was similar to that of pendimethalin fb ethoxysulfuron fb one HW (101 to 107 grains $panicle^{-1}$). Compared with the weed-free treatment, pendimethalin fb ethoxysulfuron had 5 to 7% and one HW treatment had 11 to 13% lower grains $panicle^{-1}$.

Similar to the number of rice panicles, grain yield was also influenced by the interaction between N rate and weed control method (Fig. 3). Yield increased as N rate increased up to 160 kg ha^{-1}; however, the rate of yield increase with the rate of N varied among weed control methods. The highest yield (5.37 to 5.51 t ha^{-1}) was recorded in the weed-free treatment when the crop received 160 kg N ha^{-1}. Plots treated with pendimethalin fb ethoxysulfuron fb one HW had similar yield to the weed-free treatment at all N rates; however, the plots treated with pendimethalin fb ethoxysulfuron had 12 to 34% lower yield than the weed-free treatment. One HW plots always had lower yield (2.3 to 4.2 t ha^{-1}) than the weed-free and herbicide-treated plots; however, yield in the one HW plots increased by 42, 13, and 12% with increases in N rate from 0 to 80, 80 to120, and 120 to160 kg ha^{-1}, respectively.

Table 1. Effect of nitrogen rate and weed control method on weed density (no. m^{-2}) at 32 days after sowing in 2012 and 2013.

Treatments	Weed density							
	Grass		Broadleaf		Sedge		Total	
	2012	2013	2012	2013	2012	2013	2012	2013
Nitrogen rate (kg ha^{-1})	no. m^{-2}							
0	40 a	60 a	96 a	42 a	68 b	21 a	204 b	123 a
80	46 a	64 a	91 a	41 a	109 a	26 a	246 a	131 a
120	49 a	63 a	85 a	42 a	100 a	33 a	234 a	138 a
160	41 a	54 a	100 a	43 a	96 a	32 a	237 ab	129 a
Weed control method								
One HW	95 a	126 a	178 a	80 a	142 a	56 a	415 a	262 a
Pendimethalin fb ethoxysulfuron	17 b	24 b	53 b	27 b	72 b	13 b	142 b	64 b
Pendimethalin fb ethoxysulfuron fb one HW	20 b	30 b	48 b	20 b	66 b	16 b	134 b	66 b

HW, hand weeding; fb, followed by; in a column, means followed by a common letter are significantly similar at the 5% level.

Table 2. Effect of nitrogen rate and weed control method on weed biomass (g m^{-2}) at 32 days after sowing in 2012 and 2013.

Treatments	Weed biomass							
	Grass		Broadleaf		Sedge		Total	
	2012	2013	2012	2013	2012	2013	2012	2013
Nitrogen rate (kg ha^{-1})	g m^{-2}							
0	17 ^{c}	22^{b}	19^{ab}	9 ^{c}	15 ^{c}	6 ^{b}	51 ^{c}	37 ^{d}
80	25 ^{ab}	29^{a}	23^{a}	13 ^{b}	22 ^{b}	9 ^{ab}	70 ^{b}	51 ^{c}
120	28 ^{a}	31^{a}	26^{a}	16 ^{ab}	25 ^{a}	12 ^{a}	79 ^{a}	59 ^{b}
160	29 ^{a}	34 ^{a}	27^{a}	19 ^{a}	23 ^{ab}	14 ^{a}	79 ^{a}	67 ^{a}
Weed control method								
One HW	46 ^{a}	52 ^{a}	44^{a}	28 ^{a}	31 ^{a}	19 ^{a}	121 ^{a}	99 ^{a}
Pendimethalin fb ethoxysulfuron	18 ^{b}	19 ^{b}	12^{b}	6 ^{b}	13 ^{b}	10 ^{b}	43 ^{b}	35 ^{b}
Pendimethalin fb ethoxysulfuron fb one HW	13 ^{b}	13 ^{b}	15^{b}	10 ^{b}	18 ^{b}	5 ^{b}	46 ^{b}	28 ^{b}

HW, hand weeding; fb, followed by; in a column, means followed by a common letter are significantly similar at the 5% level.

