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Effect of Establishment Methods and Weed Management Practices on Some Growth Attributes of Rice

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Abstract: Studies were carried out for two years to evaluate the effect of methods of sowing and weed control practices on the productivity of transplanted and direct wet-seeded rice in Dera Ismail Khan, NWFP, Pakistan. The experiment was laid out in a randomized complete block design with a split plot arrangement. The planting techniques viz. transplanting and direct seeding were maintained in main plots while weed control practices included the use of granular herbicide Sunstar 15WG (ethoxy sulfuron), Machete 60EC (butachlor), conventional hand weeding, and the weedy check (control) were assigned to the sub-plots. Data were recorded on weed parameters like weed density and dry weed biomass 60 and 90 days after sowing (DAS); agronomic parameters including plant population, number of panicles and paddy yield and physiological parameters like leaf area index and net assimilation rate 45 and 90 DAS. The planting methods and weed management significantly influenced most of the parameters studied. The data revealed that the paddy yield and its components were significantly higher in the transplanted method than that in direct-seeded method, while the weed density and biomass were lower in the transplanted plots than the direct-seeded plots. Among weed management tools, the maximum paddy yield was obtained in hand weeding, closely followed by herbicide application Machete 60EC during both cropping seasons.

Key words: rice; transplantation; direct-seeding; herbicides; weed population; leaf area index; net assimilation rate; paddy yield

In rice, the traditional system of transplanting gives the crop a 14 to 21-day growth advantage over the weeds [1]. The transplanting also enables rice to capture space earlier. This is because the young rice plants have leverage over germinating weeds due to shading and earlier establishment of root system. The immediate flooding after transplanting limits the establishment of many weeds [2]. Similarly, in direct seeded method, the use of high seed rates could reduce weed infestation to a large extent [3-4]. Therefore, the rice cultivation trend has been increasingly shifting to direct seeding as labor prices become higher.

An appropriate weed control cover has always been one of the major inputs in the production strategy and a vital component of sustainable development. It is important for both the direct effects of weeds on yield and production costs as well as the indirect effects on grain quality. It has been reported that for each kilogram weeds, the loss in yield is approximately 0.75 kg [1]. In wetland rice culture, weed control techniques include manual [5] and chemical [6-7]. Hand weeding is the most useful method for controlling annual and certain perennial weeds that usually do not regenerate from underground parts. It is practical and traditional but labour intensive method, which usually takes around 120 h/ha, while chemical weed control takes around 4 h/ha [1]. Moreover, hand weeding of young weeds at the initial crop growth stage is very difficult especially if the soil moisture is inadequate. Under such conditions, the use of herbicides could be the best alternative for weed control in both transplanted and direct seeded rice cultures. It is time, labour and energy saving technique, however its indiscriminate use raises concerns for the individual's safety at particular and the environment at large. Researchers have reported the diminished growth parameters of weeds and simultaneous increase in rice crop due to

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the application of herbicides or other weed management tools [8-10].

The present studies were aimed to figure out the most suitable and economical techniques of weed control in transplanted and direct wet-seeded rice and their impact on growth of weeds under the agro-ecological conditions of Dera Ismail Khan, Pakistan.

MATERIALS AND METHODS

The studies were initiated at the Agricultural Research Institute, Dera Ismail Khan, NWFP, Pakistan, during 2002 and 2003. The soil was silty clay with a pH of 8.3 and organic matter content of <1%. The experiment was laid out in a randomized complete block design with a split plot arrangement, replicated 4 times. The methods of sowing were maintained in main plots while weed control techniques (butachlor, ethoxy sulfuron, hand weeding, and weedy check) in sub-plots. The main plot size measured 80 m^2 whereas the sub-plot size was 5 × 2 m^2 with a planting distance of 20 cm each in the transplanted plots. The recommended doses of Machete 60EC (butachlor: 2 L/ha) and Sunstar 15WG (ethoxy sulfuron: 200 g/ha) were applied in respective plots. Hand weeding/herbicides application was done one week after sowing. In the direct-seeded plots, the seed was first kept immersed in water for 24 hours and then under moist gunny bags for 36 hours till a pigeon breast-like shape appeared. A seed rate of 100 kg/ha of the well adapted coarse rice variety IR-6 was used for sowing direct-seeded plots. Sowing/ transplanting was done on 20th of June, each year. Data were recorded on the weed, agronomic and physiological parameters. Weed samples were taken randomly using a 1-m^2 quadrate at three sites in each treatment at 60 and 90 days after sowing (DAS). The samples were weighed in order to record the fresh weed biomass and then oven-dried at 70°C for 48 h. The oven-dried weeds were then weighed in order to record the dry weed biomass. Data recorded on weed density and dry weed biomass was converted to the number of weed plants per m^2 and weight (g/m^2), respectively. Similarly, plant populations and number of panicles were counted in each plot at harvest, using a 1-m^2 quadrate. The paddy yield, leaf area index and net assimilation rate were calculated by the procedure as outlined by Lockhart and Wiseman [11] and Chaudhry et al [12]. Fertilizer, zinc and insecticide were applied equally to all the treatments according to standard recommendations for the locality. The data were analyzed statistically using the analysis of variance technique and significant means were separated using the least significant difference test (LSD) by MSTATC computer software [13].

