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DEVELOPMENT AND APPRAISAL OF ECONOMICAL AND SUSTAINABLE APPROACH FOR WEED MANAGEMENT IN DRILL SEEDED AEROBIC RICE (*Oryza sativa* L.)

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Conventional rice cultivation by puddling and transplanting is a labor intensive activity. Water scarcity is a threat for the sustainability of transplanted rice. In many areas of Asia, rice transplantion of rice is being replaced by direct seeding as farmers tried to solve the problems of labor cost and water scarcity but weed control is one of the major constraints to direct seeding. So, to control weeds in direct seeded rice present studies were designed. A two years study was conducted to develop sustainable and economical methods for managing weeds in aerobic rice grown by dry direct-seeding at Student's Farm, Department of Agronomy, University of Agriculture, Faisalabad during the years 2008 and 2009. Experiment was laid out in RCBD with five weed management strategies: hand weeding, hoeing with kasula, inter-row cultivation with tine cultivator, inter-row cultivation with spike hoe and chemical control with Nominee 100 SC along with control (no weeding). Weed dry weight was 300 g m^{-2}, 257 g m^{-2}, 225 g m^{-2} and 157 g m^{-2} less in hand weeding, hoeing, tine cultivator and Nominee 100 SC respectively than no weeding. Paddy yield was 221%, 203%, 181% and 105% more in hand weeding, hoeing, tine cultivator and Nominee 100 SC respectively than no weeding.
Keywords: Weeds, control methods, benefit/cost ratio, yield, rice

INTRODUCTION

Rice (*Oryza sativa* L.) is a staple food for more than half of the world population. It is the third largest crop after wheat and cotton and second major grain crop of Pakistan. It accounts for 6.4 % of value added in agriculture and 0.9 % in GDP of Pakistan (GOP, 2011). Rice is grown in many parts of the world in different ways: transplanted flooded rice, alternate wetting and drying, rice on raised beds and aerobic rice. 75% of Asian rice is produced in irrigated puddled fields with generally high irrigation requirements to sustain sub-merged conditions for most of the growing season (Boumanand Toung, 2003). Rice is also grown on 'salt affected and water logged soils', such soils are generally unfit for the production of other agricultural crops (Funakawa*et al.,* 2000).

Water is the major factor limiting crop production in many parts of the world and concerns are increasing about its future availability even in areas where water is currently abundant (Rijsberman, 2006). Water shortage is a great threat for agriculture in Pakistan because of huge exploitation of available water. Rice is mostly grown by transplanting method. In this method field is puddled before rice transplantation then water is impounded. This continuous flooding requires lot of water and intensive labor (Bhushan *et al*., 2007). Pakistan is confronting severe canal water shortage due to lack of interest for the construction of new surface reservoirs. Surface water availability in 2005-2006 was 100.9 MAF which decreased to 93.3 MAF in 2009-2010 (GOP, 2010).

Aerobic rice is a good alternative of transplanting method. Aerobic rice refers to the process of establishing rice crop from direct sowing in the field rather than transplanting seedlings (Rao *et al*., 2007). This type of rice is also known as direct seeded rice (DSR), which avoids puddling and thus decreases considerably the overall water demand for rice culture without any significant differences in yield potential (Awan *et al.*, 1989).

Weeds are serious threat to the direct seeded rice crop by competing for nutrients, light, space and moisture throughout the growing season. Aerobic soil conditions, dry-tillage practices and alternate wetting and drying are favorable for germination and growth of highly competitive weeds, causing grain yield losses up to 91 % (Elliot *et al*., 1984). Bahar and Singh (2004) also reported that weeds can decrease yield of DSR from 75 - 100%. Weeds in direct sown rice can be controlled by various methods. Weeds could be controlled by hand weeding, chemical and mechanical methods. Weeds are manually removed or uprooted in hand weeding. Hand weeding is commonly practiced against weeds on small-scale rice farms (Adesina *et al*., 1994).Herbicides provide effective weed management in DSR (Azmi *et al*., 2005) applied as pre-emergence or post-emergence. Another way to control weeds in direct seeded rice is use of manually or mechanically operated implements. In line sown DSR weeds can be controlled effectively by the use of different inter-row implements as reported by Islam *et al*. (2004), Remington and Posner (2000) and Fazlolallh *et al.* (2001).In the light of above discussion it is concluded that an effective, economical and timely weed control strategy must be developed for direct seeded rice. With the availability of proper weed management technology, it is possible to raise the productivity of direct seeded rice.