Table 3. Effect of nitrogen rate and weed control method on weed density (no. m^{-2}) at crop anthesis in 2012 and 2013.

Treatments	Weed density							
	Grass		Broadleaf		Sedge		Total	
	2012	2013	2012	2013	2012	2013	2012	2013
Nitrogen rate (kg ha^{-1})	(no. m^{-2})							
0	63 ^{a}	83 ^{a}	26 ^{c}	62 ^{b}	42 ^{a}	48 ^{a}	131 ^{b}	193 ^{a}
80	74 ^{a}	88 ^{a}	42 ^{b}	84 ^{a}	48 ^{a}	52 ^{a}	164 ^{ab}	224 ^{a}
120	78 ^{a}	90 ^{a}	53 ^{a}	81 ^{a}	60 ^{a}	48 ^{a}	191 ^{a}	219 ^{a}
160	72 ^{a}	85 ^{a}	50 ^{a}	87 ^{a}	57 ^{a}	46 ^{a}	179 ^{a}	218 ^{a}
Weed control method								
One HW	101 ^{a}	125 ^{a}	132 ^{a}	121 ^{a}	64 ^{a}	69 ^{a}	297 ^{a}	315 ^{a}
Pendimethalin fb ethoxysulfuron	68 ^{b}	80 ^{b}	103 ^{b}	71 ^{b}	48 ^{b}	42 ^{b}	219 b	193 ^{b}
Pendimethalin fb ethoxysulfuron fb one HW	44 ^{c}	54 ^{c}	73 ^{c}	45 ^{c}	43 ^{b}	34 ^{b}	160 ^{c}	133 ^{c}

HW, hand weeding; fb, followed by; in a column, means followed by a common letter are significantly similar at the 5% level.

Table 4. Effect of nitrogen rate and weed control method on weed biomass (g m^{-2}) at crop anthesis in 2012 and 2013.

Treatments	Weed biomass							
	Grass		Broadleaf		Sedge		Total	
	2012	2013	2012	2013	2012	2013	2012	2013
Nitrogen rate (kg ha^{-1})	(g m^{-2})							
0	26 ^{c}	42 ^{bc}	32 ^{c}	30 ^{b}	11 ^{a}	11 ^{a}	69 ^{c}	83 ^{c}
80	42 ^{b}	56 ^{b}	47 ^{b}	41 ^{ab}	14 ^{a}	15 ^{a}	103 ^{b}	112 ^{b}
120	53 ^{a}	71 ^{ab}	60 ^{a}	50 ^{a}	15 ^{a}	16 ^{a}	128 ^{a}	137 ^{a}
160	50 ^{a}	76 ^{a}	64 ^{a}	50 ^{a}	16 ^{a}	14 ^{a}	130 ^{a}	140 ^{a}
Weed control method								
One HW	68^{a}	93 ^{a}	80 ^{a}	64 ^{a}	19 ^{a}	21 ^{a}	167 ^{a}	178 ^{a}
Pendimethalin fb ethoxysulfuron	43 ^{b}	62 ^{b}	54 ^{b}	46 ^{b}	14 ^{ab}	14 ^{ab}	111 ^{b}	122 ^{b}
Pendimethalin fb ethoxysulfuron fb one HW	17 ^{c}	29 ^{c}	19 ^{c}	18 ^{c}	9 ^{a}	7 ^{b}	45 ^{c}	54 ^{c}

HW, hand weeding; fb, followed by; in a column, means followed by a common letter are significantly similar at the 5% level.

Economic analysis: The effect of N rate and weed control method on economic performance is shown in Table 6. Economic analysis revealed that the net profit was highest with the weed control treatment of pendimethalin fb ethoxysulfuron fb one HW (US$1,067 ha^{-1}) at 160 kg N ha^{-1}; however, similar net profit was found in the treatments pendimethalin fb ethoxysulfuron fb one HW, and pendimethalin fb ethoxysulfuron at 120 and 160 kg N ha^{-1}, respectively. Although pendimethalin fb ethoxysulfuron had 6 to 14% lower gross income than the pendimethalin fb ethoxysulfuron fb one HW treatment, the net profit was similar at all N rates. Despite the highest gross income, the season-long weed-free plots always had lower net profit than the herbicide-treated plots. The lowest gross income and net profit was recorded in the One HW treatment when no N was applied; however, the gross income and net profit increased with increases in N rate from 0 to 160 kg ha^{-1}.

