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Studies on Plant Population and Stand Establishment Techniques for Increasing Productivity of Rice in Dera Ismail Khan, Pakistan

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Abstract: Rice production in Pakistan is constraint by many factors pertaining to prevalent planting techniques. A research on the feasibility of new planting techniques (direct seeding on flat, transplanting on flat, direct seeding on ridges, transplanting on ridges and parachute planting) in transplanted and direct wet-seeded rice was undertaken at Dera Ismail Khan region of Pakistan's North West Frontier Province during 2002 and 2003. Among the planting techniques, the best performance for the yield formation and economic evaluation was noted for transplanting on flat during both years. Chinese parachute planting technology also showed very promising results in most of the parameters. Direct seeding on ridges could not excel transplanting on flat and parachute planting during both cropping seasons. The findings concluded the feasibility of parachute planting technology along with traditional rice transplanting on flat over all other planting techniques being practiced in the area.

Key words: rice; plant population; planting techniques; grain yield; leaf area index; Pakistan

Rice is the second most important food crop in Pakistan's economy. It is the third largest agricultural production in terms of area under the different crops [1]. The average yield of rice is 1.83 t/ha in Pakistan, comparing to 8.4 t/ha in Egypt and 6.6 t/ha in USA. Rice production has been limited by a number of factors, such as water scarcity, high inputs, non-availability of skilled labour, sub-optimal plant population, weeds and pest infestation, low price of rice [2].

The key of maintaining optimum plant population by using appropriate planting technique(s) has been reported by many scientists for increasing the productivity of rice. Ghosh and Sharma [3] reported that the maintenance of optimum plant population is the key to get higher productivity of rice. But the required plant population in Pakistan cannot be maintained due to scarcity of skilled labour [4-5]. This attributed to some factors such as hot weather and other off-farm activities. To overcome these problems, some alternatives need to be put into practice. Farmers generally adopt direct seeding which is economical, feasible and effective in maintaining optimum plant population, but practically, its feasibility is in question due to severe drawbacks related to poor seed quality, poor land preparation, heavy weed invasion, poor water management, large tonnage seed requirement and predation of germinating seed by several predators.

To avert the risks of direct seeding, there are some new planting techniques being introduced in the rice planted countries. These new techniques include bed planting and parachute technology, which could save 25 percent of water [6]. Similarly, in permanent bed planting rice-wheat system, 35-40 percent of irrigation water could be saved [7]. Parachute planting (seedling broadcasting), a new planting technique recently introduced in Pakistan, requires less labour and time than manual transplanting, because planter do not have to bend down to plant each seedling. In addition, the seedlings themselves are less likely to be damaged during the transplanting process [7-8]. With this technology, optimum plant population could be easily maintained. Many scientists advocate field modifications in planting technique(s) with the view to save water, get the maximum yield and retained profits. New water-saving techniques such as bed planting [6] and parachute technology [7] are more efficient than traditional techniques. Moreover, crop

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lodging is less in bed planted crop due to the better root development.

The present research was formulated with the objective of increasing productivity through standardization of plant stand establishment and planting technique and solving the socio-economic problems of paddy growers in the area.

MATERIALS AND METHODS

The study was initiated at the Agricultural Research Institute, Dera Ismail Khan, Pakistan, during 2002 and 2003. Dera Ismail Khan (31º49′ N, 70°55′ E) is the southern district of the North West Frontier Province (NWFP) of Pakistan. It is hot and dry in summer with moderate spells of rain during the monsoon season. The elevation ranges from 121 to 210 m above sea level. The average maximum temperatures in summer and winter are 45℃ and 8℃, respectively. The experiments were carried out in fields where the previous crop was wheat during 2002 and chickpea during 2003. The soil was silty clay with a pH of 8.3 and the content of organic matter is less than 1% (Table 1).