MATERIALS AND METHODS

To control weeds in direct seeded rice, experiment was conducted for two years to develop sustainable and economical methods for managing weeds in aerobic rice grown by direct-seeding at Student's Farm, Department of Agronomy, University of Agriculture, Faisalabad during the years 2008 and 2009. Experiment was laid out in RCBD having five weed control approaches: hand weeding, hoeing (with kasula), inter-row cultivation with tine cultivator, inter-row cultivation with spike hoe and chemical control with Nominee 100 SC along with control (no weeding).After the harvesting of wheat, land was ploughed twice followed by planking with tractor drawn implements to achieve the required soil tilth for direct seeded rice.

Rice cultivar Super Basmati was sown on 20th June during 2008 and 28th June during 2009 using seed rate of 75 kg ha^{-1}. Direct seeding was done by automatic drill maintaining 22.5 cm line to line distance. The crop was provided with 150 kg Nha^{-1}, 85 kg Pha^{-1} and 67 kg Kha^{-1} in the form of urea, DAP and potassium sulphate respectively. Half of N and whole of the P and K were applied at sowing, while remaining nitrogen was given in two equal splits, at tillering and panicle initiation stage of the crop. During the year 2008 crop was harvested on 15th November and during the year 2009 on 21st November. Weeds dry weight was measured on three intervals: after 15, 30 and 45 days of sowing rice crop. Weeds from an area of one square meter from each plot were collected, oven dried and then their weight was measured.

Weeds were left unchecked in all the plots of no weeding treatment. Weeds in hand pulling treatment were completely removed manually by uprooting and cutting at 15, 25, 35 and 45 DAS. Weeds in hoeing treatment were removed manually with the help of kasula at 15, 25, 35 and 45 DAS, only inter-row weeds were removed by this implement and within row weeds remain unchecked. Tine cultivator was operated manually at 15, 25, 35 and 45 DAS and it removed and uprooted inter-row weeds only; crop was laid down after the implementation of tine cultivator just like beushaning. Spike hoe was also operated manually at 15, 25, 35 and 45 DAS and its spikes removed minor amount of weeds; crop was laid down after its implementation as in tine cultivator. The weedicide Nominee 100 SC bispyribac-sodium 100 g a.i per L) was dissolved in water and sprayed after 20 days of sowing with the help of knap sack sprayer @ 250 ml ha^{-1}. The collected data were analyzed using the Fisher's analysis of variance technique. Then treatment means were compared using Least Significant Difference (LSD) test at 5% probability level (Steel *et al*., 1997).

Table 1. Presence of weed species at experimental site

English name	Local name	Botanical name
Nut sedge	Deela	*Cyperus rotundas*
Jungle rice	Swanki	*Echonocolacolona*
Barnyardgrass	Dhiden	*Echonocolacrusgalli*
Egyptian crow foot grass	Madana	*Dactylocteniumaegyptium*
Desert horse purslane	Itsit	*Trianthumportulacastrum*
False Daisy	Daryaebooti	*Eclipt alba*
Spurge	Hazardani	*Euphorbia granulata*

