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Production efficiency of rice wheat cropping system and path coefficient analysis of wheat under climate smart technologies

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Abstract
Prevalence of puddle transplanted rice (PTR) in the Indo-Gangetic plains not only poses threat to soil structure, increased water requirement, dependence on farm labour but also increases cost of cultivation in comparison to direct seeded rice (DSR). At the same time, burning of rice residue followed by cultivation of wheat crop also gives rise ecological and sustainability challenges in the intensive agriculture production system. Current experiment was conducted by PAU Krishi Vigyan Kendra, Budh Singh Wala, district Moga in the adopted village under national innovations in climate resilient agriculture (NICRA) project. The experiment was replicated four times with six treatments *viz.* T_1- DSR *fb* Conventional sown wheat, T_2- DSR *fb* Surface seeding of wheat, T_3- DSR *fb* Happy seeder sown wheat, T_4- PTR *fb* Conventionally sown wheat, T_5- PTR *fb* Surface seeding of wheat, T_6- PTR *fb* Happy seeder sown wheat. Results of the experiment showed that paddy crop in DSR (134 days) was harvested 6 days prior to the PTR (140 days). In surface seeding and happy seeder technology after DSR and PTR, wheat crop was sown 5-6 days earlier in comparison to conventional tillage. Highest number of ears was recorded in conventional cultivation of wheat after both DSR and PTR which was significantly higher than happy seeder techniques but statistically at par with surface seeding of wheat. Significantly higher 1000 grain weight was recorded in surface seeding and happy seeder after both DSR and PTR than conventional cultivation. Similarly, surface seeding and happy seeder technologies recorded significantly higher grain yield in contrast to conventional tillage. Highest production efficiency was recorded by surface seeding after DSR (44.40 kg/ha/day) which was statistically at par with happy seeder (44.33 kg/ha/day) and conventional tillage (44.37 kg/ha/day) after DSR but achieved the level of significance than all the treatments after PTR. Surface seeding after DSR and PTR recorded highest net returns and B:C which was significantly higher than conventional cultivation but statistically at par with happy seeder technology. The path analysis showed that highest positive phenotypic direct effect was exhibited by 1000 grain weight (0.328) followed by duration of wheat crop (0.206). Highly positive genotypic direct effect was exhibited by 1000 grain weight (0.618) followed by duration of wheat crop (0.241).

Keywords: Climate smart technologies, DSR, happy seeder, PTR, path analysis, production efficiency, surface seeding

Introduction

The Indo-Gangetic plains, covering some 10.5 million hectares, represent India's bread basket. In the prevailing rice-wheat cropping system in north western India, a large share of the 2.5 million farmers burn an estimated 23 million metric tons of rice stubble in October and November to prepare their fields for the subsequent wheat crop (NAAS, 2017). Climate smart agriculture options include water, energy, nutrient, carbon, weather and knowledge-smart technologies, practices, and services suitable for various crops and cropping systems in the region. Climate smart agriculture (CSA) approach is well driven by technologies like direct seeded rice (DSR), happy seeder, surface seeding etc. that certainly prove fruitful in bringing resilience in agriculture system. The contrasting edaphic requirements of rice and wheat under conventional practices leads to sub-soil compaction and destroys soil structure in surface soil, resulting in restricted root penetration and poor soil nutrient-moisture-crop root interactions of succeeding upland crop (wheat) leading to low productivity (Jat *et al*., 2009) [4].