Table 5. Effect of nitrogen rate and weed control method on tiller density (no. m^{-2}) and rice biomass (g m^{-2}) at 32 days after sowing and crop anthesis in 2012 and 2013.

Treatments	32 DAS				Crop anthesis			
	Tiller density		Rice biomass		Tiller density		Rice biomass	
	2012	2013	2012	2013	2012	2013	2012	2013
Nitrogen rate (kg ha^{-1})	(no. m^{-2})		(g m^{-2})		(no. m^{-2})		(g m^{-2})	
0	301 c	334 c	45 c	35 c	261 c	304 b	485 d	552 d
80	342 b	420 b	57 b	47 b	309 b	335 b	604 c	710 c
120	369 ab	472 ab	64 ab	58 a	357 a	405 a	854 b	943 b
160	386 a	510 a	71 a	62 a	383 a	428 a	1003 a	1072 a
Weed control methods								
One HW	288 c	359 c	45 c	42 c	290 c	343 b	642 d	735 c
Pendimethalin fb ethoxysulfuron	349 b	440 b	60 b	52 b	312 c	363 b	710 c	792 b
Pendimethalin fb ethoxysulfuron fb 1 HW	340 b	440 b	59 b	50 b	341 b	372 ab	770 b	851 a
Weed-free	421 a	498 a	74 a	58 a	369 a	394 a	823 a	899 a

HW, hand weeding; DAS, days after sowing; fb, followed by; in a column, means followed by a common letter are significantly similar at the 5% level.

Table 6. Effect of nitrogen rate and weed control method on gross income and net profit in dry-seeded aman rice.

Nitrogen rate (kg ha^{-1})	Weed control method	Nitrogen cost	Weeding cost	Total cost (nitrogen+ weeding)	Gross income	Net profit
				US$ ha^{-1}		
0	One HW	0	320	320	600 g	280 i
0	Pendimethalin fb ethoxysulfuron	0	70	70	750 f	680 d
0	Pendimethalin fb ethoxysulfuron fb one HW	0	140	140	840 e	700 d
0	weed-free	0	576	576	900 de	324 h
80	One HW	58	352	410	850 e	440 g
80	Pendimethalin fb ethoxysulfuron	58	70	128	980 d	852 c
80	Pendimethalin fb ethoxysulfuron fb one HW	58	160	218	1115 c	897 c
80	weed-free	58	624	682	1200 b	518 f
120	One HW	80	384	464	960 d	496 f
120	Pendimethalin fb ethoxysulfuron	80	70	150	1125 bc	975 b
120	Pendimethalin fb ethoxysulfuron fb one HW	80	180	260	1295 a	1035 a
120	weed-free	80	640	720	1344 a	624 e
160	One HW	103	384	487	1070 c	583 e
160	Pendimethalin fb ethoxysulfuron	103	70	173	1225 b	1052 a
160	Pendimethalin fb ethoxysulfuron fb one HW	103	180	283	1350 a	1067 a
160	weed-free	103	640	743	1365 a	622 e

HW, hand weeding; fb, followed by; N, nitrogen;1 US$ = 78 Tk; Tk, Bangladeshi Taka. Market price of urea fertilizer and herbicide commercial products: Price of urea = 20 Tk kg^{-1}, pendimethalin (Panida 33 EC) = 950 Tk L^{-1}, ethoxysulfuron (Sunrice 150 WG) = 1,000 Tk per 100 mg. Weeding cost: One hand weeding at 32 days after sowing = number of labor for one hand weeding (100 to 120 person-days ha^{-1}); pendimethalin fb ethoxysulfuron = cost of pendimethalin ha^{-1} + cost of ethoxysulfuron ha^{-1}; pendimethalin fb ethoxysulfuron fb one HW = cost of pendimethalin ha^{-1} + cost of ethoxysulfuron ha^{-1} + labor cost of one hand weeding at 45 days after sowing; weed-free = labor cost for four manual hand weedings; labor = 250 Tk per person-day; one person-day = 8 working hours; market price of paddy = 20 Tk kg^{-1}; gross income = paddy yield × market price; net benefit = gross income − total cost.

