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Influence of crop establishment methods and nutrient management practices on productivity and profitability of red rice in wet-temperate north-western Himalayas

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Abstract

To assess the impact of different crop establishment methods (CEMs) and nutrient management practices (NMPs) on red-rice variety 'HPR-2720' under north-western Himalayas (NWH), a field experiment was conducted during *kharif* seasons of 2021 and 2022 at Palampur. Three CEMs *viz*., SRI, ARS and TR in main-plots and four NMPs, *viz*. Control, organic management, natural farming management, and integrated management as sub-plot treatments were laid out in split-plot design, replicated-thrice. The higher rice grain yield, straw yield, and biological yield along with maximum net returns and B:C ratio were recorded with SRI and TR followed by ARS. Among NMPs, integrated management [75% NPK + 25% N through FYM + *Azospirillium*+ PSB (seed treatment)] recorded significantly higher grain yield of 2.5 and 2.3 t/ha during 2021 and 2022, respectively followed by organic management. SRI under INM and OF was found suitable and remunerative for farmers with small land holdings in North-Western Himalayas.

Keywords: Organic farming,net returns, nutrient management, productivity, profitability, red rice

Rice is one of the world's most widely consumed cereals. Asia grows and produces about 90% of the world's rice, where it provides ~35–80% of the total calorie intake (Choudhary *et al*. 2022). In India, rice occupied an area of 43.8 m ha with a production of 120.3 m t and 2.74 t/ha productivity. Wheat on the other hand, had an estimated area of 29.3 m ha, 103.6 m t production and productivity of 3.53 t/ha (Choudhary *et al*. 2021). In Himachal Pradesh, rice had an acreage of 71.8 thousand ha with a production of 114.9 thousand tonnes and average productivity of 1.6 t/ha while the corresponding figures for wheat are 319.0 thousand ha, 564.6 thousand tonnes and 1.8 t/ha, respectively (Anonymous 2021). Approximately 77% of worldwide rice is produced in wetlands using intensive tillage (puddling or wet-tillage), followed by transplanting. This approach of traditional tillage and crop planting is labour, water, money, and energy-intensive, and it is becoming less lucrative as these resources become scarce. Puddling has an adverse impact on the succeeding crop deteriorating soil structure, causing poor crop establishment, and limiting root development due to subsurface compaction (Choudhary *et al*. 2022). Water demand in agriculture is anticipated to grow by 20% in 2050, and irrigation accounts for about 70% of worldwide water withdrawals. However, water availability for agriculture is projected to decline by 10% by 2025.Rice alone consumes over half of total irrigation water in Asia and accounts for 24-30% of global freshwater extraction. Puddling contributes about 30% of the rice water demand, with the majority being lost through percolation and evaporation (Kumar and Ladha 2011). As a result, the adoption of resource conservation technologies (RCTs) is critical to ensuring sustainability by increasing the efficiency with which existing resources are used and creating a quality natural resource base. Crop establishment methods and crop management strategies are all part of RCTs.

Among different methods of rice cultivation,

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conventional method *i.e*., puddled transplanted rice (PTR), aerobic rice system (ARS) (Prasad 2011) and system of rice intensification (SRI) are gaining much attention. Aerobic rice system is a new way of production system in which especially developed, rice with aerobic adaptations is grown. This method involves growing of rice in well drained, non-puddled, and non- saturated soils without ponded water (Choudhary and Suri 2018). Farmers in several nations have been able to boost yields from their current rice varieties using SRI (Kabir and Uphoff 2007). These different methods of establishment due to their differences in management, particularly of tillage, nutrient, and water, leads to varying physical, chemical, and biological changes in soil, which eventually affects the yield of the present crop and shows different residual effects on the succeeding crop (Singh *et al*. 2020). Because of repeated transitions from aerobic to anaerobic to aerobic soil conditions, changes in soil structure, physical, chemical and biological properties and nutrient relations have been observed (Timsina and Connor 2001) and these variations are responsible for different nutrient dynamics. SRI principles promote the use of organic manure rather than chemical fertilizers to maximize crop potential. However, much of the existing literature argues that integrated nutrient management with a sensible balance of organic manure and inorganic fertilizer depending on the resources available to farmers is the best choice for obtaining improved crop yield (Choudhary *et al*. 2022). The adverse effect of incessant practice of application of inorganic fertilizers to crop productivity often leads to application of harmful effect on the complex system of biogeochemical cycles and reduce quality (Sharma *et al*. 2014; Sharma *et al*. 2016). Therefore, an attempt has been made to evaluate the effect of different crop establishment methods and nutrient management practices on productivity and profitability in red rice under hill ecosystem of north-western Himalayas.