RESULTS

***Weeds dry weight*:** The Table 2 showed that different weed management strategies significantly affected total weed dry weight during both the years at 15 DAS. During the year 2008 minimum weed dry weight was recorded in hand pulling (0.75 g m^{-2}) followed by hoeing (1.21 g m^{-2}) and tine cultivator (1.68 g m^{-2}). Maximum weed dry weight was found in no weeding (2.85 g m^{-2}) that was statistically similar to spike hoe (2.80 g m^{-2}) and Nominee 100 SC (2.83 g m^{-2}). During the year 2009 minimum weed dry weight was recorded in hand pulling (0.94 g m^{-2}) followed by hoeing (1.57 g m^{-2}) and tine cultivator (1.84 g m^{-2}). Maximum weed dry weight was found in Nominee 100 SC (3.01 g m^{-2}) that was statistically similar to spike hoe (2.99 g m^{-2}) and no weeding (2.99 g m^{-2}). The table 2 represents that different weed management strategies significantly affected total weed biomass during both the years at 30 DAS. During the year 2008 minimum weed dry weight was recorded in hand pulling (6.27 g m^{-2}) followed by hoeing (21.52 g m^{-2}), tine cultivator (41.35 g m^{-2}), Nominee 100 SC (70.44 g m^{-2}) and spike hoe (144.17 g m^{-2}). Maximum weed dry weight was found in no weeding (154.77 g m^{-2}). During the year 2009 minimum weed dry weight was recorded in hand pulling (10.24 g m^{-2}) followed by hoeing (26.18 g m^{-2}), tine cultivator (45.99 g m^{-2}), Nominee 100 SC (78.29 g m^{-2}) and spike hoe (135.48 g m^{-2}). Maximum weed dry weight was found in no weeding (159.46 g m^{-2}).The data presented in Table 2 indicated the significant effect of different weed management strategies on weed biomass during both the years at 45 DAS. During the year 2008 minimum weed dry weight was recorded in hand pulling (12.46 g m^{-2}) followed by hoeing (53.66 g m^{-2}), tine cultivator (85.18 g m^{-2}), Nominee 100 SC (150.64 g m^{-2}) and spike hoe (265.59 g m^{-2}). Maximum weed dry weight was found in no weeding

Table 2. Weed dry weight

Treatment	15 DAS		30 DAS		45 DAS	
	2008	2009	2008	2009	2008	2009
No weeding	2.85 a	2.99 a	154.77 a	159.46 a	308.12 a	324.48 a
Hand pulling	0.75 d	0.94 d	6.27 f	10.24 f	12.46 f	19.33 f
Hoeing	1.21 c	1.57 c	21.52 e	26.18 e	53.66 e	64.10 e
Tine cultivator	1.68 b	1.84 b	41.35 d	45.99 d	85.18 d	96.53 d
Spike hoe	2.80 a	2.99 a	144.17 b	135.48 b	265.59 b	277.09 b
Nominee 100 SC	2.83 a	3.01 a	70.44 c	78.29 c	150.64 c	167.44 c
LSD	0.17	0.10	10.06	11.27	8.98	14.86

Any two means not sharing a letter in common differ significantly ($p \leq 0.05$)

Table 3. Paddy yield and yield contributing parameters

Treatment	Plant height (cm)		Fertile tillers (m^{-2})		Kernels panicle^{-1}		1000 kernel weight (g)		Paddy yield (tha^{-1})		BCR	
	2008	2009	2008	2009	2008	2009	2008	2009	2008	2009	2008	2009
No weeding	73.97 d	72.02 d	215.58 e	181.89 e	60.43 e	59.89 e	14.5 d	15.17 e	1.47 e	1.27 e	0.64	0.61
Hand pulling	95.97 a	94.44 a	375.11 a	363.60 a	78.15 a	76.25 a	20.87 a	20.40 a	4.45 a	4.35 a	1.58	1.72
Hoeing	92.5 ab	90.57 ab	364.63 a	349.27 b	75.92ab	75.49 a	20.60 ab	20.17 a	4.21 a	4.11 a	1.58	1.72
Tine cultivator	90.83 b	89.32 b	350.44 b	343.12 b	74.31 b	73.16 b	19.47 b	19.20 b	3.91 b	3.81 b	1.62	1.75
Spike hoe	83.07 c	81.28 c	255.00 d	243.19 d	65.5 d	62.89 d	17.17 c	16.52 d	2.44 d	2.05 d	1.02	0.96
Nominee 100 SC	89.77 b	87.97 b	302.92 c	283.38 c	69.43 c	65.97 c	18.07 c	17.6 c	3.02 c	2.59 c	1.26	1.20
LSD	4.57	4.83	13.80	5.69	1.53	1.02	0.54	0.26	0.29	0.26		

Any two means not sharing a letter in common differ significantly ($p \leq 0.05$)

(308.12 g m^{-2}). During the year 2009 minimum weed dry weight was recorded in hand pulling (19.33 g m^{-2}) followed by hoeing (64.10g m^{-2}), tine cultivator (96.53 g m^{-2}), Nominee 100 SC (167.44 g m^{-2}) and spike hoe (277.09 g m^{-2}). Maximum weed dry weight was found in no weeding (324.48 g m^{-2}).