RESULTS AND DISCUSSION

Weed density 60 DAS

The analysis of data showed non-significant differences for the planting techniques while the weed management practices and interaction were found significant during 2002 (Table 1). During the subsequent year the main effects for the two factors were significant, while the interaction was non-significant statistically. Among treatments, Machete (51.00 weed plants per m^2), Sunstar (48.50 weed plants per m^2) and hand weeding (23.37 weed plants per m^2) had comparable but statistically lower weed density than the weedy check (106.62 weed plants per m^2) during 2002. The interaction showed the lowest weed density in hand weeding (20.75 weed plants per m^2) under transplanting which was statistically at par with the Sunstar (47.75 weed plants per m^2) under transplanting and hand weeding (26.00 weed plants per m^2) and Machete (43.25 weed plants per m^2) in the direct wet seeding (Table 1) in 2002. During 2003, transplanting technique produced significantly lower weed density (9.25 weed plants per m^2) than the direct seeding (20.81 weed plants per m^2). For the management practices, similar trend was noted in second year trial when weedy check gave comparatively higher weeds (18.00 weed plants per m^2), though at par statistically with herbicides application. The minimum number of weeds (9.12 weed plants per m^2) was noted in hand weeding. Contrary to the results of preceding year, the interaction was non-significant statistically during 2003. The maximum numerical weed density (27.00 weed plants per m^2) was observed in herbicide application Sunstar with direct seeding technique during 2003. However, the lowest weed population (3.75 weed plants per m^2) was shown by hand weeding under transplanting during the same year. The statistically comparable number of weeds in the interaction involving herbicides and hand weeding in either of the planting technique during 2002 exhibits success of treatments to be recommended for

Table 1. Weed density (number of weed plants per m^2) as affected by methods of sowing and weed control practices in transplanted and direct wet-seeded rice 60 DAS during 2002 and 2003.

Seeding technique	2002					2003				
	Sunstar 15WG	Hand weeding	Machete 60EC	Weedy check	Mean	Sunstar 15WG	Hand weeding	Machete 60EC	Weedy check	Mean
Transplanting	47.75 cde	20.75 e	58.75 bc	133.25 a	65.12 ^{NS}	9.00 ^{NS}	3.75	8.25	16.00	9.25 b
Direct seeding	49.25 cd	26.00 de	43.25 cde	80.00 b	49.62	27.00	14.50	21.50	20.00	20.81 a
Mean	48.50 b	23.37 c	51.00 b	106.62 a		18.13 a	9.12 b	14.87 a	18.00 a	

$LSD_{0.05}$ (Seeding techniques, 2003) = 5.72; $LSD_{0.05}$ (Weeding techniques, 2002) = 19.36; $LSD_{0.05}$ (Weeding techniques, 2003) = 5.47; $LSD_{0.05}$ (Seeding × Weeding techniques, 2002) = 27.37.

NS, Non-significant. Means followed by different letter(s) are significant at 5% level of probability using LSD test.

Table 2. Weed density (number of weed plants per m^2) as affected by methods of sowing and weed control practices in transplanted and direct wet-seeded rice 90 DAS during 2002 and 2003.

Seeding technique	2002					2003				
	Sunstar 15WG	Hand weeding	Machete 60EC	Weedy check	Mean	Sunstar 15WG	Hand weeding	Machete 60EC	Weedy check	Mean
Transplanting	4.75 c	4.00 c	4.00 c	8.00 b	5.18 b	6.00 ^{NS}	2.00	8.00	14.25	7.56 b
Direct seeding	7.75 b	4.25 c	10.00 b	15.25 a	9.31 a	14.25	9.00	16.00	24.00	15.81 a
Mean	6.25 b	4.12 c	7.00 b	11.62 a		10.12 b	5.50 c	12.00 b	19.12 a	

$LSD_{0.05}$ (Seeding techniques, 2002) = 1.99; $LSD_{0.05}$ (Seeding techniques, 2003) = 4.53; $LSD_{0.05}$ (Weeding techniques, 2002) = 1.72; $LSD_{0.05}$ (Weeding techniques, 2003) = 3.37; $LSD_{0.05}$ (Seeding × Weeding techniques, 2002) = 2.44 .