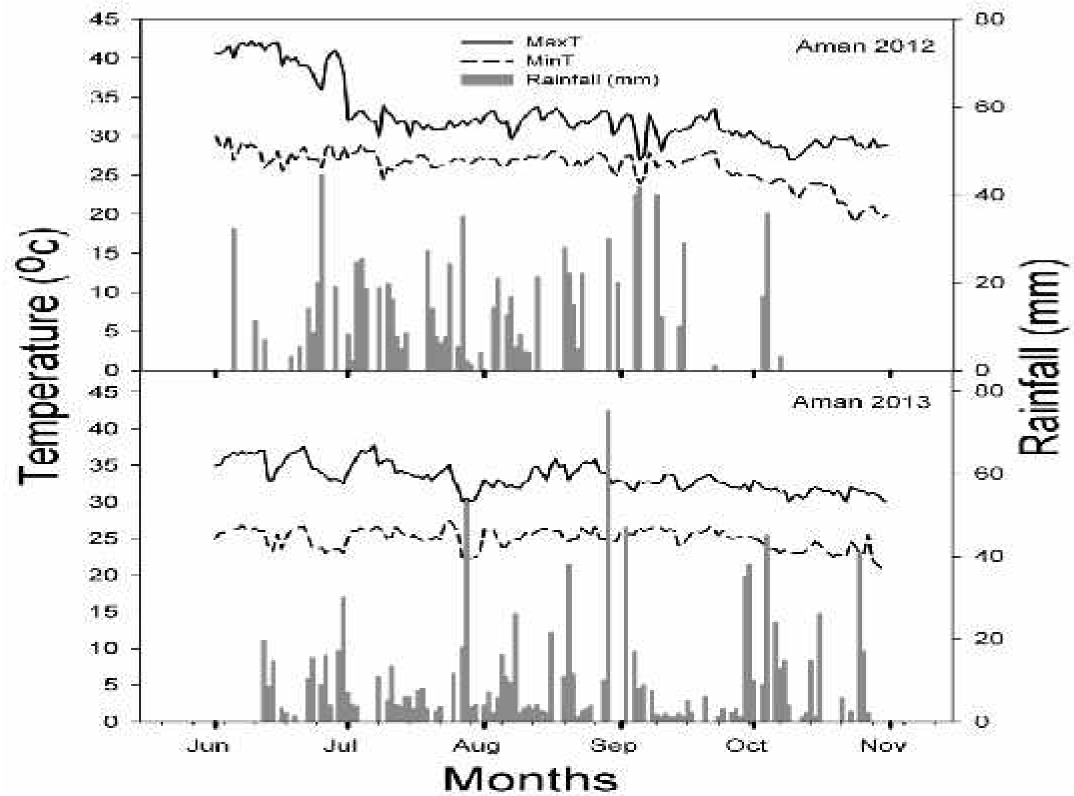

Fig. 1. Maximum and minimum temperatures and total rainfall (mm) recorded at the experimental site in aman 2012 and 2013.