The experiments were arranged in a randomized complete block design with four replications. The plot area was 3 m × 5 m. Rice variety used was IR6. In bed planting, seeds were sown through bed planter while the seedlings were transplanted manually on raised beds with a plant density of 0.20 m × 0.20 m. In parachute planting, all the plots were puddled three days before transplanting. The 25-day-old seedling with roots holding a small lump of soil was transplanted manually. In direct seeding, seeds were first kept immersing in water for 24 h and then in moist gunny bags for 36 h till the radicle and plumule protruding through the hull. A seed rate of 100 kg/ha was used in direct seeding plots. One-month-old rice seedlings were transplanted in the respective plots on June 20 each year. Fertilizer, zinc and insecticide were applied equally to all the treatments according to the standard recommendations.

Table 1. Physio-chemical characteristics of the soils used for the experiments.

Characteristic	2002	2003
Previous crop	Wheat	Chickpea
Texture class	Silty clay	Silty clay
pH (1:5)	8.3	8.3
EC × 10^6 (dS/m)	250	250
Ca^{2+} + Mg^{2+} (mol/L)	1.1	1.55
HCO_3^- (mol/L)	1.8	1.4
Cl^- (mol/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.

Data were recorded about plant population, number of panicles, number of spikelets, sterility percentage, 1000-grain weight and grain yield, number of leaves per plant and leaf area index (LAI). In addition, costs and incomes were investigated for each technique, and economic analysis was done. The data were analyzed statistically by using analysis of variance technique and subsequently Least Significance Test (LSD) was applied for comparing the treatment means by MSTATC computer software [9].

RESULTS AND DISCUSSION

Plant population

The ultimate productivity of a crop is determined by plant population per unit area. In the study, there was significant difference in plant population among the treatments (Table 2). Direct seeding on ridges had higher plant population compared to direct seeding on flat (21.2 seedlings/m^2) and transplanting on flat (21.0 seedlings/m^2) during 2002 (Table 3). Similarly, statistically higher plant population (30.5 seedlings/m^2) was noted in direct seeding on flat, followed by direct seeding on ridges (22.5 seedlings/m^2) and transplanting on flat (21.0 seedlings/m^2) in 2003. The higher plant population in direct seeding on ridges was probably due to the reason that the seed was sowed on ridges maintaining proper plant spacing. Similarly, the direct seeding on flat also resulted in higher plant population mainly due to larger net area for flat planting compared to bed sowing. The plant population in parachute planting remained the same (17.0 seedlings /m^2) during both years due to the use of counted seedlings per unit area. The higher plant population in

Table 2. Mean squares for agronomic and physiological parameters of rice.

Source of variation	*df*	Plant population	No. of panicles per m^2	No. of spikelets per panicle	Sterility (%)	1000-grain weight (g)	Grain yield (t/ha)	No. of leaves per plant (45 DAS)	No. of leaves per plant (90 DAS)	LAI (45 DAS)	LAI (90 DAS)
2002											
Replications	3	1.65^{NS}	9933.78*	75.25^{NS}	6.18^{NS}	0.90^{NS}	0.00^{NS}	4.40^{NS}	214.31^{NS}	1.04^{NS}	7.42^{NS}
Treatments	4	67.30**	16236.60**	1090.30*	32.83*	4.40*	2.02**	4495.17**	2990.80^{NS}	22.40**	47.06*
Error	12	5.40	2397.90	317.33	6.66	1.01	0.14	174.27	1670.23	1.39	15.19
2003											
Replications	3	3.33^{NS}	4107.73^{NS}	353.25^{NS}	2.29^{NS}	3.12^{NS}	0.68^{NS}	955.26^{NS}	170.85^{NS}	3.81	31.65
Treatments	4	188.70**	118564.00**	2169.30**	28.26**	4.03^{NS}	5.10*	11670.30**	1384.37^{NS}	59.67**	82.49*
Error	12	2.83	2817.2 30	363.00	2.41	3.85	1.39	692.43	1279.97	2.66	11.86

^{NS}, Non-significant; *, Significant at 5% level of probability using LSD test; **, Significant at 1% level of probability using LSD test.
DAS, Days after sowing.

Table 3. Agronomic and physiological parameters as affected by establishment techniques in rice.