NS, Non-significant. Means followed by different letter(s) are significant at 5% level of probability using LSD test.

commercial adoption. Okafor and De Datta [14] observed that weeds grow profusely in direct seeded rice and without weed control there is a total yield loss. Similarly, Johnson [2] noted that, in transplanted rice, the young rice plants have an advantage over germinating weeds, hence the crop-weed competition tends to be lesser than in direct-seeded culture.

Weed density 90 DAS

It is revealed from the data presented in Table 2 that overall density of weeds has fallen down to a considerable extent as compared to the density recorded 60 DAS, due to the suppression of weeds by the rice crop. Due to better suppression, the transplanted rice produced lower weed population (5.18 and 7.56 weed plants per m^2) than direct seeding (9.31 and 15.18 weed plants per m^2) during either year of study. Similarly, hand weeding showed significantly lower weed density (4.12 and 5.50 weed plants per m^2) as compared to herbicides Sunstar and Machete, possessing statistically at par weed population of 6.25, 10.12 and 7.00 and 12.00 weed plants per m^2, respectively during either cropping season. The significant interaction during 2002 revealed the lowest infestation in hand weeding under either planting technique and the two herbicides under transplanting. Our findings have the implication that if labor availability is a limiting factor, the herbicides could be another suitable alternative for efficient weed management. The effect of herbicides was also marvelous in direct seeding but not as effective as in transplanting technique, because in the later technique the crop also took care of weeds. Many researchers investigated the emergence time of different weeds [15] and growth competition of rice and weeds [16], competition injury due to weeds in both direct-sown and transplanted rice [17] and increase in absolute density of weeds with the increase of every kilogram of N /ha applied [18]. The findings of Hayat et al [4] and Awan et al [19] also corroborate the present results.

Dry weed biomass 60 DAS

There were significant differences among weed control practices during both experimental years while the seeding techniques reached the level of significance only during the second year trial (Table 3). The interaction was found non-significant during either year of study. Among seeding techniques, transplanting resulted in lower dry weed biomass (212.87 and 130.25 g/m^2) as compared to direct seeding, which expressed a biomass of 272.68 and 374.56 g/m^2, respectively. Likewise, hand weeding displayed a dry weed biomass of 146.50 and 88.75 g/m^2, significantly lower than herbicides application and weedy check (control) during both years. In 2003, the maximum dry weed biomass was recorded in

Table 3. Dry weed biomass (g/m^2) as affected by methods of sowing and weed control practices in transplanted and direct wet-seeded rice 60 DAS during 2002 and 2003.

Seeding technique	2002					2003				
	Sunstar 15WG	Hand weeding	Machete 60EC	Weedy check	Mean	Sunstar 15WG	Hand weeding	Machete 60EC	Weedy check	Mean
Transplanting	207.50 ^{NS}	113.00	213.50	317.50	212.87 ^{NS}	138.20^{NS}	15.50	120.25	247.00	130.25 b
Direct seeding	302.75	180.00	275.75	332.25	272.68	428.00	162.00	523.00	385.25	374.56 a
Mean	255.12 a	146.50 b	244.62 a	324.87 a		283.12 a	88.75 b	312.62 a	316.12 a	

$LSD_{0.05}$ (Seeding techniques, 2003) = 144.0; $LSD_{0.05}$ (Weeding techniques, 2002) = 82.27; $LSD_{0.05}$ (Weeding techniques, 2003) = 160.90.
NS, Non-significant. Means followed by different letter(s) are significant at 5% level of probability using LSD test.

Table 4. Dry weed biomass (g/m^2) as affected by methods of sowing and weed control practices in transplanted and direct wet-seeded rice 90 DAS during 2002 and 2003.

Seeding technique	2002					2003				
	Sunstar 15WG	Hand weeding	Machete 60EC	Weedy check	Mean	Sunstar 15WG	Hand weeding	Machete 60EC	Weedy check	Mean
Transplanting	19.00 c	12.25 c	17.25 c	27.25 c	18.93 b	30.25^{NS}	10.25	32.00	194.25	66.68 b
Direct seeding	61.25 b	14.25 c	56.25 b	102.25 a	58.50 a	253.25	164.25	226.25	354.00	249.43 a
Mean	40.12 b	13.25 c	36.75 b	64.75 a		141.75 b	87.25 b	129.12 b	274.12 a	

$LSD_{0.05}$ (Seeding techniques, 2002) = 8.66; $LSD_{0.05}$ (Seeding techniques, 2003) = 58.13; $LSD_{0.05}$ (Weeding techniques, 2002) = 13.19; $LSD_{0.05}$ (Weeding techniques, 2003) = 85.16; $LSD_{0.05}$ (Seeding × Weeding techniques, 2002) = 18.65.
NS, Non-significant. Means followed by different letter(s) are significant at 5% level of probability using LSD test.

weedy check plots (332.25 g/m^2) under direct seeding technique. Hand weeding in transplanting produced minimum dry weed biomass (113.00 and 15.50 g/m^2) among all the techniques studied. The minimum dry weed biomass in hand weeding either in transplanting or direct seeding practices was due to the reason that regenerated weeds could not compete with crop in later growth stages, when the plants attained a reasonable height 60 DAS. Similarly, the dry weed biomass in herbicide application was probably due to second flush of the weeds that were not affected by herbicides and remained in the fields till the end of the crop and depleted the nutrients to a large extent.