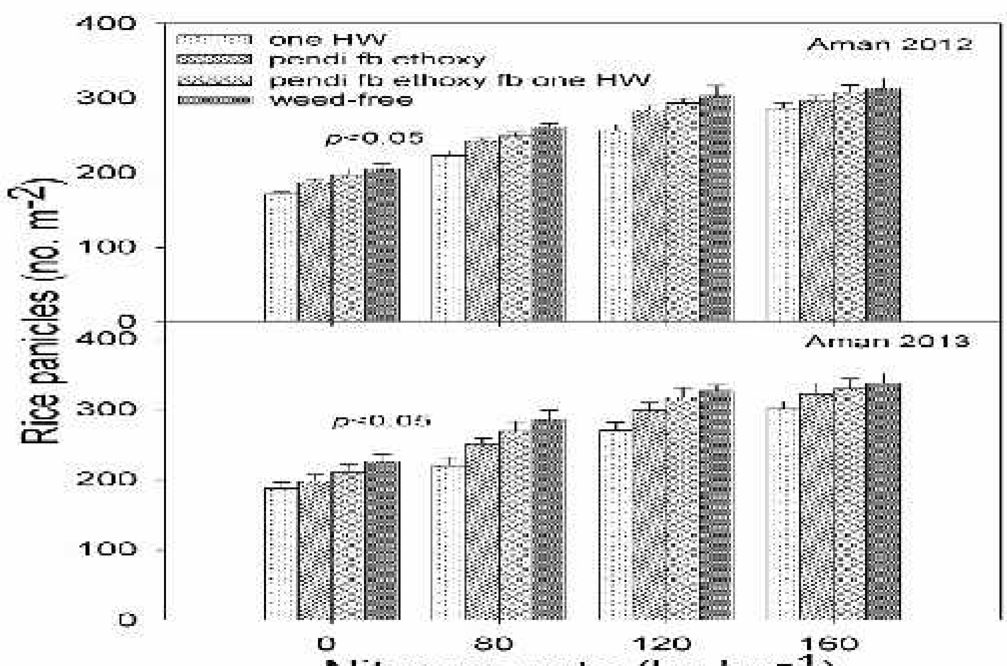

Fig. 2. Interaction effect of nitrogen rate and weed control methods on rice panicles (no. m^{-2}) in aman 2012 and 2013. Abbreviation: HW, hand weeding; pendi, pendimethalin; fb, followed by; ethoxy, ethoxysulfuron; *p*, probability at 5% level of significance. Vertical bars represent standard errors.

