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Impact of Cultivation Practices and Varieties on Productivity, Profitability, and Nutrient Uptake of Rice (*Oryza sativa* L.) and Wheat (*Triticum aestivum* L.) Cropping System in India

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Abstract: Interest in conservation measures, including reduced tillage, zero tillage, and crop residue retention, is growing in major rice growing areas of the world; particularly in the Indo-Gangetic plains. Of late, research interest is increasing in India for a specialised method of cultivation known as natural farming, which aims at maintain the functional biodiversity of the farm with little or no use of external inputs. With the increasing water crisis at a global level, it became imperative to develop technologies that can reduce the water use, particularly in water-guzzling low land paddy, by developing alternate cultivation methods; direct seeded rice is one such technology. A two-year field experiment was carried out at two locations during 2019–2020 and 2020–2021 to find out the impact of different cultivation and varieties on the productivity and profitability of the rice–wheat cropping system. The experiments were conducted in split plot design, replicated thrice, with cultivation practices in the main plot and varieties of both wheat and rice in the sub plot. The results so obtained reveal that conventional tillage significantly out yielded other methods of cultivation in both the crops at both the locations, while significantly lower grain yield in both crops was observed from natural farming. Adoption of reduced tillage, zero tillage and natural farming reduced the grain yield of wheat by 4.6%, 10.9%, and 59.4% over conventional tillage, while the corresponding decline in grain yield of rice was 10.8%, 16.1%, and 34.0% with reduced tillage, zero tillage, and natural farming, respectively. Among the varieties tested, HPW 368 and Him Palam Lal Dhan 1 (HPR 2795) produced significantly higher grain yield of wheat and rice, respectively, at both the locations during both years. Conventional tillage among cultivation practices and HPW 368 and Him Palam Lal Dhan 1 (HPR 2795) among wheat and rice varieties also proved to be better in terms of various economic indicators, including gross return, net return, and ratio benefit cost ratio (B:C ratio).

Keywords: economics; rice; reduced tillage; wheat; yield and zero tillage

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1. Introduction

The two most important food crops in the universe are wheat and rice, which act as the main sources of nutrition to almost the whole world's population. The world's largest and most advanced agricultural production system is the rice–wheat sequence. A total of 13.5 million hectares in Asia are used for this production system, with South Asia making up almost 57 percent of that total. The majority of that area is in the Indo-Gangetic plains. [1–3]. India's 9.2 million hectares under the rice–wheat production system [4] has a significant influence on the country's food security [5]. Over the past 30 years, this system, covered more than 30% of the region's total rice area and 40% of its total wheat area, and emerged as the primary food production system in the area, producing nearly one third of the rice and more than half of the wheat needed to meet the needs of over one billion people, or roughly 15% of the world's population [4]. With a total production of 107.59 million tonnes and an average productivity of 3.42 tonnes/hectare (t/ha), wheat is grown over an area of 31.45 million hectares in India [6], while for rice the corresponding figures are 43.78 million hectares, 118.43 million tonnes, and 2.71 t/ha [6], respectively.

Wheat is the most significant rabi crop, even in the state of Himachal Pradesh, where it was grown on an area of 319.0 thousand hectares in 2019–2020, giving a total production of 564.6 thousand tonnes, with an average productivity of about 1.76 t/ha [7]. Rice is also one of the important crops of our state during *kharif* season (second only to maize) and is grown over an area of around 71.81 thousand hectares, producing 114.9 thousand tonnes, with a productivity of approximately 1.6 t/ha [7]. The conventional management methods used in adjacent states to increase these two crops' production come at the price of overusing natural resources, including groundwater, soil, and energy [8], which is not sustainable over the long run.

Intensive tillage and crop establishment methods increase the cost of farming, since they need a lot of water and labour. The productivity and long-term viability of the rice–wheat farming system are becoming seriously threatened by the labour and water shortages [9,10]. The scenario is also anticipated to get worse in the upcoming years as a result of rising labour costs and their inability to be found when needed most. In the past, leftover aggregates of wheat and rice were taken out of the fields and utilised for things such as animal feed. Due to an increase in mechanised harvesting, a huge proportion of residue being left in the fields are burned to assure timely and easy planting of subsequent crops. However, in addition to ensuring environmental safety, these residues might be utilised to improve nutrient availability [11,12] and sustain soil organic matter [13]. Incorporating and decomposing rice residue before wheat planting is more difficult than doing the same with wheat residue prior to wheat planting due to low temperatures and less time between rice harvest and wheat planting. One of the most promising strategies for better utilisation, in addition to enhancing soil fertility and production, is crop residue retention. Additionally, because it improves infiltration, lowers soil water evaporation, and controls salt and nutrient levels, this method can be useful in managing soil salinity and drought [14–22]. Conservation measures can resolve all of these problems [23].

The problem of the rice–wheat farming system is to produce more food with less cost, as well as to increase labour and water productivity while preserving environmental quality. To save water, labour, and energy, farmers need alternatives to traditional extensive tillage and crop planting techniques [24]. To boost the profitability of farmers, it is urgently necessary to increase input use efficiency and total factor productivity by preserving soil health [25] and using better management techniques [26]. Conventional tillage, puddling, residue removal, and other ineffective farming practices lead to an overuse of water resources, higher energy costs, and a decline in groundwater quality, all of which have a detrimental impact on the environment and lead to low profits [10].

Therefore, it is essential to find methods that may raise yields while using less resources in order to reduce cultivation costs and boost farmers' profit margins [27]. Recent years saw a significant emphasis on alternative resource conservation strategies (RCTs) for both crops in the rice–wheat system. In the RW system, conservation agriculture-based management techniques are crucial to address the issues of timely planting in addition to the efficient use of resources. Effective crop rotations, zero tillage, enhanced crop establishment methods, residue management, and intensification systems are a few of these methods.