Direct seeding of rice (DSR) reduces irrigation water input, labour requirement, and improves the soil for non-rice crops grown in rotation with rice. It entails dry seeding of rice in non-puddled soil, aiming at high yield while decreasing the crop duration leading to early field availability for succeeding crop. On the other hand, puddled transplanted rice (PTR) is a popular method which involves dependence on labour, delayed harvesting of wheat crop. Therefore, substitution of PTR with dry seeding could be advantageous (Johnkutty *et al*., 2002) [5]. Dry seeding with AWD can greatly reduce water losses and labour requirement (Mann *et al*., 2007). [8] Residue retention helps in regulation of soil temperature, and ensure better soil moisture regime during heat stress. The happy seeder is a tractor operated machine that can sow wheat crop in standing stubbles of preceding rice crop by leaving residue on the soil surface. The leftover residue acts as mulch which helps in reducing moisture conservation, soil temperature regulation (Sidhu *et al*., 2015; Singh *et al*., 2015) [9, 12]. Highest energy efficiency was recorded in happy seeder technology, which used 19.97 l of diesel to sow one hectare area in comparison to 69.77 and 71.60 l in disc harrow-roto drill and disc harrows-broadcasting-rotavator techniques, respectively (Jaidka *et al*, 2020) [3]. Surface seeding (SS) of wheat is one such kind of technology that has the potential to improve crop productivity on a sustainable basis, without causing environmental damage. Compared to existing crop establishment methods, it has certain benefits with respect to crop productivity, soil health, environment, and socio-economic issues which recuperate the degraded RW cropping system (Singh *et al*, 2022) [10]. Promoting SS-based management practices, especially the use of improved seeds, optimum fertilization, integrated soil- and crop management, besides increased investment in agricultural R&D, is the key to a sustainable production system (Gathala *et al*, 2020) [2]. Keeping in view the importance of direct seeded rice and residue retention, the present experiment was planned in NICRA adopted village with the objectives to study the effect of crop residue management techniques on wheat yield practiced after different methods of rice establishment and to assess the production efficiency of rice-wheat cropping system (RWCS) as affected by crop residue management techniques and method of rice establishment.

Materials and Methods

Krishi Vigyan Kendra, Budh Singh Wala district Moga, Punjab works under the aegis of Punjab Agricultural University, Ludhiana. Krishi Vigyan Kendra undertakes a project entitled 'National Innovations in Climate Resilient Agriculture (NICRA)' by adopting a village where all the climate smart technologies (CST) are demonstrated at the farmers' fields. Under this project, an experiment was conducted by KVK in adopted village Meenia during 2022-23 to assess the effect of sequential exercise of direct seeded rice (DSR) and puddle transplanting (PTR) and crop residue management techniques in wheat crop on productivity of wheat crop and cropping system production efficiency. The experiment was replicated four times with six treatments *viz.* T_1- DSR *fb* Conventional sown wheat, T_2- DSR *fb* Surface seeding of wheat, T_3- DSR *fb* Happy seeder sown wheat, T_4- PTR *fb* Conventionally sown wheat, T_5- PTR *fb* Surface seeding of wheat, T_6- PTR *fb* Happy seeder sown wheat. In the experiment, rice variety PR 131 and wheat variety PBW 766 was used a planting material. Gross plot size of each treatment was 0.5 acre. Paddy crop was cultivated with DSR and PTR techniques as per the recommendations of Punjab Agricultural University, Ludhiana. Conventional method of wheat sowing involves sowing of crop after residue burning and land preparation (farmers' practice). Surface seeding involves broadcasting of wheat seed and fertilizer in the standing stubbles of rice crop *fb* mulching *fb* irrigation of the field. Happy seeder machine was used for sowing of wheat crop in standing stubbles without burning of rice straw. All the production technologies including nutrient management, weed management, water management etc. were followed as per the recommendations of Punjab Agricultural University, Ludhiana. The data pertaining to duration of the rice and wheat crop was collected as number of days taken starting from sowing till harvesting. Data on number of ears was calculated by randomly throwing tetrad at 5 locations per treatment and expressed as an average value. Number of grains per ear was expressed as an average value by counting grains in 10 randomly selected ear heads per treatment. 1000-grain weight was calculated by weighing the 1000 grains as counted 10 times per treatment to express as an average value. The data on grain yield of rice and wheat crops was collected by harvesting the crop from an area of 0.25 acre by nullifying the border effect and was expressed as q/ha. Statistical analysis of the data was performed by using OPSTAT software. From the data regarding duration and productivity of both the crops, production efficiency of the cropping system was calculated as per the formula given below:

$$\text{System Production Efficiency (kg/ha/day)} = \frac{\text{Productivity of Rice Crop + Productivity of wheat Crop}}{\text{Total Duration of Both Crops}}$$