However, in addition to common rice, red rice is a specialized rice with medicinal and culinary properties. Red rice grows faster and produces more tillers and seeds as compared to cultivated rice (Estorninos *et al*. 2005). In Himachal Pradesh, rice is grown in diverse agro-climatic conditions and there is a great variability among the red rice landraces. Hence, to develop high yielding red rice cultivars, characterization of available germplasm with respect to yield attributes and yield. After the emergence of white rices as favourites, red rices disappeared completely, except for some red japonica types that were considered sacred and protected in shrines. In native seed varieties of red rice, yields are low. Therefore, there is a need to study the comparative effect of different methods of establishment on red rice and their effect on succeeding wheat *vis-a-vis* the effect of different crop management practices on these crops. Considering the above facts in view the present investigation was done with the objective to study the effect of rice establishment methods and crop management practices productivity and economics of red rice in mid-hills of north-western Himalayas.

Materials and Methods

A field experiment was conducted during 2021 and 2022 at the Research Farm, Holta (32°6′N, 76°3′E, 1290 m amsl) of CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur. The soil was silty-clay loam in texture with pH 5.2, SOC (7.72 g/kg), and available-N (287.3 kg/ ha) and medium in available-P (17.1 kg/ha) and available K (268.2 kg/ha). Agro-climatically, Palampur falls under sub-temperate mid hill zone of Himachal Pradesh, which is characterized by mild summers and severe winters. The region receives an average annual rainfall of 2332 mm. About 80% of this amount of rainfall is received during June to September. During the rice growing period (*kharif*, June to October), the mean weekly maximum temperature ranged between 22.1 to 31.1 °C and 24.2 to 34.2 °C during 2021 and 2022, respectively, whereas mean weekly minimum temperature fluctuated between 10.5 to 20.8 °C and 10.4 to 21.8 °C during 2021 and 2022, respectively. The crop experienced well distributed rainfall of 1930 and 1890 mm in the first and second year, respectively. The average relative humidity during the rice cropping seasons of first and second year was between 60 to 94.3% and 30.5 to 91.15%. The current study was conducted in a split-plot design with three replications.