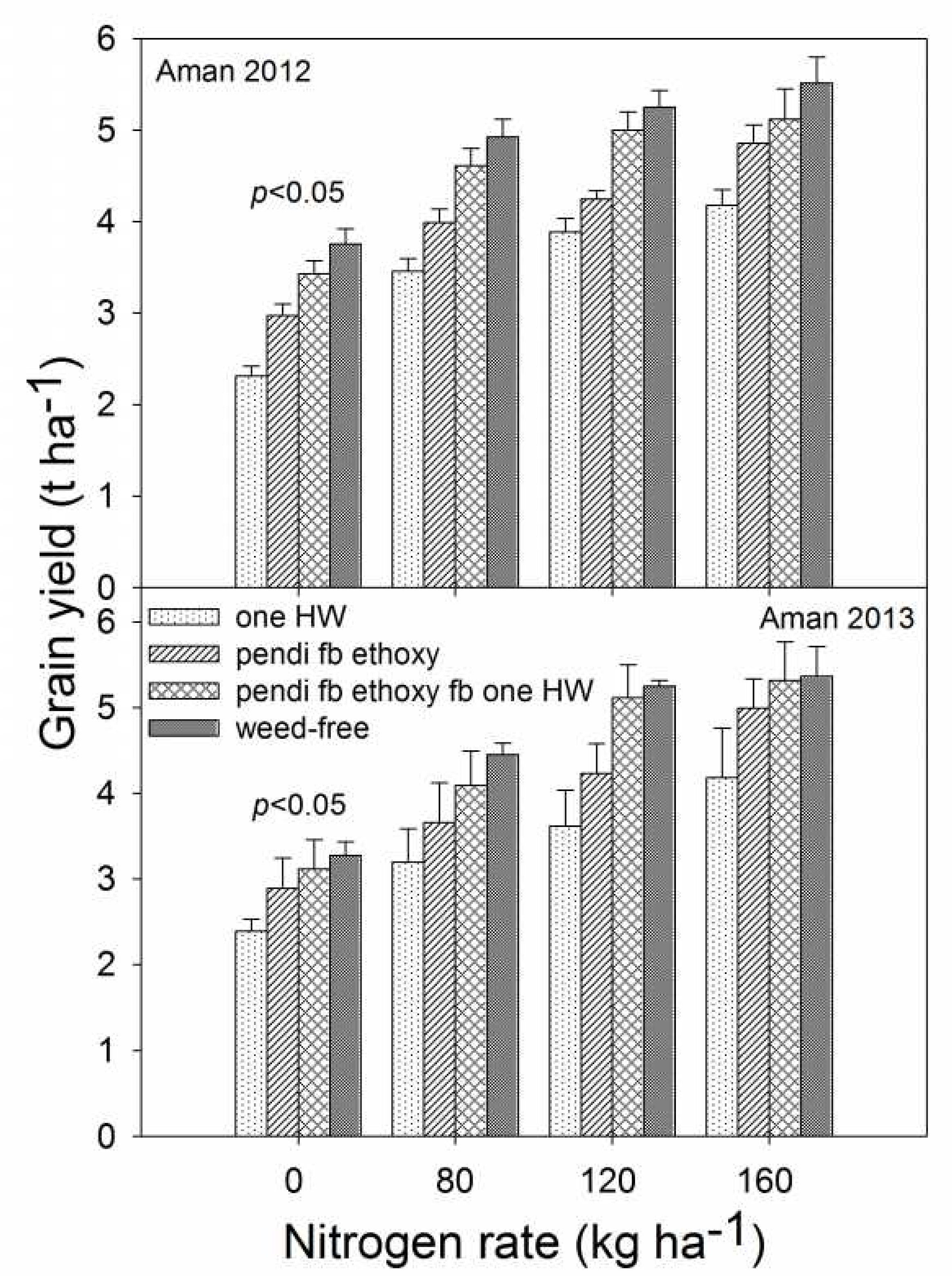

Fig. 3. Interaction effect of nitrogen rate and weed control method on grain yield (t ha^{-1}) in aman 2012 and 2013. Abbreviations: HW, hand weeding; pendi, pendimethalin; fb, followed by; ethoxy, ethoxysulfuron; *p*, probability at 5% level of significance. Vertical bars represent standard errors.

DISCUSSION

In DSR systems, weeds and rice seedling emerged simultaneously, moreover alternate wet and dry spell also stimulated weed growth. Weeds are the major constraints to DSR and success mostly depends on effective weed management. Increase crop competitiveness to weeds by using proper fertilizer management is one of the integrated weed management approaches in DSR systems. In our study, although weed biomass increased as N rate increased from 0 to 160 kg ha^{-1}; however, weed density did not follow the same pattern (Table 1-4). These results are also supported by a previous study in which weed emergence behaved differently with different N rates, some species stimulated by higher N rate and others suppressed (Andreasen *et al*., 2006). In present study, it was observed that, with the application of 120 kg N ha^{-1}, total weed density increased by 12 to 23% compared with that at 0 kg N ha^{-1}. Further increase in N beyond 120 kg ha^{-1} did not influence total weed density. However, the relative increase in weed biomass reduced with the increment in N rate. The main reason for the slow increase in weed biomass at higher N rates was because of the suppression of weed growth by higher tiller density and biomass production of rice. In general, weeds are capable of absorbing nutrients faster and in relatively larger amounts than crop plants, but the outcome depends on the competitive ability of the crop and weeds (Kristensen *et al*., 2008). If plant density and initial plant size are greater than weeds, the crop will benefit more from the applied N fertilizer and weed growth will be suppressed (Blackshaw *et al*., 2004).

The results of present study in terms of crop biomass indicated that in plots with one HW or treated with only herbicides (pendimethalin fb ethoxysulfuron), the application of N higher than the recommended rate (120 kg N ha^{-1}) had a positive effect on the crop (Table 5, Figs. 2, 3). Our results are supported by a previous study of Mahajan and Timsina (2011) on rice, in which they found that weed dry matter remained similar between N application of 120 and 150 kg ha^{-1} but rice biomass increased significantly . As a result, N-use efficiency and yield were higher with increase in N rate beyond 120 kg ha^{-1}.