Dry weed biomass 90 DAS

Data shown in Table 4 indicated an overall decline in the dry weed biomass as compared to 60 DAS. The growth of crop probably suppressed the already emerged weeds. The main effects for both factors were significant statistically during both experimental years, while the interaction was merely significant during 2002. The perusal of data exhibit that direct seeded culture with and without weed management had higher dry weed biomass (58.50 and 249.43 g/m^2) than transplanting during both years. The lower dry weed biomass of 18.93 and 66.68 g/m^2 respectively was recorded in transplanting technique. Similarly, the dry weed biomass of 64.75 and 274.12 g/m^2 noted in weedy check, was significantly higher than herbicide application Sunstar (40.12 and 141.75 g/m^2) and Machete (36.75 and 129.12 g/m^2) during 2002 and 2003. The lowest dry weed biomass was recorded in hand weeding (13.25 and 87.25 g/m^2) during either year of study. It is also revealed from the data that statistically equal dry weed biomass of 17.25, 19.00 and 27.25 g/m^2 and the lowest 12.25 g/m^2 were recorded in Sunstar, Machete, weedy check and hand weeding, respectively in transplanting during 2002. Likewise, the hand weeding displayed the lowest dry weed biomass (10.25 g/m^2) in transplanting as compared to direct seeding and all other weed management techniques. Direct seeding technique again exhibited higher dry weed biomass in weedy check and other weed control practices. Earlier studied have also communicated the efficacy of herbicides in controlling weeds in rice [6-7].

Plant population

Lockhart and Wiseman [11] suggested that it is better to go for a high population than to depend too much on tillering, which increases the risk of uneven ripening. Plant population recorded during both cropping seasons is presented in Table 5. The analysis of the data revealed non-significant differences among the main effects and interaction, except the planting techniques that differed significantly during 2003. Numerically higher plant population (22.00

Table 5. Plant population (number of rice plants per m^2) as affected by methods of sowing and weed control practices in transplanted and direct wet-seeded rice during 2002 and 2003.

Seeding technique	2002					2003				
	Sunstar 15WG	Hand weeding	Machete 60EC	Weedy check	Mean	Sunstar 15WG	Hand weeding	Machete 60EC	Weedy check	Mean
Transplanting	22.00 ^{NS}	22.00	22.00	22.00	22.00 ^{NS}	22.00 ^{NS}	22.00	22.00	22.00	22.00 b
Direct seeding	17.50	19.50	17.50	18.25	18.18	28.00	31.25	30.00	29.25	29.62 a
Mean	19.75 ^{NS}	20.75	19.75	20.12		25.00 ^{NS}	26.62	26.00	25.62	

$LSD_{0.05}$ (Seeding techniques, 2003) = 2.37.

NS, Non-significant. Means followed by different letter(s) are significant at 5% level of probability using LSD test.

plants per m^2) was noted in transplanting technique where space planting (20 cm × 20 cm) was done. However, it was at par with direct seeding where seed was broadcast without maintaining space among plants. The higher plant population (29.62 plants per m^2) was recorded in direct seeding technique during the second year trial.

Although the same seed rate was used for planting direct seeded plots during both experimental years but the variability in plant population might have been due to the emergence potential of seed and the micro and macro environmental conditions as well. It was interesting to note that weedy check, in comparison with weed management techniques, resulted in statistically at par plant population during both cropping seasons. It was probably due to the reason that weed density in weedy check plots did not reach a level of self thinning whereby the less competitive species which of course is mostly crop loses some of if its individuals beyond a certain level of critical density. The interaction between the variables was non-significant, however, maximum plant population (22.00 plants per m^2) was observed in transplanted method during 2002. In 2003, the plant population (31.25 plants per m^2) was higher in hand weeding under direct seeded technique, followed by Machete (30.00 plants per m^2). The number of plants found in transplanting technique was same (22.00 plants per m^2) during 2002 and 2003, because same number of seedlings was transplanted on standard spacing of 20 cm × 20 cm. The plant population during 2003 was higher, which might be due to difference in soil fertility status, temperature and all other biotic factors than the preceding year (Tables 6 and 7). Tuong et al [16] reported that, in wet seeded rice, genotypes that had superior crop stand establishment or faster seedling growth did not give better weed suppression than genotypes with high tillering ability.