However, depending on a variety of factors, including the tillage techniques used and the impact of microclimate changes brought on by the adoption of conservation agriculture techniques, the efficacy of rice and wheat genotypes might vary [28]. Additionally, some genotypes are advised for no-till farming on a global scale. However, there is not a lot of study in India to discover the genotype of wheat and rice for conservation agriculture. The purpose of this research was to ascertain the impact of various crop varieties and cultivation methods on the effectiveness of the rice–wheat cropping system.

2. Materials and Methods

At the Research Farm of the Department of Agronomy CSK HPKV Palampur (H.P.) and the Research Farm of the RWRC, Malan (H.P.), India, a research experiment was carried out throughout the winter (*rabi*) and rainy (*kharif*) seasons of 2019, 2020, and 2021.

2.1. Study Areas and Environmental Materials (Palampur and Malan)

The Department of Agronomy's Research Farm is situated 1290 metres above mean sea level at 32°09′ N latitude and 76°54′ E longitude. The climate is of a sub-temperate type with the three distinct seasons being summer, rainy, and winter. The region receives a lot of rain, ranging from 2000 to 2500 mm per year, with 80 percent of it falling between June and September, when the monsoon season is in full swing. During the respective crop growing seasons, the total annual rainfall of 2344.8 mm in 2019–2020 and 2523.2 mm in 2020–2021 was recorded. Before the experiment began, a composite soil was collected and evaluated for the physico-chemical characteristics of soil. Soil samples were taken randomly from different locations at a depth of 0 to 15 cm. The soil characteristics were silty clay loam in texture, pH 5.6. The soil had 11.0 g kg^{-1} organic carbon [29] and 376.3 kg ha^{-1} available nitrogen [30], 16.4 kg ha^{-1} available phosphorus [31], and 276.4 kg ha^{-1} available potassium [32].

The Research Farm of RWRC, Malan is situated 950 metres above mean sea level at 32°07′ N latitude and 76°23′ E longitude. The climate is sub-temperate and has three different seasons: summer, rainy season, and winter. The area has 2332 mm of rainfall annually on average, with roughly 80% of the total falling between June and September. From December to February, there are winter showers. The total annual rainfall of 1750.9 mm in 2019–2020 and 1693.8 mm in 2020–2021 was received during the respective crop growth periods. Before the experiment began, a composite soil sample was made and evaluated for the physico-chemical characteristics of soil. Soil samples were taken randomly from different locations at a depth of 0 to 15 cm. The soil characteristics were silty clay loam in texture, pH 5.7. The soil had 10.2 g kg^{-1} organic carbon [29] and 422.0 kg ha^{-1} available nitrogen [30], 17.8 kg ha^{-1} available phosphorus [31], and 232.6 kg ha^{-1} available potassium [32].

2.2. Experimental Design and Crop Management

The experiment was carried out in a split plot design. Cultivation practices were taken in the main plot (reduced tillage, zero tillage, conventional tillage, and natural farming). In conventional tillage, the plots were subjected to both primary and secondary tillage to get the field to optimum tilth before sowing. While on zero tillage, the non-selective herbicide was used to kill the weeds after the harvest of previous crops, and crops were sown without any tillage using a zero till precision seed drill. In the reduced tillage treatments, only the primary tillage was conducted, and about 30% of the residue of the previous crop was incorporated into the soil before sowing. Natural farming is a new concept, which is becoming popular amongst the farming community of the state and at the national level, where there is little use of external farm inputs, including fertilisers, herbicides, and other plant protection chemicals and only those inputs which are produced by the farmers at their farm are used. This method of cultivation involves the use of products including ghanjeevamrit, beejamrit, and jeevamrit at periodic intervals, besides using mulch to conserve moisture and control weeds, the basic premise of using these specific products being to enhance the microbial activity in the soil. Main plots were split into sub-plots with three varieties each of wheat (*viz.*, HPW 349, HPW 368, and HS 562) and rice (*viz.*, Sukara Dhan 1(HPR 1156), Him Palam Dhan 1 (HPR 2656) and Him

Palam Lal Dhan 1 (HPR 2795)) tested in subplots. Thus, there was a total 12 treatment combinations, which were replicated thrice at both Palampur and Malan.

At both locations, the wheat and rice crops were sown at a 0.2 m spacing on the usual sowing dates in an east–west row direction. When wheat was sown, all plots received inorganic fertiliser at rates of 120:60:40 kg N:P:K (nitrogen, phosphorus, and potassium) ha^{-1} [33] and 60:30:30 kg N:P:K ha^{-1} [34] at the sowing of rice through urea (46:0:0 N:P:K), single super phosphate (0:16:0 N:P:K), and muriate of potash (0:0:60 N:P:K). Phosphorus and potassium were supplied in their whole at planting time, whereas nitrogen was supplied in two equal portions at sowing time and three weeks later. Glyphosate/paraquat was sprayed in zero tillage plots prior to sowing. The crop was raised using a recommended package of practices. Vesta (clodinafop propargyl + metsulfuron methyl) @ 400 g/ha was used to control weeds in wheat and butachlor @ 1.5 kg ha^{-1} was used to control weeds in rice in all treatments except in natural farming treatment, in which weeds were manually removed. Rice and wheat straw @ 3t/ha were used as mulch material and applied in the reduced tillage treatment. All the practices of natural farming were also adopted to raise the wheat and rice crop.