Three crop establishment methods, *viz*. SRI (system of rice intensification), ARS (aerobic rice system) and TR (transplanted rice) were kept in main-plots; and four nutrient management practices, *viz*. control, Organic management (15 t FYM/ha +*Azospirillium/* + PSB (seed treatment) + Vermiwash (monthly interval), Natural farming management (Mulch + *Bijamrit* + *Jivamrit* + *Ghanjivamrit* as per recommendations) *Azospirillium* and Integrated management (75% NPK + 25% N through FYM + *Azospirillium* + phosphorus solubilising bacteria (PSB) (seed treatment) were allotted to sub-plots in a split-plot design and replicated thrice. Farmyard manure (0.86% N, 0.33% P, and 0.65% K) at the rate of 10 t/ha was thoroughly incorporated in soil 15 days before sowing in *Kharif* season. Application of panchgavya and vermiwash at 10% dilution was done for supplying nutrients at monthly intervals in all the treatments in organic plots and *jivamrit* application at 10% dilution at 21 days interval in natural plots. Soil treatment with *Beejamrit* (10%) and 250 kg ha^{-1} *Ghanjeevamrit* followed by sprays of *Jeevamrit* (10%) at 21 days interval for rice crop. With a view to avoid the mixing of soil in different treatments, individual plots were thoroughly prepared by power tiller in each season. Cultivation practices were followed as per standard recommendation for each crop by the university. Properly decomposed organic manures were applied at 15 days before sowing the crops. The seed was inoculated with biofertilizers (*Azotobacter*+PSB) and sown as per treatment. In order to have the same crop growth duration in all three methods of cultivation, sowing of rice in main field for ARS and sowing rice in nursery for transplanting in both TR and SRI was performed on the same date. The level of standing water was maintained by reduction in soil infiltration rate through soil cultivation in standing water before transplanting (puddling) and applying irrigation at frequent intervals. The level of water was maintained at 2–3 cm during vegetative growth stage and increased up to 5 cm during flowering and grain filling stage. In SRI, soil puddling was carried-out the same as that of TR and soil water level was maintained at saturation. The 14 days old seedlings were transplanted with single healthy seedling per hill at a spacing of 25×25 cm in SRI plots while for transplanted rice (TR), 20-days old seedlings at 2 seedlings/hill with a spacing of 20×20 cm and for aerobic rice culture sowing was done at the time of nursery sowing. The ARS is growing of rice in unsaturated, unpuddled and arable soil conditions. The soil was maintained at field capacity and direct sowing of pre-soaked rice grain was conducted through seed-drill The seed was inoculated with biofertilizers (*Azotobacter*+PSB) and sown as per treatment.

In case of INM, farmyard manure (FYM) at the rate of 10 t ha^{-1} was incorporated in the soil just before soil puddling and transplanting of rice. For application of N, P and K chemical fertilizers, urea, single super phosphate (SSP) and muriate of potash were used. A half dose of N and full dose of P and K were applied as basal. Remaining half dose of N was applied in two equal splits at maximum tillering and panicle initiation stages. Two hand weeding (HWs) in TR (20 and 45 days after transplanting (DAT) and two hand weeding's (HWs) (15 and 45 DAT) and one weeding with cono-weeder (30 DAT) was done in SRI and TR methods. The complete recommended method of water management for SRI and TR could not be followed due to high rainfall pattern. For easy irrigation and drainage of water, a channel of 30 cm width and 20 cm depth was provided around each individual plots. A continuous flooded water level of about 3-4 cm was maintained in the TR plots. The rice crop was plot-wise harvested in October and threshed to record grain and straw yields on per hectare basis.

The gross and net plot sizes were 4.0×3.0 m and 3.2×2.25 m, respectively and treatments were superimposed in the same plot every year to study the cumulative effect of treatments. Gross return, net return and benefit: cost ratio in different nutrient management systems were derived by computing the prevailing price of input and output. Rice grain yield and economics were calculated considering the prevailing market prices rice grain (INR 60/kg). The analysis of variance method (Gomez and Gomez 1984) was followed to statistically analyze the various data. The significance of different sources of variations was tested by error mean square of Fisher Snedecor's 'F' test at probability level (P =0.05).

Results and Discussion

Red-rice grain yield

Grain yield is a crucial parameter for assessing the productivity and performance of different rice production systems (Table 1). It represents the quantity

Table 1. **Effect of rice establishment methods and nutrient management practices on yield of red rice (t/ha) (2021-22)**