Year and Parameter	Direct seeding on flat	Transplanting on flat	Direct seeding on ridges	Transplanting on ridges	Parachute planting	$LSD_{0.05}$	*CV* (%)
2002							
Plant population (seedlings/m^2)	21.2 a	21.0 a	21.5 a	12.0 c	17.0 b	3.23	12.53
No. of panicles per m^2	438.5 a	431.2 a	305.2 b	336.5 b	436.2 a	75.44	12.57
No. of spikelets per panicle	150.5 ab	176.5 a	135.0 b	155.2 ab	170.5 a	27.44	11.31
Spikelet stertility (%)	15.8 a	9.5 b	13.9 a	14.0 a	9.7 b	3.97	20.57
1000-grain weight (g)	24.1 a	24.5 a	21.9 b	24.1 a	24.2 a	1.55	4.23
Grain yield (t /ha)	4.2 b	5.9 a	4.3 b	4.4 b	4.8 b	0.58	8.02
No. of leaves per plant at 45 DAS	69.0 b	121.0 a	71.2 b	138.5 a	131.3 a	20.34	12.43
No. of leaves per plant at 90 DAS	159.7^{NS}	176.7	230.7	177.7	172.7	---	---
Leaf area index at 45 DAS	2.7 c	7.5 a	3.3 c	5.4 b	7.8 a	1.81	21.95
Leaf area index at 90 DAS	12.1 ab	15.9 a	17.7 a	9.21 b	11.8 ab	6.00	29.10
2003							
Plant population per m^2	30.5 a	21.0 b	22.5 b	12.0 d	17.0 c	2.59	8.17
No. of panicles per m^2	424.5 b	710.5 a	307.5 c	463.0 b	677.5 a	81.77	10.27
No. of spikelets per panicle	152.5 b	192.5 a	150.5 b	193.0 a	196.2 a	29.35	10.77
Spikelet sterility (%)	15.7 a	11.4 bc	12.0 b	9.2 c	9.2 c	2.39	13.49
1000-grain weight (g)	30.3^{NS}	32.0	30.7	31.2	32.8	---	---
Grain yield (t/ha)	4.0 b	6.5 a	5.1 ab	6.5 a	6.5 a	1.82	20.49
No. of leaves per plant at 45 DAS	69.0 c	124.8 b	105.3 bc	192.8 a	189.8 a	40.54	19.31
No. of leaves per plant at 90 DAS	172.7^{NS}	167.7	179.0	192.7	214.0	---	---
Leaf area index at 45 DAS	4.8 c	9.3 b	4.6 c	11.9 a	12.9 a	2.51	18.67
Leaf area index at 90 DAS	24.5 a	15.6 bc	19.9 a	13.1 c	21.2 a	5.30	18.23

^{NS} Non-significant. Means followed by different letter(s) within a row are significant at 5% level of probability using LSD test.
DAS, Days after sowing.

direct seeding plots was due to the use of higher number of seeds/m^2 and their increased germination percentages as compared to other treatments, wherein, fixed number of plants (seedlings) were planted. The overall lower plant population might be attributed to very heavy soils of the experimental area accompanied with the extremely high temperatures, which were not conducive to stand establishment.

Number of panicles

Almost similar trend of producing panicles was observed during both years (Table 3). The number of panicles was significantly affected by planting technique (Table 2). In 2002, the number of panicles per m^2 in direct seeding on flat, parachute planting and transplanting on flat were 438.5, 436.2 and 431.2, respectively. The less number of panicles in transplanting and direct seeding on ridges might be due to less number of panicle-bearing tillers in these treatments. However, significantly maximum number of panicles was observed in transplanting on flat (710.5 panicles/m^2) and parachute planting (677.5 panicles/m^2) compared to the other treatments in 2003. Direct seeding on ridges during both years produced the least number of panicles, being attributed to low panicle-bearing tillers per m^2 in this treatment. The number of panicles was more in 2003 than that in 2002, which could be due to previous legume crop and higher organic matter that increased the soil fertility through improving the soil physical, chemical and biological qualities and eventually improved the panicle production. The higher and at par number of panicles in transplanting on flat and parachute planting were due to equal number of tillers per unit area. Also, each individual tiller produced higher number of fertile tillers due to ample availability for space, light and aeration. While in case of direct seeding on flat and on ridges, there was severe competition amongst densely germinated seeds, causing less number of fertile tillers per m^2. As number of panicles per m^2 has a direct relationship with grain yield, therefore, higher number of panicles in transplanting on flat and parachute planting techniques also produced increased paddy yield.