Results of economic analysis indicated that, despite the highest gross income, the season-long weed-free plots always had lower net profit than the herbicide-treated plots, which was mainly because of manual weeding four times (a total 180 to 200 labors used) to keep the plots weed-free. The data on gross income revealed that, when plots were One HW or applied with herbicides only, N rates higher than the recommended rate (120 kg ha^{-1}) produced more gross income due to higher yield. These results suggested that higher N rates help to increase the competitive ability of rice plants against weeds. On the other hand, when weed control treatments were the weed-free, and pendimethalin fb ethoxysulfuron fb one HW, N rate higher than the recommended rate did not increase the yield and net profit significantly.

Our study confirmed that grain yield and gross income were higher when plots were kept weed-free for whole the season through manual weeding; however, the net profit was lower because of the high cost of manual weeding. One HW is a common practice in the puddled transplanted system in Bangladesh; however, in the DSR system, one HW was not enough to control weeds, resulting in poor yield. In addition, the labor cost for one HW in DSR was high, thus, it failed to produce sufficient net profit. The plots that received pendimethalin fb ethoxysulfuron fb one HW had a similar yield with the manually weeded weed-free plots. This was because the application of herbicides (pre- fb post-emergence) fb one HW was effective in controlling a significant amount of weeds, resulting in higher yield. The weeding cost of the pendimethalin fb ethoxysulfuron fb one HW treatment was much lower than the weed-free and One HW treatments because herbicide cost was low and one hand weeding after application of pre- and post-emergence herbicides demanded less labor. Although pendimethalin fb ethoxysulfuron always had lower yield than the same treatment with one HW added, the net profit was similar between these two treatments because of the low cost for weed control.

Conclusions: Under weed-free conditions, the application of 120 kg N ha^{-1} had a similar net profit with application of 160 kg N ha^{-1}. However, when weeds were present in the field, 160 kg N ha^{-1} provided the highest net profit. Among weed control method, pendimethalin fb ethoxysulfuron fb one HW with 120 kg N ha^{-1} is the best option to control weeds and obtain higher yield and net profit. However, if labor is not available or farmers do not want to perform hand weeding after the application of herbicides (pendimethalin fb ethoxysulfuron), there is a need to increase N rate (160 kg ha^{-1}) to obtain high yield.

Acknowledgments: We would like to thank Ms. Grace Cañas for providing comments on the manuscript. We also gratefully acknowledge the support of the International Fund for Agricultural Development (IFAD), the Cereal Systems Initiative for South Asia (CSISA, Bangladesh) and the Bangladesh Agricultural Research Institute (BARI), Regional Agricultural Research Station at (RARS), Jessore.

REFERENCES

Abouziena, H.F., M.F. El-Karmany, M. Singh, and S.D. Sharma (2007). Effect of nitrogen rates and weed control treatments on maize yield and associated weeds in sandy soils. Weed Technol. 21: 1049–1053.

Ahmed, S., and B.S. Chauhan (2014). Performance of different herbicides in dry-seeded rice in Bangladesh. Sci. World J. dx.doi.org /10.1155/2014/729418.

Ahmed, S., M, Salim, and B.S. Chauhan (2014). Effect of weed management and seed rate on crop growth under direct dry seeded rice systems in Bangladesh. PLoS ONE 9(7):10.1371/journal.pone.0101919.

Ahmed, S., M.R. Islam, M.M. Alam, M.M. Haque, and A.J.M.S. Karim (2011). Rice production and profitability as influenced by integrated crop and resources management. Eco-Friendly Agril. 11: 720–725.

Andreasen, C., A.S. Litz, and J.C. Streibig (2006). Growth response of six weed species and spring barley (*Hordeum vulgare*) to increasing levels of nitrogen and phosphorus. Weed Res. 46: 503–512.