Number of panicles

Having a direct bearing on vegetative growth, the reproductive growth is the ultimate aim of farmers and researchers alike. The planting methods influenced the number of panicles where transplanting method produced more panicles (363.25 and 425.81 per m^2) during both years (Table 8). Significantly higher number of panicles was found in hand weeding (381.50 and 512.25 per m^2) during 2002 and 2003. Sunstar and Machete followed it with more or less similar trend of producing panicles per m^2. The lowest number of panicles was produced in weedy check (266.00 and 329.25 per m^2) during either year of study. The data further revealed that maximum number of panicles (413.25 per m^2) was observed both for Sunstar and conventional hand weeding in transplanting method during 2002. Likewise, the hand weeding excelled all other treatments by producing more number of panicles (532.75 per m^2) in direct seeding method in 2003. The production of more panicles per unit area in weed control treatments was probably due to less severe competition among crop plants and the weeds in treated plots, where the weeds were eliminated to a large extent. Sultana [20] observed

Table 6. Physio-chemical characteristics of the soils used for experimentation.

Symbol	Unit	Value	
		2002	2003
Previous crop	-	Wheat	Chickpea
Textural class	-	Silty Clay	Silty Clay
pH (1:5)	1-14	8.3	8.3
EC× 10^6	dS/m	250	250
$Ca^{2+} + Mg^{2+}$	mmol/L	1.10	1.55
HCO_3	mmol/L	1.8	1.4
Cl	mmol/L	1.3	1.7
Organic matter	%	0.62	0.96
N	%	0.03	0.05
P	mg/L	7.0	7.0

Source: Soil Chemistry Laboratory, Agricultural Research Institute, Dera Ismail Khan, Pakistan.

Table 7. Meteorological data recorded during the rice-growing seasons.

Month	2002					2003				
	Temperature (℃)		Relative humidity (%)		Rainfall (mm)	Temperature (℃)		Relative humidity (%)		Rainfall (mm)
	Max	Min	08:00	14:00		Max	Min	08:00	14:00	
May	42	24	69	35	29	39	22	71	42	3
June	42	27	60	34	10	42	26	63	34	1
July	40	27	66	37	-	38	27	75	46	60
Aug.	39	27	67	38	5	37	26	78	57	102
Sept.	34	22	64	37	21	35	24	79	57	16
Oct.	32	17	63	40	11	33	33	76	48	-

Source: Arid Zone Research Institute, Dera Ismail Khan, Pakistan.

Table 8. Number of panicles per square meter as affected by methods of sowing and weed control practices in transplanted and direct wet-seeded rice during 2002 and 2003.

Seeding technique	2002					2003				
	Sunstar 15WG	Hand weeding	Machete 60EC	Weedy check	Mean	Sunstar 15WG	Hand weeding	Machete 60EC	Weedy check	Mean
Transplanting	413.25 a	413.25 a	331.50 bc	295.00 cd	363.25 a	401.50 ^{NS}	491.75	469.00	341.00	425.81 ^{NS}
Direct seeding	289.50 d	349.75 b	290.25 d	237.00 e	291.62 b	372.25	532.75	434.00	317.50	414.12
Mean	351.37 b	381.50 a	310.87 b	266.00 c		386.87 c	512.25 a	451.50 b	329.25 d	

$LSD_{0.05}$ (Seeding techniques, 2002)= 21.72; $LSD_{0.05}$ (Weeding techniques, 2002) = 28.64; $LSD_{0.05}$ (Weeding techniques, 2003) = 50.36; $LSD_{0.05}$ (Seeding× Weeding techniques, 2002) = 40.50.

NS, Non-significant. Means followed by different letter(s) are significant at 5% level of probability using LSD test.

that when a weed density of 200 per m^2 competed with rice, it reduced about 59% of panicle production. Mamun et al [21] also found similar reduction in panicles due to competition from weeds. While, a target stand of around 400 tillers per m^2 has been reported to be reasonable to shade out weeds at the panicle initiation stage [1].