2.3. Estimation of Productivity, Profitability and Uptake

The wheat and rice crop were harvested from the net plot and sundried for a few days and then weighed to get biological yield. The crops were then threshed, cleaned, and the weight of grains were recorded. The moisture content in grains of both wheat and rice were recorded using a moisture meter and the grain was adjusted at 14% moisture content in both the crops using the formula given [6,35,36].

$$\textbf{Grain yield (at 14 \% moisture)} = \frac{\textbf{100} - \textbf{moisture (\%) in grain}}{\textbf{100} - \textbf{14}} \times \textbf{grain yield at recorded moisture}$$

The adjusted grain yield was then subtracted from the total biological yield to get the straw yield. All the yields recorded from the net plot were converted into tones/hectare (t/ha).

The economic yield of both crops was subjected to economic analysis by calculating the cost of cultivation, gross returns, net returns, and B:C ratio in order to determine the economic profitability of treatments in a system. The cost of cultivation of both crops was calculated individually for each type of treatment total. According to the current market rates. The required labour and mechanical power for various operations, such as ploughing, harrowing, and harvesting, were determined on a per-hectare basis. Based on the exact dosage/quantity used, the cost of inputs, such as seed, fertiliser, and herbicides was calculated. Gross returns were calculated based on the prevailing local market price of grain and straw for each treatment separately and expressed in Indian rupee (INR) ha^{-1}. By deducting the cost of cultivation from the gross returns and expressing the results in INR ha^{-1}, the treatment wise net returns were calculated. Benefit: cost ratio was calculated as per the formula given by [6,35,36].

$$\textbf{B:C ratio} = \frac{\textbf{Net return from treatment (INR ha}^{-1}\textbf{)}}{\textbf{Cost of cultivation of the treatment (INR ha}^{-1}\textbf{)}}$$

For chemical analysis the representation sample of grain and straw from each plot was taken and subjected to chemical analysis to get the nutrient content in both grain and straw. The yield data, as well as the nutrient content data, were used to calculate the uptake of the nutrients in grain and straw, which were recorded to get the total nutrient uptake.

2.4. Statistical Analysis

To test whether significant differences resulted from the split plot design, the data were analysed using analysis of variance (ANOVA), and conclusions were drawn at 5% level of probability. Each case was subjected to a standard error of mean calculation.

When the ‘F’ value from the analysis of variance tables was significant, a minimum significant difference was calculated.

3. Results and Discussion

The data presented in Table 1 reveal that the experiment under study had a significant impact on grain yield, straw yield, and biological yield of wheat at both locations (Palampur and Malan). During both research years, conventional tillage produced the maximum grain yield and was comparable to reduced tillage, however, the natural farming treatment produced significantly lower grain yield.

Table 1. Effect of cultivation practices on yield (t/ha) of different wheat varieties at Palampur and Malan.

Treatments	**Palampur**						**Malan**					
	Grain		**Straw**		**Biological**		**Grain**		**Straw**		**Biological**	
	2019–2020	**2020–2021**	**2019–2020**	**2020–2021**	**2019–2020**	**2020–2021**	**2019–2020**	**2020–2021**	**2019–2020**	**2020–2021**	**2019–2020**	**2020–2021**
Cultivation practices												
Reduced tillage	4.33	4.20	6.22	5.87	10.56	10.07	4.67	4.22	7.05	6.16	11.73	10.43
Zero tillage	4.00	3.98	5.88	5.67	9.88	9.66	4.38	3.91	6.92	5.82	11.30	9.74
Conventional tillage	4.48	4.45	6.29	6.22	10.77	10.68	4.82	4.50	7.08	6.30	11.90	10.80
Natural farming	1.68	1.61	2.68	2.50	4.36	4.11	1.97	2.16	3.28	3.41	5.26	5.57
SEm ±	0.7	0.7	1.1	0.9	1.7	1.6	0.6	0.6	1.2	1.0	1.8	1.7
CD (P = 0.05)	2.5	2.7	3.8	3.2	6.1	5.7	2.2	2.4	4.2	3.5	6.3	5.9
Varieties												
HPW 349	3.48	3.40	5.05	4.83	8.54	8.24	3.74	3.50	5.84	5.13	9.59	8.63
HPW 368	3.72	3.70	5.48	5.34	9.21	9.04	4.17	3.92	6.59	5.94	10.76	9.86
HS 562	3.65	3.58	5.27	5.03	8.93	8.61	3.98	3.71	5.82	5.20	9.80	8.91
SEm ±	0.4	0.4	0.7	0.6	1.0	0.9	0.7	0.6	1.1	1.1	1.7	1.7
CD (P = 0.05)	1.3	1.2	2.0	1.9	3.2	2.9	2.2	1.9	3.3	3.4	5.2	5.2

SEm ±: standard error of mean; CD: critical difference.

The higher values of all the yield attributes were responsible for the greater grain yield observed under conventional tillage, whereas the lower values of the same attributes in the natural farming treatment were responsible for the lower grain yield. The conventional tillage of the cultivation practice includes primary and secondary tillage operations. These operations improve the soil’s physical condition, thereby promoting optimum root growth and development. This facilitates better uptake of nutrients from the soil, especially nitrogen and phosphorus. The enhanced uptake of the nutrients promotes good seed setting and tillering, as well as other yield attributing characteristics. The availability of nitrogen further helps the plant to remain green for a longer duration; hence, the crop is able to perform photosynthesis for a longer duration, resulting in an increase in the crop yield. Similar results, indicating higher yield under conventional tillage, were reported by a number of workers in previous studies [37–41].

Among the varieties tested at both locations, a significantly higher grain yield of wheat was recorded in HPW 368, while a significantly lower grain yield was recorded in the HPW 349 variety of wheat. The higher yield recorded in HPW 368 was due to the higher values of all the yield attributes, while the lower values of these attributes in HPW 349 resulted in a significantly lower yield of this variety. At RWRC, Malan, similar results were also achieved.