***Plant height, number of fertile tillers m^{-2}, Kernels per panicle and 1000 kernel weight*:** The data presented in table 3 indicated the significant effect of different weed management strategies on height of rice plants. During the year 2008, maximum plant height (95.97 cm) was recorded for the hand pulling treatment followed by tine cultivator (90.83 cm), Nominee (89.77 cm) and spike hoe (83.07 cm). Minimum plant height was observed in no weeding (73.97 cm). During the year 2009, maximum plant height was recorded in hand pulling (94.44 cm) followed by tine cultivator (89.32 cm) and spike hoe (81.28 cm). Plant height in Nominee 100 SC (87.97 cm) was similar to tine cultivator. Minimum plant height was found in no weeding (72.02 cm).The data presented in Table 3 indicated that different weed management strategies had significant effect on number of fertile tillers per unit area. During the year 2008, maximum number of fertile tillers was recorded in hand pulling (375.11 m^{-2}) followed by hoeing (364.63 m^{-2}), tine cultivator (350.44 m^{-2}), Nominee 100 SC (302.92 m^{-2}) and spike hoe (255.00 m^{-2}). Minimum number of fertile tillers was recorded in no weeding (215.58 m^{-2}). Similar trend was observed during the year 2009. Significantly maximum number of fertile tillers was observed in hand pulling (363.60 m^{-2}) followed by tine cultivator (343.12 m^{-2}), Nominee 100 SC (283.38 m^{-2}) and spike hoe (243.19 m^{-2}). In no weeding (181.89 m^{-2}) significantly minimum number of fertile tillers was recorded.

The data (Table 3) revealed that different weed management strategies affected kernels per panicle significantly. During the year 2008 maximum kernels per panicle were recorded in hand pulling (78.15) and hoeing (75.92) followed by tine cultivator (74.31), Nominee 100 SC (69.63), spike hoe (65.50) and no weeding (60.43). During the year 2009 maximum kernels per panicle were recorded in hand pulling (76.25) and hoeing (75.49) followed by tine cultivator (73.16), Nominee 100 SC (65.97), spike hoe (62.89) and no weeding (59.89).During the year 2008 significantly heavier 1000 kernel weight was recorded in hand pulling (20.87g) followed by tine cultivator (19.47 g), Nominee 100 SC (18.07 g), spike hoe (16.52 g) and no weeding (15.17 g). During the year 2009 heavier 1000 kernel weight was recorded in hand pulling (20.40g) similar to hoeing (20.17 g) followed by tine cultivator (19.20 g), Nominee 100 SC (18.07 g), spike hoe (17.17 g) and no weeding (14.50 g).

***Paddy yield*:** The data pertaining paddy yield presented in Table 3 indicated that all weed management strategies had significant effect on paddy yield. During the year 2008, significantly maximum paddy yield (4.45 t ha^{-1}) was recorded in hand pulling similar to hoeing (4.21 t ha^{-1}) followed by tine cultivator (3.91 t ha^{-1}), Nominee 100 SC (3.02 t ha^{-1}) and spike hoe (2.44 t ha^{-1}). Minimum paddy yield was recorded in no weeding (1.47 t ha^{-1}). Similar trend was observed during the year 2009. Significantly maximum paddy yield (4.35 t ha^{-1}) was recorded in hand pulling and hoeing (4.11 t ha^{-1}) followed by tine cultivator (3.81t ha^{-1}), Nominee 100 SC (2.59 t ha^{-1}) and spike hoe (2.05). Lowest paddy yield was found in no weeding (1.27 t ha^{-1}).

Total weed biomass (45 DAS) and paddy yield were linearly related and the regression accounted for 96 and 97% of the variation during 2008 and 2009, respectively (Fig. 1). Relationship of paddy yield with number of fertile tillers, kernels per panicle and 1000 kernel weight was linear during 2008 and 2009 (Fig. 2-4).