The benefit cost ratio was calculated by using the formula given below:

$$\text{B:C} = \frac{\text{Gross returns}}{\text{Total cost of cultivation}}$$

Multicollinearity was evaluated through path coefficient analysis according to Dewey and Lu (1959) [1] by following the 'Do Little' techniques as follow:

$$Py_1 + Py_2.r_{12} + Py_3.r_{13} + \ldots\ldots + Pyn.r_1n = ry_1$$

$$Py_1.r_{12} + Py_2 + Py_3.r_{23} + \ldots\ldots + Pyn.r_2n = ry_2$$

$$Py_1.r_{13} + Py_2.r_{23} + Py_3 + \ldots\ldots + Pyn.r_3n = ry_3$$

$$Py_1.rn_{12} + Py_2 + Py_3.rn_3 + \ldots\ldots + Pyn = ry_n$$

Where, Py_1, Py_2, Py_3…. Py_n are the direct path effects of 1, 2, 3… n variables on the dependent variable 'y'. r_{12}, r_{13} …. r_1n----r(n-1)n are the possible coefficients of correlation between various independent variables, and ry_1, ry_2, …. ry_n are the coefficients of correlation of independent variables with dependent variable 'y'. The variation in the dependent variable which remained undetermined by including the given variables was assumed to be due to variable not included in the present investigation.

Results and Discussion

Crop Yield and Yield Attributes

Analysis of data (Table 1) showed an advancement of paddy var. PR 131 by 6 days when cultivated in direct seeding technique (DSR) (134 days) in comparison to puddle transplanted rice (PTR) technique (140 days). Advancement in crop in DSR can be attributed to complete omission of transplanting shock, shortening of vegetative growth phase. In comparison to conventional tillage, wheat crop was sown 5-6 days earlier in surface seeding and happy seeder technology. Advancement in wheat sowing can be due to direct sowing of wheat crop in standing stubbles without burning, otherwise farmers go for shredding and drying of rice straw for 2-4 days to burn the straw. Data revealed that conventional cultivation of wheat in both DSR and PTR technique recorded highest number of ears which was significantly higher than happy seeder techniques but statistically at par with surface seeding of wheat. On the contrary, surface seeding and happy seeder technology significantly out-yielded the conventional tillage in both DSR and PTR in terms of 1000 grain weight. For instance, surface seeding and happy seeder technology after DSR recorded 8.03 (48.86 g) and 4.55 per cent (47.29 g) higher 1000 grain weight as compared to conventional tillage (45.23 g). This increase in 1000 grain weight can be due to maintenance of favorable soil moisture regime, better regulation of soil temperature, in turn, mitigation of heat stress resulting in more efficient translocation of assimilates towards developing grains and prevention of shrinking of grains. Similarly, surface seeding and happy seeder technologies recorded significantly higher grain yield in contrast to conventional tillage. After DSR, surface seeding (51.13 q/ha) and happy seeder technique (50.25 q/ha) recorded 4.03 and 2.24 per cent higher grain yield than conventional tillage (49.15 q/ha). Although ear number was less in happy seeder technique than conventional practice, but high 1000 grain weight led to realization of better grain yield in happy seeder technique. Therefore, high grain yield in crop residue management techniques can be attributed to better soil moisture regime, soil temperature regulation, longer crop duration, better grain filling and high 1000 grain weight which, on the contrary, could not achieved in conventional practice. The results of surface seeding of wheat are in concurrence with Singh *et al*, 2022. Furthermore, all the treatments, irrespective of crop residue management, realized higher 1000 grain weight as well as grain yield when applied after DSR paddy instead of PTR. Highest production efficiency was recorded by surface seeding after DSR (44.40 kg/ha/day) which was statistically at par with happy seeder (44.33 kg/ha/day) and conventional tillage (44.37 kg/ha/day) after DSR but achieved the level of significance than all the treatments after PTR. This improvement in production efficiency of system can be attributed to shortening of duration of paddy and wheat crops, enhancement in grain yield of wheat crop. Out of DSR and PTR system, crop residue management techniques proved more efficient in DSR technique of rice cultivation as compared to PTR system.