The interaction between the cultivation practices and varieties was found to be non-significant for grain yield. The straw yield was significantly influenced by both cultivation practices and varieties during both years (Table 1). The natural farming treatment recorded significantly lower straw yield during both of the years, while significantly higher straw yield during both of the years was recorded in conventional tillage, followed by reduced tillage and zero tillage, in that order, with the latter two treatments being at par with one another. The higher straw yield recorded with conventional tillage might be due to better root growth, enhanced nutrient availability, and its mining, which resulted in higher photosynthetic efficiency and consequently higher straw yield. Similarly, an inadequate supply of nutrients in natural farming treatment resulted in significantly lower straw yield, the reason for which was discussed earlier. Similar results indicating better straw yield were reported in previous studies [37,38,42–44].

Among the varieties tested, HPW 368 recorded the highest straw yield in both years, which was followed by wheat variety HS 562. The higher straw yield in HPW 368 was due to a higher number of tillers produced in this variety (data not given here), which resulted in a higher leaf area index (LAI), particularly during the initial stages of crop growth. The higher LAI enables this variety to effectively use the available sunlight, leading to higher photosynthetic activity and consequently higher straw yield. Similar results showing higher leaf area of wheat as a result of higher tillering and consequently higher dry matter production were also reported by Rahman et al. [45].The significantly lower straw yield was recorded in HPW 349. Similar results were also obtained at RWRC, Malan.

The interaction between the cultivation practices and varieties was found to be non-significant for straw yield. A perusal of data revealed that significantly higher biological yield of wheat was recorded in conventional tillage, which was followed by reduced tillage and zero tillage during both years, while natural farming treatment resulted in significantly lower biological yield of wheat. Increased nutrient availability and absorption resulted in better development and enhanced photosynthetic activity, which may be the cause of the higher biological yield under conventional tillage. Similar results were also reported by Nehra et al. [42] and Rana [41]. Among the varieties tested, HPW 368 recorded a significantly higher biological yield than the other two varieties, while the variety HPW 349 recorded a significantly lower biological yield. The higher biological yield of HPW 368 was due to the higher number of tillers produced in this variety leading to higher leaf area, which resulted in higher photosynthetic activity. Similar results were also obtained at RWRC, Malan.

The interaction between the cultivation practices and varieties was found to be non-significant for biological yield. The data on the effect of different cultivation practices and varieties on grain yield of rice at Palampur and Malan are given in Table 2. A perusal of data revealed that the cultivation practices and varieties both have a significant impact on the grain yield of rice at both locations (Palampur and Malan) and during both years. Conventional tillage produced significantly higher grain yield, which was followed by reduced tillage and zero tillage, respectively, whereas natural farming produced significantly lower grain yield of rice during both years.

Table 2. Effect of cultivation practices on yield (t ha^{-1}) of different rice varieties at Palampur and Malan.

Treatments	Palampur						Malan					
	Grain		Straw		Biological		Grain		Straw		Biological	
	2020	2021	2020	2021	2020	2021	2020	2021	2020	2021	2020	2021
Cultivation Practices												
Reduced tillage	3.01	3.06	5.40	5.44	8.41	8.51	3.06	3.21	5.49	5.65	8.5	8.86
Zero tillage	2.87	2.91	5.32	5.30	8.20	8.21	2.77	3.05	5.12	5.51	7.89	8.56

Conventional tillage	3.38	3.45	5.97	6.04	9.36	9.49	3.42	3.58	6.01	6.24	9.43	9.83
Natural farming	2.35	1.90	4.51	3.58	6.37	5.49	2.28	2.60	4.32	4.84	6.60	7.45
SEm ±	0.7	0.6	1.5	1.2	2.1	1.7	0.6	0.6	1.2	1.14	1.8	1.7
CD (p = 0.05)	2.5	2.1	5.1	4.2	7.4	6.0	2.3	2.2	4.1	3.9	6.5	6.0
Varieties												
Sukara Dhan 1 (HPR 1156)	2.89	2.83	5.18	4.99	8.07	7.82	2.88	3.12	5.13	5.47	8.01	8.60
Him Palam Dhan 1 (HPR 2656)	2.75	2.68	5.17	5.03	7.90	7.71	2.70	2.86	5.10	5.37	7.80	8.24
Him Palam Lal Dhan 1 (HPR 2795)	3.10	2.99	5.55	5.24	8.66	8.24	3.07	3.34	5.48	5.84	8.55	9.19
SEm ±	0.6	0.6	0.7	0.7	1.2	1.3	0.6	0.6	1.0	1.0	1.7	1.6
CD (P = 0.05)	1.8	1.9	2.1	2.1	3.7	3.8	2.0	1.8	3.2	3.1	5.1	4.84

SEm ±: standard error of mean; CD: critical difference.

The higher values of all the yield attributes were responsible for the greater grain yield observed under conventional tillage, whereas the lower values of the same attributes in the natural farming treatment were responsible for the lower grain yield. When fields are prepared using conventional tillage, the soil becomes soft. As compared to reduced and zero tillage, crop roots develop more effectively in soft soil. Increased nutrient absorption by the crop and better root development help to absorb more nutrients from the soil. In reduced tillage, residues on the soil surface can temporarily immobilise nitrogen, reducing its availability during the early stages of growth, resulting in somewhat slow initial growth. Lack of adequate aeration to the roots under zero tillage conditions led to poor root growth, which potentially limited the soil profile from which the roots could extract plant nutrients, possibly resulting in poor initial growth and a lower grain yield. Similar results, indicating better growth and higher values of differing yield contributing characters under conventional tillage, as well as under reduced tillage as compared to zero tillage in wheat, were reported by a number of workers all over the world [3,37,38,40,44,46–48].