Paddy yield

Paddy yield increased as a result of many factors, thus the crop production is most successful when all available factors are utilized favorably. The data shown in Table 9 manifested a considerable yield reduction due to competition from different weed densities. This reduction in paddy yield increased progressively with the increase in weed density. However, among planting techniques, the paddy yield recorded in transplanting method (5.78 and 8.54 t/ha) was higher about 2-fold than the direct seeding, which exhibited significantly lower paddy yield of 3.16 and 4.18 t/ha, respectively during both planting seasons. Similarly, the hand weeding excelled all other treatments by producing paddy yield of 4.78 t/ha during 2002. In 2003, the higher paddy yield (6.94 and 6.53 t/ha) was noted in Machete and hand weeding, though at par statistically with Sunstar (6.31 t/ha). The paddy yield noted for Sunstar was in turn statistically at par with the weedy check (5.66 t/ha) during 2003. Weedy check produced lowest paddy yield during both experimental years. The interaction was found non-significant, transplanting method however gave the maximum paddy yield of 6.15 and 8.98 t/ha in hand weeding and Machete, respectively during either year of study. The yield response of

Table 9. Paddy yield as affected by methods of sowing and weed control practices in transplanted and direct wet-seeded rice during 2002 and 2003. t/ha

Seeding technique	2002					2003				
	Sunstar 15WG	Hand weeding	Machete 60EC	Weedy check	Mean	Sunstar 15WG	Hand weeding	Machete 60EC	Weedy check	Mean
Transplanting	5.71 ^{NS}	6.15	5.93	5.35	5.78 a	8.58 ^{NS}	8.95	8.98	7.65	8.54 a
Direct seeding	3.24	3.42	3.11	2.90	3.16 b	4.04	4.11	4.90	3.67	4.18 b
Mean	4.47 ^{NS}	4.78	4.52	4.11		6.31 ab	6.53 a	6.94 a	5.66 b	

$LSD_{0.05}$ (Seeding techniques, 2003)= 0.54; $LSD_{0.05}$ (Seeding techniques, 2002)= 0.47; $LSD_{0.05}$ (Weeding techniques, 2003) = 0.80.

NS, Non-significant. Means followed by different letter(s) are significant at 5% level of probability using LSD test.

Table 10. Leaf area index as affected by methods of sowing and weed control practices in transplanted and direct wet-seeded rice 45 DAS during 2002 and 2003.

Seeding technique	2002					2003				
	Sunstar 15WG	Hand weeding	Machete 60EC	Weedy check	Mean	Sunstar 15WG	Hand weeding	Machete 60EC	Weedy check	Mean
Transplanting	10.46 NS	11.44	10.06	7.77	9.93 a	16.06 a	16.89 a	14.86 a	10.95 b	14.69 a
Direct seeding	3.95	5.43	4.01	2.36	3.94 b	2.09 c	2.80 c	1.16 c	1.16 c	1.80 b
Mean	7.21 b	8.44 a	7.04 b	5.06 c		9.07 ab	9.84 a	8.01 b	6.05 c	

$LSD_{0.05}$ (Seeding techniques, 2002) = 1.19; $LSD_{0.05}$ (Seeding techniques, 2003) = 1.45; $LSD_{0.05}$ (Weeding techniques, 2002) = 0.66; $LSD_{0.05}$ (Weeding techniques, 2003)=1.63; $LSD_{0.05}$ (Seeding × Weeding techniques, 2003) = 2.31.

NS, Non-significant. Means followed by different letter(s) are significant at 5% level of probability using LSD test.

Sunstar and hand weeding was also comparable in transplanting technique during 2003. The reduction in paddy yield in direct seeded and weedy check plots might be due to high weed infestation which competed with the crop at all growth stages and resulted in lower yield. Previously, Hach et al [22] found out that yield of direct seeded rice is characteristically at risk from weeds that establish concurrently with the crop in contrast to transplanted rice. Similarly, Haque et al [23] reported that *E. colona* caused 88% yield loss in transplanted rice due to its faster growth, well-branched root system and higher root length. Sultana [20] observed that weed infestation of 100-200 weeds per m^2 reduced paddy yield 51-64% compared with weed free conditions. Subhas and Jitendra[5] also reported higher grain yield and better weed control with hand weeding.

Leaf area index (LAI) 45 DAS

In cereals, high plant densities restrict leaf area development [11]. The data shown in Table 10 revealed that significantly higher LAI was recorded in transplanting technique (9.93 and 14.69) while considerably lower LAI was noted in direct seeding (3.94 and 1.80). The highest and statistically at par LAI of 8.44 and 9.84 was documented in conventional hand weeding, followed by Sunstar (7.21 and 9.07) and Machete (7.04 and 8.01) during 2002 and 2003. Weedy check plots having 5.06 and 6.05 LAI was significantly lower than all the other treatments. The interaction between variables indicated that in direct seeded technique, weeds showed a detrimental effect on LAI. Direct seeding had LAI ranging from 1.16 to 5.43, considerably lower than transplanting (10.06 to 16.89) during either year of study. The maximum LAI (11.44 and 16.89) was shown by hand weeding in transplanting technique while the trend of producing LAI was same during 2003 when the same treatment gave increased LAI in direct seeding method. All the treated plots produced higher LAI than the weedy check with the planting techniques. The lowest LAI in direct seeding plots especially during 2003 might be due to lower leaf length, width etc. Similarly, the greater variation in LAI at the higher population density indicated the problem of managing leaf area through plant populations. Okafor and De Datta[14] had the view that reduction in paddy yield due to competition from weeds was due to reduced LAI and less light transmission. Prasad et al [24] advocated transplanting method for higher use efficiency of both soil and fertilizer N and finally the greater LAI. Hoon et al [25] noted that photosynthesis was lower in direct sown crop than in transplanting.