Awan, T.H., M.E. Safdar, Z. Manzoor, and M.M. Ashraf (2006). Screening of herbicides as post-emergent application for effective weed control without affecting growth and yield of direct seeded rice plant. J. Anim. Plant Sci.16 (1-2): 60-65.

Awan, T.H., R.I. Ali, Z. Manzoor, M. Ahmad, and M. Akhtar (2011). Effect of different nitrogen levels and row spacing on the performance of newly evolved medium grain rice variety, KSK-133. J. Anim. Plant Sci. 21 (2): 231-234.

Beldar, P., B.A.S. Bouman, J.H.J. Spiertz, S. Peng, and A.R. Castaneda (2005). Crop performance, nitrogen and water use in flooded and aerobic rice. Plant Soil. 273: 167–182.

Blackshaw, R.E., L.J. Molnar, and H.H. Janzen (2004). Nitrogen fertilizer timing and application method affect weed growth and competition with spring wheat. Weed Sci. 52: 614–622.

Blackshaw, R.E., R.L. Anderson, and D. Lemerle (2007). Cultural weed management. In: Non-chemical Weed Management: Principles, Concepts and Technology. pp: 35- 47. M.K. Upadhyaya, R.E. Blackshaw (eds.). Oxfordfordshire, UK: CABI.

Blackshaw, R.E., R.N. Brandt, H H. Janzen, C.A. Grant, and D.A. Derksen (2003). Differential response of weed species to added nitrogen. Weed Sci. 51: 532–539.

Camara, K.M., W.A. Payne, and P.E. Rasmussen (2003). Long-term effects of tillage, nitrogen, and rainfall on winter wheat yields in the Pacific Northwest. Agron. J. 95: 828–835.

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

Chauhan, B.S., and J. Opeña (2013a). Implications of plant geometry and weed control options in designing a low-seeding seed-drill for dry-seeded rice systems. Field Crops Res. 144: 225–231.

Chauhan, B.S., and J. Opeña (2013b). Weed management and grain yield of rice sown at low seeding rates in mechanized dry-seeded systems. Field Crops Res. 141: 9–15.

Chauhan, B.S., G. Mahajan, V. Sardana, J. Timsina, and M.L. Jat (2012). Productivity and sustainability of the rice-wheat cropping system in the Indo-Gangetic Plains of the Indian subcontinent: Problems, opportunities, and strategies. Adv. Agron. 117: 315–369.

Chauhan, B.S., S. Ahmed, T.H. Awan, K. Jabran, and S. Manalil (2015). Integrated weed management approach to improve weed control efficiencies for sustainable rice production in dry-seeded systems. Crop Prot. 71: 19-24.

FAO (2013). Food and Agricultural Organization. Statistical Yearbook. http://www.fao.org/docrep/018/i3107e/i3107e00 .htm. Accessed: June 19.

Fischer, A.J., C.M. Ateh, D.E. Bayer, and J.E. Hill (2000). Herbicide-resistant *Echinochloa oryzoides* and *E. phyllopogon* in California *Oryza sativa* fields. Weed Sci. 48: 225-230.

Kirkland, K.J., and H.J. Beckie (1998). Contribution of nitrogen fertilizer placement to weed management in spring wheat (*Triticum aestivum* L). Weed Technol. 12: 507–514.

Kristensen, L., J. Olsen, and J. Weiner (2008). Crop density, sowing pattern, and nitrogen fertilization effects on weed suppression and yield in spring wheat (*Triticum aestivum* L.). Weed Sci. 56: 97–102.

Mahajan, G., and B.S. Chauhan (2013). The role of cultivars in managing weeds in dry-seeded rice production systems. Crop Prot. 49: 52-57.

Mahajan, G., and J. Timsina (2011). Effect of nitrogen rates and weed control methods on weeds abundance and yield of direct seeded rice. Arch. Agron. Soil Sci. 10.1080/03650340903369384.

Olsen, J.M., L. Kristensen, J. Weiner, and H.W. Griepentrog (2005). Increased density and spatial uniformity increases weed suppression by spring wheat (*Triticum aestivum* L.). Weed Res. 45: 316–321.