Among the tested varieties, Him Palam Lal Dhan 1 (HPR 2795) reported significantly higher grain yield during both years, while Him Palam Dhan 1 (HPR 2656) recorded significantly lower grain yield. The highest yield recorded in Him Palam Lal Dhan 1 was due to a significantly higher number of panicles m^{-2} and grains panicle $^{-1}$, as well as 1000-grain weight in this variety, which combined to produce a higher yield. Lower values of all these attributes in Him Palam Dhan 1 (HPR 2656) resulted in the lower yield of this variety. Similar results were also obtained for this parameter at RWRC, Malan.

The interaction between the cultivation practices and varieties was found to be non-significant for grain yield. At Palampur and Malan during both years, cultivation practices had a significant impact on straw yield (Table 2). Conventional tillage recorded significantly higher straw yield, which was followed by reduced tillage and zero tillage, the latter two treatments being at par with each other during both years. Higher straw yield under conventional tillage might be due to better root growth, enhanced nutrient availability, and uptake, which result in better initial growth and higher photosynthetic activity as compared to natural farming. The results are in accordance with [3,28,39,44]. Further perusal of the data revealed significantly lower straw yield in natural farming, which as explained earlier, was due to the inadequate supply of nutrients in this treatment.

Among the tested varieties, Him Palam Lal Dhan 1 (HPR 2795) reported significantly greater straw yield over the course of the study of two years, and similar results were also obtained for this parameter at RWRC, Malan. The interaction between the cultivation practices and varieties was found to be non-significant for straw yield. The data on the effect of cultivation practices on the biological yield of different rice varieties at Palampur and Malan is given in Table 2. A close perusal of data revealed that a significantly higher biological yield of rice was recorded in conventional tillage, which was followed by reduced tillage and zero tillage, in that order, the latter two treatments being at par with each other. The lowest biological yield was observed in natural farming treatment. The reason for higher biological yield with conventional tillage was discussed earlier.

Among the varieties tested, Him Palam Lal Dhan 1 (HPR 2795) recorded significantly higher biological yield during both years, which was followed by variety Sukara Dhan 1 (HPR 1156) and Him Palam Dhan 1 (HPR 2656), both of which were at par with each other. Similar results were also reported by Saini et al. [48] and Ankit et al. [47]. Similar results were also obtained for this parameter at RWRC, Malan.

The interaction between the cultivation practices and varieties was found to be non-significant for biological yield. Table 3 contains data on various economic indicators (cost of cultivation, gross return, net return, and B:C ratio) for the cultivation of various wheat cultivars in Palampur and Malan under various cultivation practices. The cost of cultivation varies across different cultivation practices due to variations in ploughing and mulch application with conventional tillage, reduced tillage, and natural farming having larger costs of cultivation due to the higher cost of ploughing. Similar results were reported in previous studies [10,26,35,41].

Table 3. Effect of cultivation practices on the profitability of different wheat varieties at Palampur and Malan.

Treatments	**Cost of Cultivation ($\times 10^3$ INR ha^{-1})**	**Gross Return ($\times 10^3$ INR ha^{-1})**		**Net Return ($\times 10^3$ INR ha^{-1})**		**B:C Ratio**		**Gross Return ($\times 10^3$ INR ha^{-1})**		**Net Return ($\times 10^3$ INR ha^{-1})**		**B:C Ratio**	
	Palampur							**Malan**					
	Both Years	**2019–2020**	**2020–2021**	**2019–2020**	**2020–2021**	**2019–2020**	**2020–2021**	**2019–2020**	**2020–2021**	**2019–2020**	**2020–2021**	**2019–2020**	**2020–2021**
Cultivation practices													
Reduced tillage	43.5	129.2	124.1	85.7	80.6	1.97	1.85	141.8	127.5	98.3	84.0	2.26	1.93
Zero tillage	41.4	120.2	118.5	78.8	77.1	1.90	1.86	135.1	118.2	93.7	76.8	2.26	1.85
Conventional tillage	43.9	132.5	131.6	88.6	87.7	2.02	2.00	144.9	133.0	101.0	89.1	2.30	2.03
Natural farming	40.6	52.0	49.4	11.4	8.8	0.28	0.22	62.1	66.6	21.5	26.0	0.53	0.64
Varieties													
HPW 349	42.4	104.3	101.1	61.9	58.8	1.44	1.37	114.9	105.1	72.5	62.7	1.70	1.47
HPW 368	42.4	112.0	110.5	69.6	68.1	1.62	1.59	128.6	119.1	86.2	76.8	2.01	1.80
HS 562	42.4	109.2	106.1	66.8	63.7	1.56	1.48	119.4	109.8	77.1	67.4	1.80	1.58

According to an evaluation of the data in Table 3, conventional tillage produced the highest gross returns during both years, followed by reduced tillage, while natural farming produced the lowest gross returns. Similar results were reported in previous studies [10,26,35,41]. In terms of gross return, the varieties also behaved differently with respect to gross returns, with HPW 368 giving higher gross returns during both years. Though the cost of cultivation in zero tillage was lowest among the three tillage options, the lower grain and straw yield of wheat recorded in this treatment resulted in lower gross returns, which was followed by HS 562. HPW 349 recorded lowest gross returns during both years, which was due to the lower grain yield recorded in this variety.

Net return from an agricultural enterprise indicates the income achieved from an investment after deducting all the expenses incurred in production. Table 3 shows the net return obtained for each treatment, with conventional tillage recording the maximum net return, followed by reduced tillage, zero tillage, and natural farming, in that sequence, with natural farming recording the lowest net return. Similar results indicating higher values of net return under conventional tillage were reported by several workers [10,35,41].