***Economics*:** Maximum benefit-cost ratio (BCR) during the year 2008 was obtained by tine cultivator (1.62) followed by hoeing (1.58), hand weeding (1.58), Nominee (1.26) and spike hoe (1.02) and no weeding (0.64). During the year 2009 maximum benefit-cost ratio (BCR) was obtained by tine cultivator (1.75) followed by hoeing (1.72), hand weeding (1.72), Nominee (1.20) and spike hoe (0.96) and no weeding (0.61).

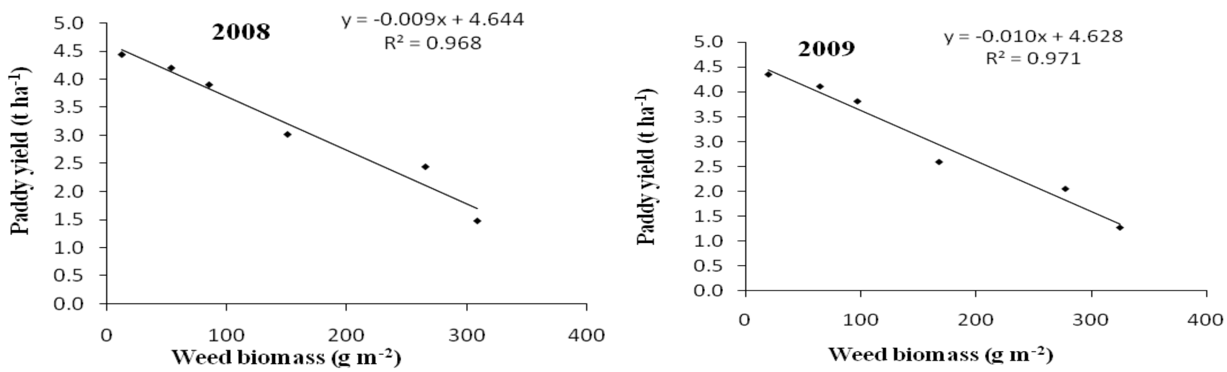

Figure 1. Relationship between paddy yield and total weed biomass (45 DAS)