Number of spikelets per panicle

Number of spikelets per panicle recorded during two years is given in Table 3. The data revealed significant differences among planting techniques in both years (Table 2). Transplanting on flat and parachute planting produced more number of spikelets per panicle (176.5 and 170.5) in 2002. While in transplanting on ridges and direct seeding on flat numbers of spikelets per panicle were 155.2 and 150.5, respectively, which were significantly higher than that in direct seeding on ridges (135.0 spikelets per panicle). Similarly, parachute planting, transplanting on ridges and transplanting on flat were significantly higher in number of spikelets per panicle than direct seeding on flat and direct seeding on ridges in 2003. The number of spikelets per panicle in 2002 was comparatively lesser than that in 2003. This might be due to the ecological differences during either years of the study. Similar to the number of panicles per m^2, greater light interception, uniformity in space and better aeration also instigated higher number of spikelets per panicle both in transplanting on flat and parachute planting techniques.

Spikelet sterility

Spikelet sterility is induced by high temperature largely in anthesis. The major causes why high temperature induced sterility were attributed to disturbed pollen shedding and reduced the viability of pollen grains, resulting in decreased number of germinated pollen grains on stigma [10]. As shown in Table 3, transplanting on flat and parachute planting showed significantly lower spikelet sterility (9.5% and 9.7%) while all the other treatments displayed higher spikelet sterility in 2002. Similarly, parachute planting and transplanting on ridges resulted in significantly lower spikelet sterility of 9.2% in 2003. Direct seeding on flat during both years showed significantly higher spikelet sterility than the other treatments. It might be due to higher plant population, which caused disturbance in pollen shedding and resulted in higher spikelet sterility. Moreover, the severe competition among the spikelets for photosynthesis might result in failure of fertilization and subsequent sterility in this treatment. Since temperature during first half of July and August is very high in Pakistan than the second half, it might be the major reason in inducing sterility in direct seeding treatments, in which the plants usually flower in the first half of the month.

1000-grain weight

As shown in Table 3, transplanting on flat showed comparatively heavier 1000-grain weight (24.5 g), similar to parachute planting (24.2 g), direct seeding on flat and transplanting on ridges (24.1 g) in 2002. The lowest grain weight (21.9 g) occurred in direct seeding on ridges treatment. Similarly, parachute planting and transplanting on flat had heavier grains (32.8 and 32.0 g), although the differences among treatments were non-significant in 2003. The weight of 1000-grain in 2003 was higher than that in 2002, which might be due to supply of adequate organic matter and other nutrients throughout the grain developmental stages eventually activated the florets to absorb nutrients to their fullest extent and to develop heavy kernels. It might be also attributed to sufficient soil nitrogen (Table 1), because previous chickpea crop released N slowly and remained N availably during all growth period in 2003. In addition, availability of more space and light interception amongst hills in rows also resulted in the production of heavier grains.

Grain yield

The statistical analysis showed significant differences in grain yields among treatments in 2002 and 2003 (Table 2). As shown in Table 3, transplanting on flat produced the highest yield of 5.9 t/ha in 2002, while parachute planting, transplanting on ridges, direct seeding on ridges and direct seeding on flat produced yield of 4.8, 4.4, 4.3 and 4.2 t/ha, respectively. Also, transplanting on flat, parachute planting and transplanting on ridges produced significantly higher or equivalent grain yield of 6.5 t/ha as compared with other treatments in 2003. The lower grain yield of direct seeding on ridges and direct seeding on flat during both years might be attributed to higher spikelet sterility and lower 1000-grain weight. The grain yield in transplanting on flat was higher in 2003 than in 2002, which might be due to increased number of panicles and spikelets and lower sterility. It might also be better moisture conditions at the filling stage, fluctuations in temperature and humidity and increased nitrogen utilization efficiency because of preceding legume crop. Researchers like Awan et al [4] obtained higher rice yield by transplanting as compared to direct seeding. Similarly, space planting (20 cm × 20 cm) has been reported to excel all other methods for all parameters by giving significantly higher grain yield than traditional transplanting [11]. The higher grain yield in parachute planting might have been due to increased yield components in this treatment [12]. Significantly grain yield at par in all treatments, except in transplanting on flat during 2002, was also supported by previous findings of Budhar and Tamilselvan [13]. The menace of severe competition among crop plants for soil and climatic resources, production of less number of panicles per m^2, less spikelets per panicle, the highest sterility percentage as well as lower weight of grains in direct seeding treatments might be the cause of their lower grain yield than transplanting on flat and parachute planting whereby all the yield contributing factors were optimum due to excellent growth conditions.