Among the varieties tested, the highest net return during both years was recorded in HPW 368, followed by HS 562, while the lowest net return during both years was recorded in HPW 349. The cost of cultivation in all three varieties was similar, and the differences in net returns were only due to differences in the grain and straw yield. The variety HPW 368, which recorded higher grain and straw yield, resulted in higher net return, while HPW 349 had the lower yield and recorded the lowest net return.

The B:C ratio, which shows the net return achieved per rupee invested, determines the effectiveness of any treatment applied to a crop. The B:C ratio was influenced by cultivation practices (Table 3). Over the course of the study of two years, conventional tillage had the greatest B:C ratio, whereas natural farming had the lowest. The lowest B:C ratio was recorded in natural farming, which was due to the lowest yield obtained in this treatment without any significant reduction in the cost of cultivation. During the first year, B:C ratio was higher in reduced tillage as compared to the zero tillage, while during the second year, the B:C ratio in these two tillage treatments was almost similar. The results so obtained indicate that the extra cost involved in the practices of reduced tillage (primary tillage and addition incorporation of straw) could not increase the net return in the same proportion as the cost of cultivation. Similar outcomes from earlier research were reported [10,35,41].

Among the varieties tested, HPW 368 recorded the highest B:C ratio during both years, which was followed by HS 562. The lowest B:C ratio during both the years was recorded in HPW 349. Similar results were also obtained for all the parameters at RWRC, Malan. Table 4 contains data on various economic indicators for the cultivation of various rice cultivars in Palampur and Malan under various cultivation practices. Due to variations in ploughing and mulch application in conventional tillage, reduced tillage, and natural farming during both years, the cost of cultivation differed between various cultivation practices.

According to Table 4, conventional tillage produced the highest gross returns during both years, followed by reduced tillage and zero tillage, while natural farming practices produced the lowest gross returns. Varieties also behaved differently with respect to gross return, with Him Palam Lal Dhan 1 (HPR 2795) giving higher gross return during both years (2020 and 2021), which was followed by Sukara Dhan 1 (HPR 1156). Him Palam Dhan 1 (HPR 2656) recorded the lowest gross return during both years (2020 and 2021), which was due to the lower grain yield recorded in this variety. Additionally, the higher price of the grain of Him Palam Lal Dhan 1 also resulted in a higher gross return achieved from this variety. Similar results indicating higher values of gross returns under conventional tillage were reported by several workers [36,47,49].

Net return from an agricultural enterprise indicates the income achieved from an investment after deducting all the expenses incurred in production (Table 4). Conventional tillage recorded the highest net returns during both the years (2020 and 2021), while net return obtained in zero tillage and reduced tillage was almost similar, while natural farming recorded the lowest net return. Though the gross return in reduced tillage was considerably higher than the zero tillage, the lower cost of cultivation in zero tillage resulted in an almost similar net return in these two tillage options. Similar results were reported in previous studies [36,47,49].

Table 4. Effect of cultivation practices on the profitability of different rice varieties at Palampur and Malan.

Treatments	Cost of Cultivation (×10^3 INR ha^{-1})	Gross Return (×10^3 INRha^{-1})		Net Return (×10^3 INRha^{-1})		B:C		Gross Return (×10^3 INRha^{-1})		Net Return (×10^3 INRha^{-1})		B:C	
	Palampur							Malan					
	Both Years	2020	2021	2020	2021	2020	2021	2020	2021	2020	2021	2020	2021
Cultivation practices													
Reduced tillage	38.9	79.0	80.4	40.1	41.4	1.03	1.07	80.3	84.2	41.4	45.3	1.07	1.16
Zero tillage	35.8	76.0	76.7	40.2	40.9	1.12	1.14	73.4	80.3	37.6	44.5	1.05	1.24
Conventional tillage	39.3	88.8	90.0	49.5	50.7	1.26	1.29	89.4	93.6	50.1	54.3	1.27	1.38
Natural farming	35.9	62.9	50.6	27.0	14.7	0.75	0.41	60.6	68.9	24.7	33.0	0.69	0.92
Varieties													
Sukara Dhan 1 (HPR 1156)	37.5	69.3	67.7	31.9	30.2	0.85	0.80	69.0	74.6	31.5	37.1	0.83	0.99
Him Palam Dhan 1 (HPR 2656)	37.5	66.3	65.0	28.8	27.5	0.77	0.73	65.6	69.4	28.1	32.0	0.75	0.85
Him Palam Lal Dhan 1 (HPR 2795)	37.5	94.3	90.6	56.8	53.1	1.51	1.41	93.2	101.2	55.7	63.8	1.48	1.70

Among the varieties tested, the highest net return during both the years was recorded in Him Palam Lal Dhan 1 (HPR 2795), which was followed by Sukara Dhan 1 (HPR 1156), while lowest net return was recorded in Him Palam Dhan 1 (HPR 2656). The effectiveness of any treatment applied to a crop is determined by the B:C ratio, which indicates the net return achieved per rupee invested. The data presented in Table 4 reveal the B:C ratio obtained from different cultivation practices, as well as from different varieties. Conventional tillage recorded the highest B:C ratio while the lowest was recorded in the natural farming treatment during both the years (2020 and 2021). Though the net return in reduced tillage was almost similar to that in zero tillage, the B:C ratio in zero tillage was higher, which was due to the lower cost of cultivation in zero tillage. Similar results were reported in previous studies [36,41,49]. Among the varieties tested, Him Palam Lal Dhan 1 (HPR 2795) recorded the highest B:C ratio during both the years (2020 and 2021), which was followed by Sukara Dhan 1 (HPR 1156). Lowest B:C ratio during both the years (2020 and 2021) was recorded in Him Palam Dhan 1 (HPR 2656).