Net assimilation rate 45 DAS

It is considered that C_3 plants including rice have a lower net assimilation rate (NAR) due to photo-respiration, thus, less efficiently utilizing solar energy, especially at high light intensity [11]. The data presented in Table 11 indicated that transplanting technique produced significantly higher NAR [33.39 and 32.67 g/(m^2·d)] during 2002 and 2003, respectively. Whereas, herbicide treated plots with statistically at par NAR of 28.06 and 28.94 g/(m^2·d) followed the hand weeding which showed significantly higher NAR (33.72) during 2002. While, in 2003, application of Machete surpassed all other treatments giving NAR of 20.64 g/(m^2·d), though the results were non-significant. Weedy check plots showed decreased NAR [19.80 and 18.86 g/(m^2·d)] during both years. Although, non-significant statistically,

Table 11. Net assimilation rate as affected by methods of sowing and weed control practices in transplanted and direct wet-seeded rice 45 DAS during 2002 and 2003.

g/(m²·d)

Seeding technique	2002					2003				
	Sunstar 15WG	Hand weeding	Machete 60EC	Weedy check	Mean	Sunstar 15WG	Hand weeding	Machete 60EC	Weedy check	Mean
Transplanting	33.91 NS	40.07	33.59	26.01	33.39 a	32.26 NS	31.27	35.36	31.78	32.67 a
Direct seeding	23.97	27.37	22.53	13.59	21.86 b	6.01	6.90	5.95	5.93	6.20 b
Mean	28.94 b	33.72 a	28.06 b	19.80 c		19.13 NS	19.08	20.64	18.86	

$LSD_{0.05}$ (Seeding techniques, 2002) =7.04; $LSD_{0.05}$ (Weeding techniques, 2002) =4.69; $LSD_{0.05}$ (Seeding techniques, 2003) = 2.80.

NS, Non-significant. Means followed by different letter(s) are significant at 5% level of probability using LSD test.

Table 12. Leaf area index as affected by methods of sowing and weed control practices in transplanted and direct wet-seeded rice 90 DAS during 2002 and 2003.

Seeding technique	2002					2003				
	Sunstar 15WG	Hand weeding	Machete 60EC	Weedy check	Mean	Sunstar 15WG	Hand weeding	Machete 60EC	Weedy check	Mean
Transplanting	10.85 NS	11.00	9.90	7.94	9.92 a	14.56 NS	17.20	17.51	12.51	15.44 a
Direct seeding	5.59	7.63	4.94	3.67	5.46 b	6.71	10.35	8.94	6.76	8.19 b
Mean	8.22 b	9.31 a	7.42 c	5.81 d		10.63 b	13.77 a	13.22 a	9.63 b	

$LSD_{0.05}$ (Seeding techniques, 2002) = 1.51; $LSD_{0.05}$ (Seeding techniques, 2003) = 2.13; $LSD_{0.05}$ (Weeding techniques, 2002)= 0.79; $LSD_{0.05}$ (Weeding techniques, 2003) =1.65.

NS, Non-significant. Means followed by different letter(s) are significant at 5% level of probability using LSD test.

the NAR [40.07 and 35.36 g/(m²·d)] produced by hand weeding and Machete, respectively in transplanting method, was markedly higher than other treatments in both seeding cultures. Weedy check again produced the decreased NAR with either planting technique or weed control practices. The lowest NAR in direct seeded culture during 2003 might be due to lower LAI that in turn was probably due to different moisture conditions, fluctuations in temperatures, humidity (Table 7) and weed flora. The work of Gogoi and Kalita[26], Bhargavi and Reddy[8]and Rana and Angrias [10] showed a higher NAR in rice and lower growth rate in weeds in the plots treated with herbicides as compared to the unweeded check.