Number of leaves per plant at 45 and 90 days after sowing

A significant variation in number of leaves among seeding techniques was noted during both years at 45 days after sowing (DAS) (Tables 2 and 3). In 2002, maximum numbers of leaves per plant were recorded for transplanting on ridges (138.5), parachute planting (131.3) and transplanting on flat (121.0), respectively. Almost similar trend occurred in 2003 (Table 3). The numbers of leaves per plant were minimum for direct seeding on flat and on ridges treatments, which might be due to the reason that the plants in direct seeding treatments were at the seedling stage with less number of leaves compared to transplanting treatments which attained a better height as well as a number of leaves at this stage. Transplanting on flat, parachute planting and transplanting on ridges exhibited more leaves per plant and subsequently produced higher grain yield. The higher number of leaves in transplanting treatments as compared to direct seeding might be due to the reason that 35 days old seedlings were transplanted which increased the number of leaves substantially 10 days after transplanting.

The variation in number of leaves among planting techniques was non-significant during both years at 90 DAS (Table 2). However, direct seeding on ridges produced more leaves (230.7), followed by transplanting on ridges (177.7) and transplanting on flat (176.7), respectively during 2002 (Table 3). Whereas, parachute planting surpassed all other treatments by exhibiting 214.0 leaves per plant, followed by transplanting on ridges (192.7) and direct seeding on ridges (179.0), respectively in 2003. The number of leaves per plant was found higher in 2003 might be due to higher soil fertility status on account of previous legume (chickpea) crop (Table 1).

Leaf area index (45 and 90 DAS)

LAI showed significant differences among treatments (Table 2). Of planting techniques,

Table 4. Economic evaluation for stand establishment techniques in rice during 2002 and 2003.

Treatment	2002						2003					
	Grain yield (t/ha)	Total variable cost (Rs/ha)	Gross income[d] (Rs/ha)	Total cost (Rs/ha)	Net income (Rs/ha)	BCR	Grain yield (t/ha)	Total variable cost (Rs/ha)	Gross income (Rs/ha)	Total cost (Rs/ha)	Net income (Rs/ha)	BCR
Direct seeding on flat	4.22	560[a]	21600	16430	5170	1.31	4.08	560	20900	16430	4470	1.27
Transplanting on flat	5.96	1800[b]	30300	17670	12630	1.71	6.58	1800	33400	17670	15730	1.89
Direct seeding on ridges	4.32	560	22100	16430	5670	1.34	5.10	560	26000	16430	9570	1.58
Transplanting on ridges	4.46	1800	22800	17670	5130	1.29	6.50	1800	33000	17670	15330	1.86
Parachute planting	4.80	2580[c]	24500	18450	6050	1.32	6.55	2580	33250	18450	14800	1.80

[a] Rs 560 = Rs 500 for 100 kg seed/ha (Rs 5/kg) and Rs 60 for seed broadcasting (Rs 80/man • day);
[b] Rs 1800 = Transplanting charges;
[c] Rs 2580 = Rs 2500 for 500 plastic trays (Rs 5/tray) and Rs 80 for seedling broadcasting (Rs 80/ man • day);
[d] Price of rice IR6= Rs 5/kg; Income (straw) = Rs 500/ha.
1 US Dollar = 60 Pak rupees (Rs). BCR, Benefit cost ratio.