Table 5 contains the data on the effect of cultivation practices and varieties on total nitrogen uptake. Significantly higher total nitrogen uptake was recorded in conventional tillage, while lowest total nitrogen uptake was recorded in the case of natural farming during both years. The nutrient uptake is a function of yield and nutrient content; higher yield and higher nutrient content results in higher uptake of a particular nutrient. Significantly higher grain and straw yield of wheat recorded under conventional tillage, as well as higher nitrogen content in both grain and straw in this treatment, contributed to the significantly higher total nitrogen uptake by wheat cultivated under conventional tillage. Similar results indicating higher uptake of nitrogen by wheat raised with conventional tillage were reported in studies carried out earlier [28,41,50].

Table 5. Effect of cultivation practices on total N, P, and K uptake of different wheat varieties at Palampur and Malan.

Treatments	N Uptake (kg ha^{-1})				P Uptake (kg ha^{-1})				K Uptake (kg ha^{-1})			
	Palampur		Malan		Palampur		Malan		Palampur		Malan	
	2019–2020	2020–2021	2019–2020	2020–2021	2019–2020	2020–2021	2019–20-20	2020–2021	2019–2020	2020–2021	2019–2020	2020–2021
Cultivation practices												
Reduced Tillage	95.3	92.2	101.9	89.7	18.83	17.52	20.01	16.99	89.0	87.2	104.1	93.4
Zero tillage	85.4	85.1	95.1	81.9	16.98	16.22	18.76	15.46	81.6	81.4	99.9	87.3
Conventional tillage	100.9	100.1	106.4	95.9	19.92	19.35	20.82	18.13	94.3	95.3	107.7	99.6
Natural Farming	39.9	34.1	42.3	43.9	6.92	6.52	8.34	8.31	35.7	34.9	45.8	48.7
SEm ±	1.6	1.8	2.4	2.1	0.39	0.44	0.45	0.40	1.8	1.6	1.7	2.1
CD (p = 0.05)	5.4	6.1	8.4	7.4	1.35	1.52	1.56	1.38	6.2	5.4	6.0	7.3
Varieties												
HPW 349	74.0	72.9	81.2	72.7	14.92	13.93	15.95	13.79	71.6	70.8	85.2	79.2
HPW 368	82.4	81.9	92.1	82.7	15.81	15.59	18.04	15.67	80.1	80.0	96.0	88.4
HS 562	80.9	78.8	85.9	78.2	16.26	15.19	16.96	14.70	73.7	73.3	87.0	79.1
SEm ±	1.1	1.1	101.9	89.7	0.23	0.23	0.35	0.37	1.1	1.1	1.5	1.6
CD (p = 0.05)	3.3	3.2	95.1	81.9	0.70	0.69	1.05	1.11	3.2	3.4	4.4	4.9

SEm ±: standard error of mean; CD: critical difference.

Among varieties tested, the highest total nitrogen uptake was recorded in HPW 368, which was due to the higher uptake of nitrogen in both grain and straw, while significantly lower total nitrogen uptake was recorded in variety HPW 349. Similar results were also obtained for this parameter at Malan. Interaction between cultivation practices and varieties for total nitrogen uptake was not found to be significant. The data pertaining to the effect of cultivation practices and varieties on total phosphorus uptake are presented in Table 5. Significantly higher total phosphorus uptake was recorded in conventional tillage, which was followed by reduced tillage during both the years of study. Natural farming treatment resulted in the lowest total phosphorus uptake. As discussed earlier, the uptake of any nutrient is directly proportional to yield and nutrient content in the crop. Higher phosphorus content, as well as yield observed in conventional tillage, resulted in significantly higher total phosphorus uptake in this treatment. Similarly, lower phosphorus content, as well as lower yield observed in natural farming, resulted in significantly lower total phosphorus uptake. Similar results indicating higher values of phosphorus content in wheat were reported in previous studies by several workers [28,41,50].

The total phosphorus uptake was significantly influenced by varieties with HS 562 recording significantly higher phosphorus uptake during 2019–2020, though this variety was at par with HPW 368. However, during 2020-21, HPW 368 recorded significantly higher total phosphorus uptake, though this variety was at par with HS 562. The lowest phosphorus total uptake was observed from HPW 349. As discussed earlier, the uptake of nutrients is a function of yield and nutrient content; higher phosphorus content in both grain and straw in HS 562 resulted in higher uptake of phosphorus in this variety, while the higher yield of HPW 368 resulted in higher uptake of phosphorus by this variety. Similar results were also obtained for this parameter at Malan.

Total phosphorus uptake was not influenced by the interaction between cultivation practices and varieties. The data on the total potassium uptake, as influenced by cultivation practices and varieties, are given in Table 5. A perusal of the data revealed that significantly higher total potassium uptake was recorded in conventional tillage, which was followed by reduced tillage during both years. Natural farming treatment resulted in the lowest total potassium uptake during both years. As discussed earlier, the uptake of any nutrient is directly proportional to yield and nutrient content in the crop. Higher potassium content, as well as yield observed in conventional tillage, resulted in significantly higher total potassium uptake in this treatment. Similarly, lower potassium content, as well as lower yield, observed in natural farming resulted in significantly lower total potassium uptake.

Similarly, higher potassium uptake in grains and straw, as recorded in HPW 368, ultimately resulted in higher total potassium uptake in this variety, which was followed by variety HS 562, while significantly lower potassium uptake was recorded in variety HPW 349, which was due to lower uptake of grain and straw during both years. Similar results were also obtained for this parameter at Malan.

The interaction between varieties and cultivation practices was not found to be significant for the total potassium uptake.

The data on the effect of cultivation practices and varieties on total nitrogen uptake by rice crops are given in Table 6. The data revealed that conventional tillage logged the highest uptake of nitrogen, which was followed by reduced tillage, while lowest total nitrogen uptake was recorded in the case of natural farming during both years. Significantly higher grain and straw yields of rice, as well as higher nitrogen content in grains and straw of rice under conventional tillage contributed to the significantly higher uptake of nitrogen under conventional tillage, while lower values of yield and content under natural farming resulted in lower uptake of nitrogen under natural farming. Similar results from earlier research were reported [28,51].