Table 1: Effect of method of rice establishment and crop residue management techniques on efficiency of rice-wheat cropping system (RWCS)

Treatment	Rice		Wheat					Production Efficiency (kg/ha/day)
	Grain yield (q/ha)	Crop duration (days)	Date of sowing	Ears/m^2	1000-grain weight (g)	Grain yield (q/ha)	Crop Duration (days)	
T1	76.85	134	03.11.2022	465.33	45.53	49.15	150	44.37
T2	77.18	134	29.10.2022	464.89	47.26	51.13	155	44.40
T3	76.53	134	28.10.2022	456.43	47.19	50.25	152	44.33
T4	76.20	140	14.11.2022	465.52	45.07	47.93	149	42.95
T5	76.68	140	09.11.2022	464.07	47.14	49.33	153	43.03
T6	76.25	140	08.11.2022	453.39	45.44	48.98	151	43.00
LSD	NS	-	-	2.97	1.87	1.28	-	0.79

Economics of wheat crop

The data (Table 2) indicate decrease in cost of cultivation and increase in gross returns, net returns as well as B:C of wheat crop in happy seeder and surface seeding technology. Minimum cost of cultivation was recorded when wheat crop was cultivated by surface seeding after DSR (T_2) which was significantly different from conventional cultivation after DSR as well as PTR (T_1 and T_4) and statistically at par with T_3, T_5 and T_6. Decrease in cost of cultivation in surface seeding and happy seeder technology can be attributed to complete omission of preparatory tillage, less weed infestation, less use of herbicides etc., which in turn led to saving of working capital. The results regarding decrease in cost of cultivation in happy seeder technology due to reduced expenses in preparatory tillage are in line with Jaidka *et al* (2020) [3]. On the contrary, increase in cost of cultivation in conventional methods can be attributed to involvement of expenses incurred for preparatory operations like ploughing, levelling etc. Furthermore, surface seeding and happy seeder technology both after DSR and PTR registered increased gross returns than conventional cultivation but it could not reach level of significance. Similarly, surface seeding after DSR recorded highest net returns and B:C, which was significantly different from conventional cultivation after DSR as well as PTR (T_1 and T_4) and statistically at par with rest of the treatments (T_3, T_5 and T_6). Likewise, the increase in net returns and B:C of wheat in surface seeding and happy seeder technology can be attributed to increase in grain yield, decrease in cost of cultivation in comparison to conventional cultivation. Kadam *et al* (2023) [6] also reported 65.53 per cent saving in cost of operation by sowing of wheat crop with happy seeder technique relative to conventional practice.

Table 2: Effect of method of rice establishment and crop residue management techniques on economics of wheat crop

Treatment	Cost of Cultivation ($\times 10^3$Rs/ha)	Gross Returns ($\times 10^3$Rs/ha)	Net Returns ($\times 10^3$Rs/ha)	B:C
T_1	32.05	104.55	72.50	3.44
T_2	27.86	107.38	79.52	3.85
T_3	28.86	106.79	77.93	3.71
T_4	31.99	101.85	69.87	3.35
T_5	27.94	104.79	76.85	3.75
T_6	28.84	104.05	75.21	3.61
LSD	2.95	NS	6.04	0.41

Path analysis

Correlation analysis of data (Table 3) depicted that 1000 grain weight registered significant positive correlation (0.501) with the grain yield of wheat. A positive correlation between duration of wheat crop and yield (0.399) was also reported but it could not reach level of significance. At the same time, negative and significant correlation was also observed between duration of paddy crop and wheat yield (-0.460) which clearly demonstrates that decrease in duration of preceding paddy crop favourably increases the wheat yield and vice-versa. Kumar *et al* (2023) [7] also reported highly significant positive phenotypic correlation coefficient (0.271) between 1000 grain weight and grain yield. The path analysis of the data (Table 4) showed that highest positive phenotypic direct effect was exhibited by 1000 grain weight (0.328) followed by duration of wheat crop (0.206). 1000 grain weight showed positive direct effect via duration of wheat crop (0.097) followed by duration of paddy crop (0.056). Furthermore, duration of wheat showed direct effect indirectly via 1000 grain weight (0.154) followed by duration of paddy crop (0.045). At the same time, duration of paddy crop exhibited highly negative direct effect (-0.396) which was indirectly contributed by 1000 grain weight (-0.046) followed by duration of wheat crop (0.023). The results of high positive phenotypic direct effect of 1000 grain weight on grain yield of wheat are also in line with Kumar *et al* (2023) [7].