Treatment	2021			2022			Pooled		
	Grain yield (t/ha)	Straw yield (t/ha)	Biological yield (t/ha)	Grain yield (t/ha)	Straw yield (t/ha)	Biological yield (t/ha)	Grain yield (t/ha)	Straw yield (t/ha)	Biological yield (t/ha)
Establishment Methods									
M_1 Puddled transplanted rice	2.47	3.88	6.36	2.32	3.73	6.05	2.39	3.80	6.20
M_2 SRI	2.52	3.96	6.48	2.39	3.82	6.21	2.45	3.89	6.35
M_3 Aerobic rice	2.23	3.58	5.81	2.12	3.48	5.60	2.17	3.53	5.71
S.E (m) ±.	0.038	0.076	0.010	0.032	0.035	0.039	0.024	0.05	0.05
C.D. at 5%	0.15	0.31	0.42	0.13	0.14	0.15	0.068	0.16	0.15
Nutrient management									
C_1 Organic Farming POP*	2.60	4.07	6.61	2.46	3.92	6.38	2.53	3.96	6.50
C_2 Natural Farming POP (SPNF)	2.25	3.72	6.00	2.19	3.63	5.83	2.24	3.66	5.91
C_3 INM	2.79	4.35	7.07	2.63	4.10	6.73	2.70	4.19	6.90
C_4 Absolute control	1.90	3.31	5.19	1.82	3.06	4.88	1.87	3.15	5.04
S.E (m) ±.	0.030	0.012	0.013	0.026	0.060	0.077	0.024	0.08	0.09
C.D. at 5%	0.09	0.03	0.04	0.07	0.18	0.23	0.052	0.18	0.19

POP* (Package of practices)

of rice harvested per unit area, providing insights into the effectiveness of various cultivation methods. The data indicated significant influence of different rice establishment method and nutrient management practices on grain yield during both the seasons. The data indicated better yield of rice at first year as compared to second, which could be due to better growth of the crop with respect to plant height, shoot number and dry matter during the first year over the second. Conducive environmental conditions in particular to temperature and rainfall after in the initial year probably favoured the growth of the crop and resulted in higher yield. During *kharif* 2021 & 2022, SRI method resulted in significantly higher grain yield of rice (2.52 & 2.39 t ha^{-1}) which was statistically at par with puddled transplanted rice (2.48 & 2.32 t ha^{-1}). Significantly lower yield was obtained with aerobic method of rice establishment (2.23 & 2.12 t ha^{-1}). The trend remained similar during the second year of study. The grain yield of rice was 11.3 and 9.6 % higher with SRI and puddled transplanted rice, respectively over aerobic method of rice establishment during the first year. In the following year, grain yield of rice was 11.4 and 8.8 % higher with SRI and puddled transplanted rice, respectively over aerobic method. SRI method typically involves wider plant spacing and reduced water use, which promote healthier root development and allow better resource allocation to individual plants. This might result in increased tillering, greater panicle development and ultimately higher grain yield compared to other establishment methods (Choudhary *et al*. 2022). Puddled transplanted rice and SRI methods typically involve some form of water management, either through puddling and transplanting or through intermittent irrigation in the case of SRI. Adequate water availability during critical growth stages promotes optimal plant growth, flowering and grain filling, contributing to higher grain yield compared to the aerobic method, which relies solely on rainfed conditions. Similar findings have been reported by Kumari *et al*. (2022). The aerobic method of rice establishment, characterized by non-flooded conditions, may subject the rice plants to greater environmental stresses such as drought and soil moisture fluctuations. These stresses can adversely affect plant growth, flowering, and grain development, resulting in lower grain yield compared to establishment methods that provide more stable growing conditions (Silwal *et al*. 2020).

In terms of nutrient management practices, in general, higher grain yield was recorded with integrated nutrient management, which was followed by organic farming practices and natural farming practices. Significantly lower yield was obtained under the absolute control. During *kharif* 2021, the highest grain yield of 2.79 t ha^{-1} was obtained with integrated nutrient management, which was followed by rice grown under organic farming practices (2.60 t ha^{-1}) and natural farming practices (2.25 t ha^{-1}). In natural farming chemical fertilizers were not used and only natural bioformulations along such as *jeewamrit, ghanjeewamrit* were applied which could not meet the nutrient requirement of rice leading to lower yields. Similar results were obtained by Dogra *et al*. 2021. The lowest grain yield was obtained with absolute control. The grain yield with integrated nutrient management was 31.7% higher than absolute control, while organic farming and natural farming practices were higher by 26.9 and 15.3%. In the succeeding year, the trend was similar. The grain yield of rice with integrated nutrient management, organic farming and natural farming practices were 30.6, 25.8 and 16.9 % higher than absolute control. This might be due to better availability of nutrients through super imposition of organic manures along with biofertilizers (Gaur 2006).