Table 6. Effect of cultivation practices on total N, P, and K uptake of different rice varieties at Palampur and Malan.

Treatments	**N Uptake (kg ha^{-1})**				**P Uptake (kg ha^{-1})**				**K Uptake (kg ha^{-1})**			
	Palampur		**Malan**		**Palampur**		**Malan**		**Palampur**		**Malan**	
	2020	**2021**	**2020**	**2021**	**2020**	**2021**	**2020**	**2021**	**2020**	**2021**	**2020**	**2021**
Cultivation practices												
Reduced tillage	67.3	68.9	67.6	72.5	13.97	15.13	14.97	16.19	70.0	71.4	72.4	74.4
Zero tillage	63.8	64.3	61.1	68.3	13.15	14.08	13.27	15.04	68.3	68.7	66.5	71.7
Conventional tillage	76.5	77.8	75.6	81.5	16.47	17.81	17.26	18.98	78.6	80.5	80.8	83.5
Natural Farming	50.5	40.0	48.4	56.3	10.56	8.88	10.48	12.07	56.4	44.5	53.9	60.7
SEm ±	1.7	1.4	1.9	1.4	0.40	0.30	0.31	0.28	1.8	1.3	1.4	1.7
CD (p = 0.05)	5.9	4.7	6.7	5.0	1.40	1.04	1.08	0.98	6.1	4.5	4.9	5.7
Varieties												
Sukara Dhan 1 (HPR 1156)	64.1	62.4	63.0	70.0	13.28	13.86	13.83	15.38	66.7	65.1	67.5	71.5
Him Palam Dhan 1 (HPR 2656)	61.1	60.3	60.0	64.8	12.41	12.80	12.97	14.12	66.0	64.8	66.6	69.3
Him Palam Lal Dhan 1 (HPR 2795)	68.3	65.5	66.4	74.1	14.91	15.27	15.18	17.22	72.2	69.0	71.2	77.0
SEm ±	1.3	1.1	1.6	1.3	0.21	0.34	0.33	0.30	1.0	1.2	1.3	1.4
CD (p = 0.05)	4.0	3.3	4.7	4.0	0.63	1.02	0.99	0.91	2.9	3.6	3.9	4.1

SEm ±: standard error of mean; CD: critical difference.

Similarly, among different varieties, Him Palam Lal Dhan 1 (HPR 2795) recorded significantly higher total nitrogen uptake, which was due to the higher uptake of nitrogen in both grain and straw, while significantly lower total nitrogen uptake was recorded in Him Palam Dhan 1 (HPR 2656) during both years, which was due to the lower uptake of nitrogen in both grain and straw. Similar results were also obtained for this parameter at Malan.

Interaction between cultivation practices and varieties for total nitrogen uptake was not found to be significant. The data pertaining to the effect of cultivation practices and varieties on total phosphorus uptake are presented in Table 5. A perusal of the data revealed that significantly higher total phosphorus uptake was recorded in conventional tillage, which was followed by reduced tillage during both years. Natural farming treatment resulted in a significantly lower total phosphorus uptake. As discussed earlier, the uptake of any nutrient is directly proportional to yield and nutrient content in the crop, higher phosphorus content, as well as yield observed in conventional tillage, resulted in significantly higher total phosphorus uptake in this treatment. Similarly, lower phosphorus content, as well as yield, observed in natural farming resulted in significantly lower total phosphorus uptake. Similar results from earlier research were reported [28,51].

The total phosphorus uptake was significantly influenced by varieties with Him Palam Lal Dhan 1 (HPR 2795) recording significantly higher total phosphorus uptake, while Him Palam Dhan 1 (HPR 2656) showed significantly lower uptake during both years. The results so obtained are due to the significantly higher and lower yields observed with Him Palam Lal Dhan 1 (HPR 2795) and Him Palam Dhan 1 (HPR 2656), respectively. Similar results were also obtained for this parameter at Malan.

Total phosphorus uptake was not influenced by the interaction between cultivation practices and varieties. The data on the total potassium uptake, as influenced by cultivation practices and varieties, are given in Table 6. As discussed earlier, the total nutrient uptake by the crop is the sum total of nutrient uptake by grains and straw, higher potassium uptake by both grains and straw in conventional tillage ultimately resulted in significantly higher total potassium uptake during both years, while significantly lower total potassium uptake in natural farming treatment was due to the significantly lower potassium uptake in both grains and straw in this natural farming treatment. Similar results were reported in previous studies, Seth 2020. Similar results were reported by several workers in previous studies [28,51].

Similarly, higher potassium uptake in grains and straw in Him Palam Lal Dhan 1 (HPR 2795) ultimately resulted in higher total potassium uptake in this variety, while the remaining two varieties recorded lower potassium uptake and were at par with each other. Similar results were also obtained for this parameter at Malan. The interaction between varieties and cultivation practices was not found to be significant for the total potassium uptake.

4. Conclusions

Adoption of conventional tillage in wheat and rice in the rice–wheat cropping system resulted in significantly higher productivity and profitability of both the crops in the system, while natural farming failed to give satisfactory results in both the crops. Similarly, the conventional tillage resulted in higher content of all the primary nutrients in grain and straw of both wheat and rice, thereby resulting in higher uptake of nitrogen, phosphorus, and potassium, while natural farming gave the lowest corresponding values. Among the varieties evaluated, wheat variety HPW 368 and rice variety Him Palam Lal Dhan 1 (HPR 2795) gave better productivity and profitability under direct seeded upland conditions.

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