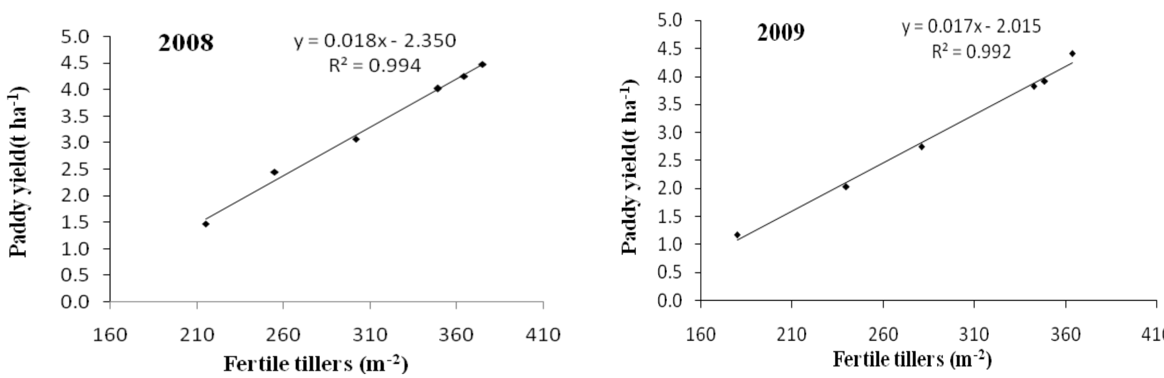

Figure 2. Relationship between paddy yield and number of fertile tillers

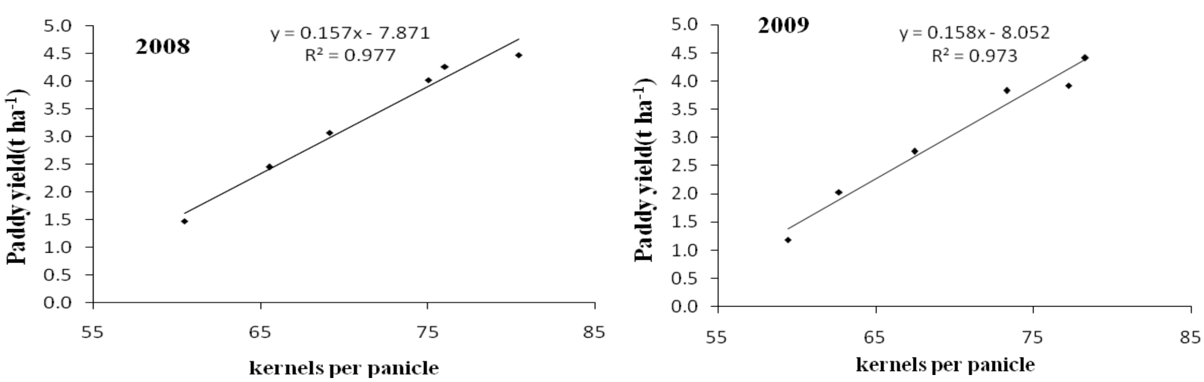

Figure 3. Relationship between paddy yield and kernels per panicle

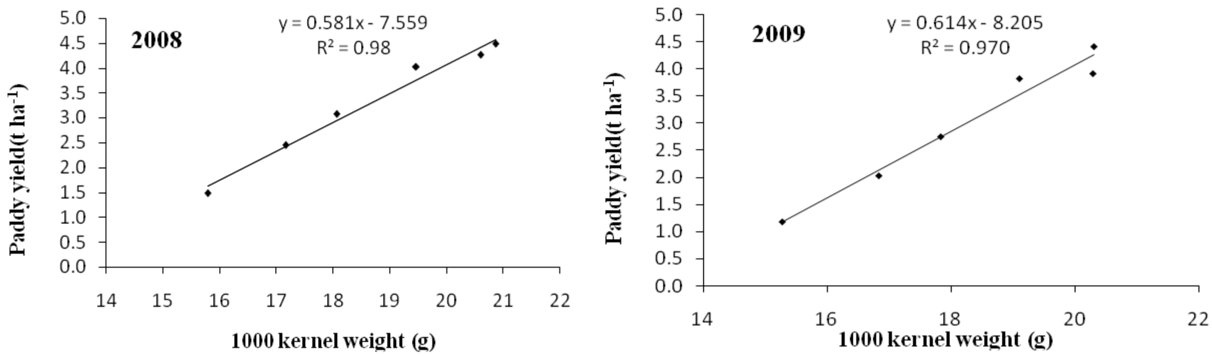

Figure 4. **Relationship between paddy yield and 1000 kernel weight**

DISCUSSION

Four times manual weeding resulted in the lowest weed dry weight (at 45 DAS) among all treatments. Sharma (1997) and Johnson *et al.* (2004) also reported minimum weed dry weight in hand weeding. Hoeing by kasula produced less weed dry weight as compared to control, spike hoe, Nominee 100 SC and tine cultivator. Hoeing removed inter-row weeds which might be the reason of low weed dry weight. Similar results were observed by Akbar *et al.* (2011). More weed dry weight in hoeing than hand pulling was possibly due to within the rows weeds that were remained uncontrolled. Weed dry weight in tine cultivator was less than no weeding, spike hoe and Nominee 100 SC possibly because it uprooted and removed inter-row weeds, controlling early flushes of weeds. Second reason of less weed biomass might be beushening (drawing of a heavy flat wooden object over the crop) which killed the weeds with single stem. This was also reported by Rao *et al.* (2007) and Sharma (1997). Tine cultivator produced more weed dry weight than hoeing and hand pulling possibly because weeds that were within rows not controlled. Results of Fazlollaalh *et al*. (2011), Remington and Posner (2000) and Sharma (1997) were also in line with above findings. Application of Nominee 100 SC resulted in less weed biomass than spike hoe and no weeding. Reason might be because Nominee (bispyrabic sodium) is an acetol-actate synthase inhibitor which controlled weeds. Similar observations were reported by Fischer *et al*. (2000). Nominee 100 SC produced more weed dry weight than hand pulling, hoeing and tine cultivator. Increased weed dry weight in this study might have been due to increased critical period of weed infestation. Nominee 100 SC was applied at 20 DAS and weeds might have competed with rice crop for a longer period. This prolonged competition period possibly provided a considerable opportunity for weeds to emerge subsequently and produce seeds. Studies by Chauhan and Johnson (2011) revealed that in direct seeded rice weed competition period was prolonged. Findings of Johnson *et al*. (2004) were contradictory who expressed that critical period for weed competition in aerobic rice was 29-32 days. Highest weed biomass was recorded in no weeding, might have been due to several reasons. Firstly aerobic soil conditions were conducive to the germination and growth of weeds as reported by Rao *et al*. (2007). Secondly emerging direct seeded rice seedlings were less competitive with concurrently emerging weeds (Kumar *et al*., 2008). Third reason of highest weed biomass might be competitive advantage of C4 weeds which increased their efficiency to use crop nutrients more than rice. Findings of Holm *et al*. (1991) were in support of this reason. Heavy and quicker second flush of weeds might be another reason of highest weed biomass. Almost similar results were reported by Ekleme *et al.* (2009), Singh *et al.* (2008) and Mann *et al.* (2007).