Straw yield

During *kharif* 2021 & 2022, SRI method resulted in significantly higher straw yield of rice (3.96 and 3.82 t ha^{-1}) which was at par with puddled transplanted rice (3.88 and 3.73 t ha^{-1}). Significantly lower yield was obtained with aerobic method of rice establishment (3.58 and 3.48 t ha^{-1}). The trend remained similar during the second year of study. The straw yield of rice was 9.7 and 7.8% higher with SRI and puddled transplanted rice, respectively over aerobic rice during the first year. In terms of nutrient management practices, in general, higher straw yield was recorded with INM, which was followed by organic farming practices and natural farming practices. Significantly lower yield was obtained under the absolute control. In *kharif* 2021 and 2022, the highest straw yield of 4.35 and 4.10 t ha^{-1} was obtained with INM, which was at par with rice grown under organic farming practices (4.07 and 3.92 t ha^{-1}). It was followed by natural farming practices recording 3.73 and 3.64 t ha^{-1} of straw yield. The lowest straw yield was obtained with absolute control (3.32 and 3.04 t ha^{-1}). The straw yield with INM was 23.7% higher than absolute control, while organic farming and natural farming practices were higher by 18.5 and 10.9%. In the subsequent year, it followed the same trend as the first year. The straw yield of rice with INM, organic farming and natural farming practices were 25.4, 22.0 and 15.9% higher than absolute control during the subsequent year.

Biological yield

During *kharif* 2021, SRI method resulted in significantly higher biological yield of rice (6488.7 kg ha^{-1}) which was at par with puddled transplanted rice (6.36 t ha^{-1}). Significantly lower yield was obtained with aerobic method of rice establishment (5.82 t ha^{-1}). The trend remained similar during the second year of study and the biological yield ranged between 5.61 and 6.23 t ha^{-1}. The biological yield of rice was 10.3 and 8.5% higher with SRI and puddled transplanted rice, respectively in the first year and 9.8 and 7.3% higher in the second year, respectively over aerobic method of rice establishment.

Among NMPs, during *kharif* 2021, the highest biological yield of 7.15 t ha^{-1} was obtained with INM. Addition of organic manure is necessary for maintaining soil fertility and sustained productivity (Sharma and Sharma 2016) but they cannot supply all nutrient requirements on their own. As a result, combining nutrients from fertilizers and organic sources is critical for providing plant nutrients and sustaining soil health (Sharma *et al*. 2003). This significant response might be due to enhanced nutrient availability to crop by the application of organic manures in combination with inorganic fertilizers (Choudhary *et al*. 2022). Integration of organics in nutrient management has advantages for both organic and inorganic fertilization systems, and it has been shown to have a consistent release of nitrogen (Bhardwaj *et al*. 2020). It was followed by organic farming practices (6.68 t ha^{-1}) and natural farming practices recording 6.03 t ha^{-1} of biological yield. The lowest biological yield was obtained with absolute control (5.26 t kg ha^{-1}). The biological yield with INM was 26.4% higher than absolute control, while organic farming and natural farming practices were higher by 21.3 and 12.8%. The biological yield of rice with INM, organic farming and natural farming practices were 27.4, 23.4 and 16.3% higher than absolute control. The interaction between the various establishment methods and nutrient management practices was found to be non-significant for grain, straw and biological yield of rice.