parachute planting and transplanting on flat excelled all other treatments with LAI of 7.8 and 7.5 in 2002. Similarly, parachute planting and transplanting on ridges produced the highest LAI of 12.9 and 11.9, respectively in 2003. The higher LAI noted for parachute planting was probably due to its higher number of leaves, leaf length, width and so on. The reasonable length of 25-day-old rice seedlings used in parachute planting allowed them to land, fix firmly, withstand transplanting shock and develop vigorously, which eventually resulted in higher LAI than other planting techniques. In transplanted treatments, 35 days old nursery and subsequent 10 days after transplanting increased the LAI, drastically. The treatments (transplanting on flat and parachute planting) had higher LAI , produced more grain yield, indicating a positive relationship between LAI and grain yield. These results are in line with Singh et al [15] who reported that LAI was positively correlated with grain yield. Likewise, Hari et al [16] also obtained maximum LAI in transplanting technique. Thakur and Patel [17] found that increased LAI is ultimately reflected in higher yield.

Data presented in Table 2 revealed significant variations in LAI among treatments at 90 DAS. The maximum LAI occurred in direct seeding on ridges (17.7) and transplanting on flat (15.9) in 2002. In second cropping season, it showed maximum LAI of 24.5 at direct seeding on flat, 21.2 at parachute planting, and 19.9 at direct seeding on ridges (Table 3). Similar results were reported by a number of researchers. For instance, Heu and Yong [18] who compared two sowing techniques and noticed higher LAI in direct seeding cultivation than transplanting method. Hoon et al [19] noted higher crop growth rate and leaf area index in direct seeded cultivation from the tillering to heading stages. Zhong et al [20] described that transplanting spacing had little effect on LAI.

Economic analysis

The economic analyses are presented in Table 4. Data indicated that maximum net income of 12 630 Rs/ha (210.50 USD/ha) and benefit cost ratio (BCR) of 1.71 was obtained from transplanting on flat in 2002. This was due to higher net income recorded in this treatment. Likewise, parachute planting gave higher net income of 6 050 Rs/ha (100.83 USD/ha) than other treatments, but due to higher cost of production, the differences among the BCR values of direct seeding on flat, transplanting on ridges and parachute planting were very little in 2002. All these treatments were better in 2003 than in 2002. In 2003, transplanting on flat was the best with the maximum net income of 15 730 Rs/ha (262.16 USD /ha) and BCR of 1.89. While, transplanting on ridges and parachute planting were the next with the net income of 15 330 and 14 800 Rs/ha (255.50 and 246.66 USD/ha) and BCR of 1.86 and 1.80, respectively. Parachute planting, though having higher cost, gave encouraging results in terms of net income and BCR during both years. The net income and the BCR value in 2003 were higher due to higher grain yield, which might be attributed to better soil fertility status and environmental conditions in 2003 than in 2002. Previous findings also recommended transplanting method for higher grain yield, net income and benefit cost ratio [20].

The use of different planting techniques in the present research and their evaluation provides an insight into the relationship of different yield and yield contributing variables and maintenance of optimum plant population with respect to different planting methods. The lesser incidence of spikelet sterility, higher number of panicles, higher number of spikelets per panicle, heavier grains and resultant higher grain yields in transplanting on flat and parachute planting as compared to direct seeding methods shows their suitability under ecological and socio-economic perspective in Pakistan. Skilled labour shortages and prevalence of extreme planting conditions during rice growing season are also dictating selection of different methods. Furthermore, proper plant population/even distribution of seedlings, optimum light interception, ample space utilization, proper aeration as well as rich canopy were also instrumental in the production of the highest grain yields in transplanting on flat and parachute planting, which further advocate their suitability under the agro-ecological conditions of the area.

CONCLUSION

It is concluded that, if skilled labour is available, transplanting on flat is the most appropriate technique. It has optimum plant population and more grain yield. Parachute planting also showed the similar results with transplanting on flat in almost all yield-contributing parameters. The initial cost of parachute technology is higher, though it is time and energy saving technique. Moreover, it is less labour intensive as compared to traditional rice transplanting. The higher initial cost in parachute planting can be compensated, for example the equipment (plastic trays) can be utilized for at least three years. This method is practically applicable, agronomically viable and eco-friendly under the cropping pattern of the area.

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