Table 3: Phenotypic correlation coefficient between various parameters and grain yield of wheat

	PD	EN	GW	WD	WY
PD	1.000	-0.046^{NS}	-0.141^{NS}	-0.113^{NS}	-0.460*
EN	-0.046^{NS}	1.000	-0.192^{NS}	0.044^{NS}	-0.144
GW	-0.141^{NS}	-0.192^{NS}	1.000	00.470*	0.501*
WD	-0.113^{NS}	0.044^{NS}	0.470*	1.000	0.399^{NS}
WY	-0.460*	-0.144^{NS}	0.501*	0.399^{NS}	1.000

Table 4: Phenotypic direct and indirect effects of various parameters on grain yield of wheat

	PD	EN	GW	WD	WY
PD	-0.396	0.005	-0.046	-0.023	-0.460
EN	0.018	-0.109	-0.063	0.009	-0.144
GW	0.056	0.021	0.328	0.097	0.501
WD	0.045	-0.005	0.154	0.206	0.399

Underlined numbers are positive direct effects (bold face). Values in the off diagonal or columns show indirect effects on grain yield. PD= duration of paddy crop; EN= number of ears; GW=1000 grain weight; WD=duration of wheat crop; WY= wheat yield

A highly significant positive genotypic correlation (Table 5) was exhibited by duration of wheat crop (1.98) followed by 1000 grain weight (1.048). At the same time, highly significant negative correlation (-1.175) was observed between duration of paddy crop and grain yield of wheat. Furthermore, duration of wheat crop had highly significant positive correlation with 1000 grain weight which means that increase in period of grain filling provides more opportunity for translocation of assimilated to developing grains which in turn leads to enhancement in grain yield. Singh *et al* (2023) [11] also reported highly significant positive genotypic correlation (0.325) between 1000 grain weight and grain yield per plant in wheat crop. Highly positive genotypic direct effect (Table 6) was exhibited by 1000 grain weight (0.618) followed by duration of wheat crop (0.241). 1000 grain weight showed positive direct effect via duration of wheat crop (0.409) followed by number of ears (0.029). Duration of wheat showed direct effect indirectly via 1000 grain weight (1.047) followed by duration of paddy crop (0.694). At the same time, duration of paddy crop had highly negative direct effect (-1.038) which was indirectly contributed by duration of wheat crop (-0.161). The results of high positive genotypic direct effect of 1000 grain weight on grain yield of wheat are also in line with Singh *et al* (2023) [11].

Table 5: Genotypic correlation coefficient between various parameters and grain yield of wheat

	PD	EN	GW	WD	WY
PD	1.000	-0.095^{NS}	0.007^{NS}	-0.668**	-1.175**
EN	-0.095^{NS}	1.000	-0.137^{NS}	0.009^{NS}	-0.197^{NS}
GW	0.007^{NS}	-0.137^{NS}	1.000	1.695**	1.048**
WD	-0.668**	0.009^{NS}	1.695**	1.000	1.980**
WY	-1.175**	-0.197^{NS}	1.048**	1.980**	1.000

Table 6: Genotypic direct and indirect effects of various parameters on grain yield of wheat

	PD	EN	GW	WD	WY
PD	-1.038	0.020	0.005	-0.161	-1.175**
EN	0.099	-0.213	-0.085	0.002	-0.197
GW	-0.008	0.029	0.618	0.409	1.048**
WD	0.694	-0.0019	1.047	0.241	1.980**

Underlined numbers are positive direct effects (bold face). Values in the off diagonal or columns show indirect effects on grain yield. PD= duration of paddy crop; EN= number of ears; GW=1000 grain weight; WD=duration of wheat crop; WY= wheat yield

Conclusion

Direct seeded rice technique proved worthwhile in shortening of crop duration, improvement in production efficiency of system in comparison to puddle transplanted rice (PTR) in all the treatments. At the same time, surface seeding of wheat crop without burning of rice straw realized highest grain yield of wheat, higher production efficiency of RWCS than happy seeder technique and conventional tillage under DSR and PTR system of rice cultivation. Surface seeding and happy seeder technology both recorded increase in net returns and B:C after DSR as well as PTR in comparison to conventional cultivation of wheat.

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