Leaf area index (LAI) 90 DAS

The higher dry matter production is always associated with optimum leaf area index, because of high sunlight interception and photosynthesis at maximum rate. The data given in Table 12 indicated higher LAI (9.92 and 15.44) in transplanting method. Whereas, the hand weeding and herbicide treated plots gave significantly increased LAI over weedy check. Among weed control practices, significantly higher LAI was shown by hand weeding (9.31), followed by Sunstar and Machete, respectively during 2002. The trend of higher LAI in weed treated plots as compared to weedy check was almost same during 2003. As far as the interaction of the variables is concerned, LAI expressed by hand weeding was the highest (11.00 and 17.20) in transplanting method, compared with LAI in herbicides application and weedy check. It is obvious from the data that LAI was reduced to more or less 50% in direct seeding method during both planting seasons. This reduction was probably due to the leaves with short length and width. It might be further due to severe competition among weeds and crop plants during all growth stages. Seedlings planted at proper spacing produced the highest paddy yield, might be due to the optimum leaf area. Keeping in view, Escabarte et al [27] advocated transplanting method for higher initial growth rate and leaf area index. Rana and Angrias [10] also communicated that pretilachlor at 0.80 kg/ha remaining statistically at par with hand weeding twice, increased leaf area index, crop growth rate and paddy grain yield and decreased LAI and growth rate of weeds.

Net assimilation rate 90 DAS

Number of factors such as temperature, light, CO_2 content, water, leaf age, mineral nutrients, chlorophyll content and genotype influence net

Table 13. Net assimilation rate as affected by methods of sowing and weed control practices in transplanted and direct wet-seeded rice 90 DAS during 2002 and 2003. g/(m^2·d)

Seeding technique	2002					2003				
	Sunstar 15WG	Hand weeding	Machete 60EC	Weedy check	Mean	Sunstar 15WG	Hand weeding	Machete 60EC	Weedy check	Mean
Transplanting	33.36 ^{NS}	39.02	36.43	25.15	33.49 a	34.87 ab	41.04 a	37.40 ab	31.53 bc	36.21^{NS}
Direct seeding	26.29	28.47	25.85	21.89	25.62 b	34.08 ab	39.15 a	26.99 c	19.24 d	29.86
Mean	29.82 b	33.74 a	31.14 ab	23.52 c		34.47 b	40.10 a	32.19 b	25.39 c	

$LSD_{0.05}$ (Seeding techniques, 2002) = 4.90; $LSD_{0.05}$ (Weeding techniques, 2002) = 3.57; $LSD_{0.05}$ (Weeding techniques, 2003)=4.97; $LSD_{0.05}$ (Seeding × Weeding techniques, 2003) = 7.02.

NS, Non-significant. Means followed by different letter(s) are significant at 5% level of probability using LSD test.

assimilation rate. The direct seeding method, like in all yield-contributing parameters, produced decreased NAR [25.62 and 29.86 g/(m^2·d)] during both cropping seasons (Table 13). However, the transplanting method efficiently utilized the sun's energy showing higher NAR of 33.49 and 36.21 g/(m^2·d). It is also obvious that NAR was significantly influenced by weed control practices and conventional hand weeding did better than all other treatments by producing NAR of 33.74 and 40.10 g/(m^2·d). The herbicides application, by following the hand weeding, produced statistically at par NAR of 29.82 and 34.47 g / (m^2 · d) in Sunstar and 31.14 and 32.19 g / (m^2 · d), respectively in Machete plots during both years. Among variables, the maximum NAR was shown by hand weeding both in transplanting and direct seeding methods, respectively. It was followed by herbicides application Machete and Sunstar in transplanting method and rendered null and void in direct seeding method. Weedy check, in one way or the other, produced comparatively lower NAR, which might be due to the reason that plants could not utilize all the biotic factors favorably on account of high population pressures. Previously, Lockhart and Wiseman [11] stated that shading and aging of leaves decrease NAR values because of reduced rates of photosynthesis. Contrary to the present findings, Heu and Yong [28] and Peng et al [29] reported rapid leaf area development and dry matter accumulation in direct seeding method. It might be due to variations in genotype, cultural practices used and environmental conditions under which the crop was planted.

CONCLUSION

The findings of the present research reveal that transplanting method improved the growth, yield and its associated components markedly as compared to direct seeding. In direct seeding method, weed density was higher, which competed with the crop for resources. The plant population in direct seeding method was also comparatively higher during the second year trial, which further created a keen competition between crop plants and weeds for soil and climatic resources. Under a high planting pressure, low moisture and nutrients were available to crop plants that eventually resulted in low vegetative and reproductive growth and ultimately low paddy yield. As regards weeding techniques, growth of weeds in the treated plots nearly ceased resulting in low dry weed biomass as compared to weedy check where weeds were left unchecked. Overall, the paddy yield was noticeably higher in conventional hand weeding and herbicide treatment Machete 60EC as compared to granular herbicide Sunstar 15WG and weedy check. Therefore, it can be concluded that rice crop may be transplanted rather than direct-seeded for good economic returns. The use of herbicide like Machete 60EC also offers a good alternative in case of skilled labour scarcity for rice transplantation.

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