Paddy yield recorded in hand pulling and hoeing was increased 221 and 203% as compared to control. This increase in yield might be due to minimum presence of weeds during critical competition period. Studies of Haefele *et al*. (2000) suggested that there was a considerable scope to increase yield with improved weed control in direct seeded rice. Proper availability of nutrients, space and moisture resulted in more fertile tillers, more kernels per panicle and heavier 1000 kernel weight. Similar finding was observed by Phoung *et al.* (2005). Paddy yield observed in tine cultivator was 141, 71 and 37% higher than control, spike hoe and Nominee respectively while 13 and 7% less in case of hand pulling and hoeing. Increase in yield might be due to good inter-row weed control and low weed dry weight as compared to control. Fazlollah *et al*. (2011) reported similar results. Second reason of increased paddy yield might be due to an increase in soil ventilation resulting in better growth of root, stem and claw. Findings of Fernandes and Uphoff(2002) favored our observations. Third reason was probably the beushening effect that was also reported by Sharma (1997). Similar findings were reported by Kumar (2003): he compared the rotary hand weeders with the common methods of weeding in India. In that study the mechanical weed control significantly increased the grain yield of rice plants and mechanical weeding had advantage of 10.9% yield increase per hectare rather than using hand weeding. Fazlolallh *et al*. (2001), an Iranian scientist, compared two mechanical weeders in rice: mechanical weeder with engine power and mechanical weeder without engine power both resulting in good yield as compared to no weeding. Paddy yield was 12% less than hand pulling probably due to more weed dry weight than hand pulling because with in row weeds were mostly not controlled. Yield resulted in weed control by Nominee 100 SC was 105 and 25% more than no weeding and spike hoe respectively while 58 and 37% less than hand pulling and tine cultivator respectively. Reduction in yield might be due to more weeds infestation for a longer period. Findings of current study are also in line with Remington and Posner (2000),they did a research about weeds control in the direct cultivation of rice in Gambia and found that delay in weed control during weed competition period causes 25 kg ha^{-1} day^{-1} decrease in rice yield. Nominee 100 SC resulted in more paddy yield than spike hoe and no weeding. Reason might be because Nominee (bispyrabic sodium) is an acetol-actate synthase inhibitor which controlled weeds of rice and rice yield was increased. Similar observations were reported by Fischer*et al*. (2000).

Conclusions: On the basis of above results it was concluded that hand weeding resulted in minimum weed dry weight at 45 DAS indicating the efficient weed control, producing maximum number of fertile tillers, kernels per panicle, 1000 kernel weight and yield along with BCR 1.72.

Tine cultivator also controlled weeds and produced good yield along with maximum BCR (1.75). Farmers having high financial status can control weeds by hand weeding in DSR and farmers with limited finance can manage weeds successfully in DSR by using Tine cultivator.

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