Economic yield of red-rice

Gross income, net income, B: C ratio was influenced by crop establishment methods and among the crop establishment methods (Table 2), the puddled transplanted rice method (M_1) was the most expensive, with a cost of INR 0.051 million ha^{-1} in 2021 and 0.053 million ha^{-1} in 2022. In contrast, the SRI method (M_2) proved to be more economical, with costs of INR 0.049 million ha^{-1} in 2021 and INR 0.050 million ha^{-1} in 2022. Aerobic Rice (M_3) had the lowest cost of cultivation among the establishment methods, costing INR 0.048 million ha^{-1} in 2021 and INR 0.048 million ha^{-1} in 2022. In terms of nutrient management, Integrated Nutrient Management (C_3) incurred the highest costs, at INR 0.071 million ha^{-1} in 2021 and INR 0.072 million ha^{-1} in 2022, while the Natural Farming Package of Practices (SPNF) (C_2) was the least costly, with INR 0.035 million ha^{-1} in 2021 and INR 0.036 million ha^{-1} in 2022. This indicates a significant variation in input costs associated with different agricultural practices. Gross returns were highest for the SRI, generating INR 0.143 million ha^{-1} in 2021 and INR 0.135 million ha^{-1} in 2022, demonstrating its strong revenue-generating potential. However, TP method (M_1) also performed well, albeit with slightly lower gross returns, at INR 0.140 million ha^{-1} in 2021 and INR 0.131 million ha^{-1} in 2022. Among nutrient management practices, INM (C_3) achieved the highest gross returns, with INR 0.158 million ha^{-1} in 2021 and INR 0.149 million ha^{-1} in 2022.

Higher net returns from the crop establishment methods were seen in SRI which consistently showed the highest net returns in both years, INR 0.093 million ha^{-1} in 2021 and INR 0.085 million ha^{-1} in 2022 with benefit: cost ratio of 2.2 and 2.0. This might be due to higher productivity of the rice crop. Higher value of net returns were observed in the natural farming which was due to lower cost of cultivation. Treatment receiving FYM (OF) and wheat straw in combination with fertilizers (INM) had lower benefit: cost ratio of 1.2 and 1.1 which was due to use of higher quantity of organic manure before sowing of *kharif* crop that raised cost of cultivation (Sathiya and Ramesh 2009) compared to absolute control and SPNF, this might be due to FYM had more cost of cultivation. These results are in conformity with the findings of Kumar *et al.* (2015). These findings suggest that SRI for crop establishment and Natural Farming Package of Practices (SPNF) for nutrient management are the most profitable options. In nutrient management, the Natural Farming Package of Practices (SPNF) (C_2) delivered the highest net returns, at INR 0.096 million in 2021 and INR 0.089 million in 2022. These results indicate that while C_3 generates high gross returns, C_2 offers superior profitability by keeping input costs low (Verma *et al.* 2024).

The R^2 value was 0.9794, suggesting an extremely high degree of correlation between net returns and

Table 2. Effect of rice establishment methods and nutrient management practices on economics of red rice (2021 & 2022)

	Treatments	Cost of Cultivation (Rs. millions ha^{-1})		Gross Returns (Rs. millions ha^{-1})		Net Returns (Rs. millions ha^{-1})		B:C Ratio	
		2021	2022	2021	2022	2021	2022	2021	2022
	Rice establishment methods								
M_1	Puddled transplanted rice	0.051	0.053	0.140	0.131	0.089	0.078	2.0	1.7
M_2	SRI	0.049	0.050	0.143	0.135	0.093	0.085	2.2	2.0
M_3	Aerobic Rice	0.048	0.048	0.127	0.120	0.078	0.072	1.9	1.8
	S.Em. ±.	-	-	0.020	0.021	0.002	0.002	0.04	0.04
	C.D. at 5%	-	-	0.080	0.083	0.008	0.008	0.16	0.17
	Nutrient management								
C_1	Organic Farming POP	0.065	0.066	0.147	0.139	0.082	0.073	1.3	1.1
C_2	Natural Farming POP (SPNF)	0.035	0.036	0.130	0.124	0.096	0.089	2.8	2.5
C_3	INM	0.071	0.072	0.158	0.149	0.087	0.077	1.2	1.1
C_4	Absolute control	0.028	0.029	0.110	0.104	0.082	0.074	2.9	2.6
	S.Em. ±.	-	-	0.017	0.016	0.002	0.002	0.03	0.03
	C.D. at 5%	-	-	0.050	0.049	0.005	0.005	0.13	0.11

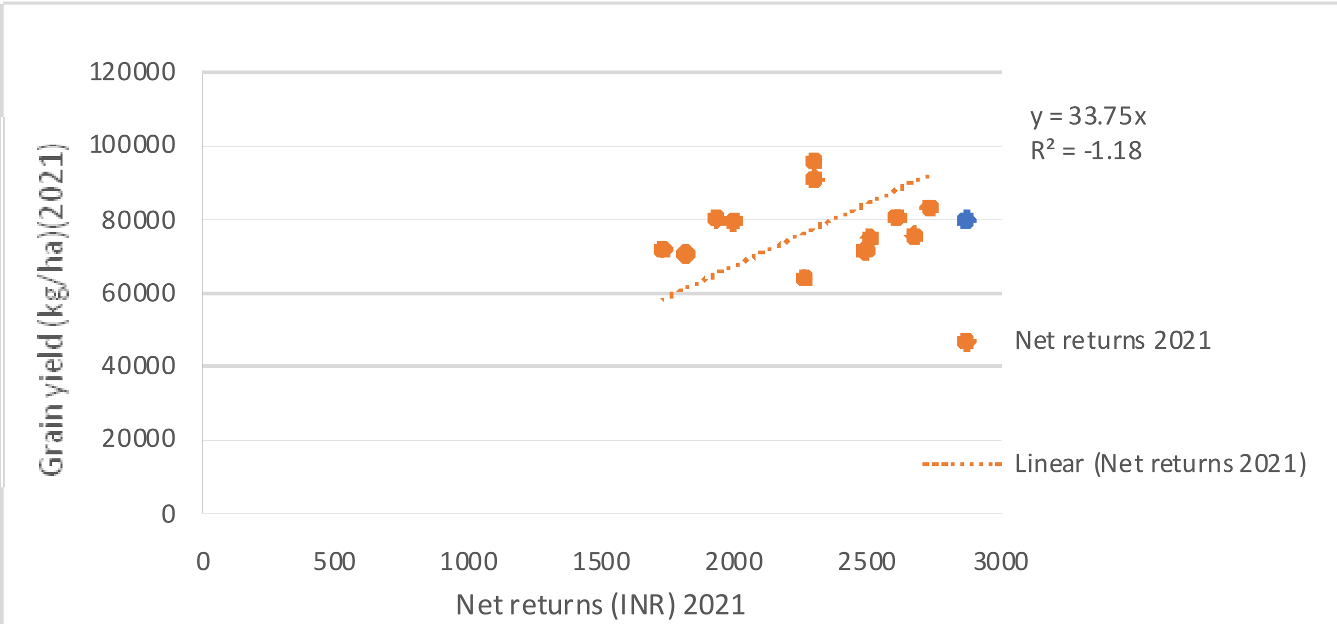

Fig. 1 Correlation between net returns and grain yield during 2021

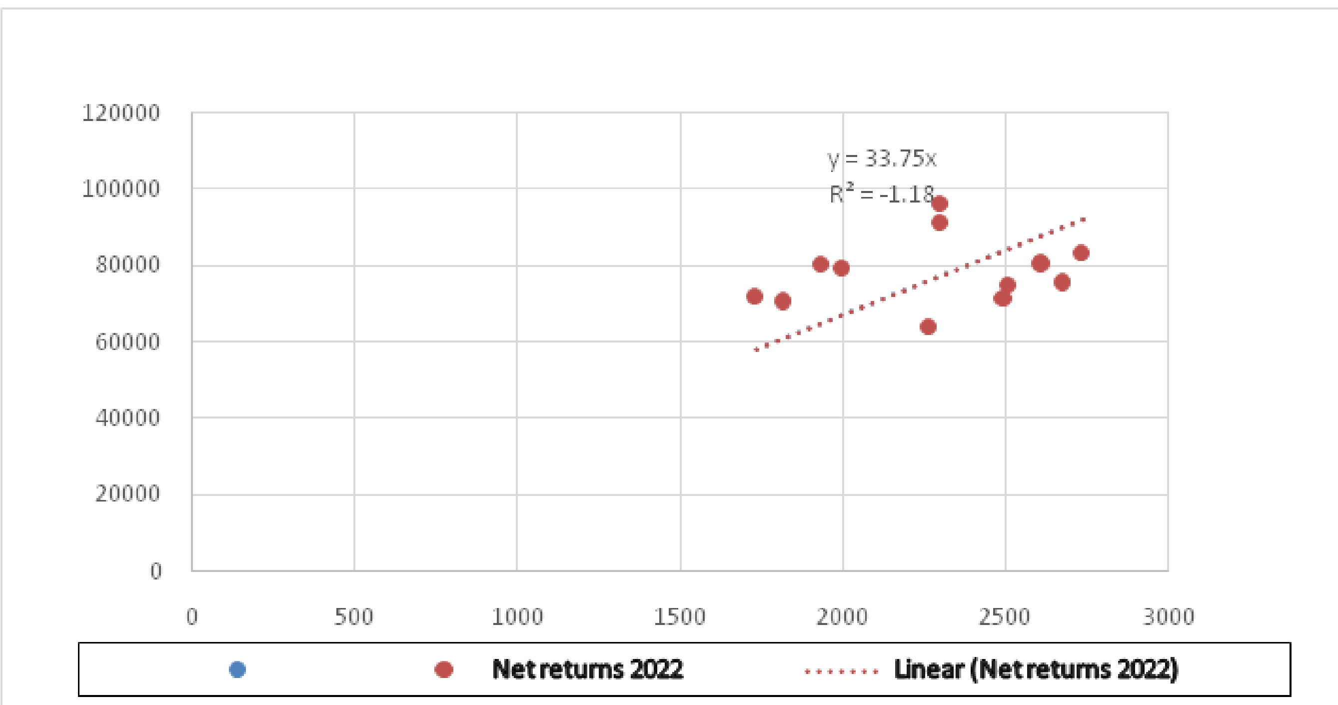

Fig. 2 Correlation between net returns and grain yield during 2022

grain yield. This means that 97.94% of the variability in grain yield could be explained by the net returns. The regression equation is y=35.415x. This implies that for every unit increase in net returns, the grain yield increased by 35.415 units. As net returns increased, grain yield also increased significantly, and this relationship was highly predictable given the high R^2 value.

The scatter plot with a linear regression line suggested a strong positive correlation between grain yield (y-axis) and net returns (x-axis) for the year 2022. The R^2 value was 0.9742, indicating a very high degree of correlation between grain yield and net returns. This means that approximately 97.42% of the variability in net returns could be explained by the grain yield. The regression equation is y=33.755x. This implies that for every unit increase in grain yield, the net returns increased by 33.755 units. As grain yield increased, net returns also increased significantly, and this relationship was highly predictable given the high R^2 value.

Conclusion

The results suggest that SRI and transplanted rice along with INM and organic farming practices are favourable for obtaining higher grain yields in red rice. The decline in grain yield from 2021 to 2022 across most treatments may indicate potential challenges or variations in environmental conditions. It can be concluded that rice grown under SRI along with organic sources with biofertilizers was suitable and remunerative for farmers, stable and profitable in the hills followed by transplanted method. In summary, the study highlights the economic efficiency of the System of Rice Intensification (SRI) method (M_2) and the Natural Farming Package of Practices (SPNF) (C_2) in rice cultivation. M_2 is particularly notable for its balance of lower costs and high returns, resulting in superior net returns and B C ratios. Similarly, C_2 stands out for its low cultivation costs and high profitability, making it an economically and environmentally sustainable choice. These findings suggest that adopting SRI and SPNF practices can enhance the economic viability of red rice farming, offering substantial benefits to farmers.

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