Indian Journal of Agricultural Sciences **94** (9): 940–945, September 2024/Article
https://doi.org/10.56093/ijas.v94i9.134752

Productivity, nutrient status and energy dynamics of rice (*Oryza sativa*) genotypes under different tillage systems in unirrigated ecosystem

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Received: 28 March 2023; Accepted: 12 July 2024

ABSTRACT

The study was carried out during rainy (*kharif*) seasons of 2020 and 2021 at Chaudhary Sarwan Kumar Himachal Pradesh Krishi Vishvavidyalaya, Palampur, Himachal Pradesh to assess the impact of different tillage practices on the crop productivity, nutrient status, and energy dynamics of three distinct rice (*Oryza sativa* L.) genotypes. The experiment was conducted in a split-plot design (SPD), replicated three times. The study examined the impact of two major factors, viz. (A) Factor 1 (Main plot), Four tillage system: Reduced tillage; Traditional tillage; Natural farming: and Zero tillage; (B) Factor 2 (Sub plot): Three rice genotypes: HPR 2656; HPR 2795; and HPR 1156. Based on the findings of two years we found that the conventional tillage recorded notably higher grain yield (3420 kg/ha) and straw yield (6010 kg/ha) while significantly lower values of grain yield (2134 kg/ha) and straw yield (4053 kg/ha) were found in natural farming treatment. Significantly higher nutrient contents (N, P, and K) and their uptake were observed in conventional tillage, followed by reduced tillage treatment. In contrast, significantly lower values of nutrient contents (N, P, and K) and their uptake were recorded in natural farming treatment. Among genotypes evaluated HPR 2795 recorded significantly higher values of grain yield (3050 kg/ha) and straw yield (5402 kg/ha) owing to significantly higher values of yield attributes recorded in this variety. The present study shows that the conventional tillage method led to a higher yield for rice crops. Among all the genotypes tested, HPR 2795 exhibited the best performance.

Keywords: Nutrient content, Rice, Tillage systems, Uptake, Yield

Globally, rice (*Oryza sativa* L.) is by far the most significant crop. Due to its tolerance to climatic, cultural and edaphic locations, it ranks high among cereal crops. Rice is one of the crops that ensures food security at global level. In India, rice is cultivated in 6.38 million hectares, yielding 130.29 million tonnes as the harvest and 28.09 q/ha as the average productivity (Anonymous 2022). Conventional tillage methods are simple to implement and help maintain clean crop areas. However, these techniques require substantial fuel and energy, especially in the rice-wheat cropping system prevalent in the Indo-Gangetic plains. Using conservation tillage techniques, such as minimum and zero tillage, can assist reduce excessive fuel and energy usage, resulting in crop production that is sustainable (Mathew *et al*. 2012). These practices are also ecologically beneficial as well as cost effective. Of late the government is putting more focus on natural farming, a traditional practice that avoids the use of costly external inputs and focuses more on the use of inputs available within the farm. This farming practice is expected to reduce the cost of cultivation resulting in enhance productivity.

Breeders around the world have developed many high-yielding and disease resistant rice genotypes. However, most of these genotypes and corresponding agricultural practices are tailored for traditional farming systems. The efficacy of rice genotypes may be significantly affected by the micro-climate of the field, which may be influenced by various tillage systems (Ankit *et al*. 2022b). Although some research has been conducted globally to identify genotypes recommended for conservation tillage, there has been limited work in this area within India. Therefore, this study was undertaken to identify rice genotypes that are suitable for various tillage systems in the Indian context.

MATERIALS AND METHODS

A study was carried out during rainy (*kharif*) seasons of 2020 and 2021 at Chaudhary Sarwan Kumar Himachal Pradesh Krishi Vishvavidyalaya, Palampur, Himachal Pradesh. The experiment was conducted in a split-plot design (SPD), with each plot measuring 4.0 m width and 4.3 m length, replicated three times. The study examined the

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impact of two major factors, viz. (A) Factor 1 (Main plot), Four tillage system: Reduced tillage; Traditional tillage; Natural farming: and Zero tillage; (B) Factor 2 (Sub plot): Three rice genotypes: HPR 2656; HPR 2795; and HPR 1156.

Texture of the soil for investigation site was silty clay loam, which exhibited acidic reaction (owing to the very heavy rains received in this region of Himachal Pradesh) and moderate in available nitrogen (373.6 kg/ha), phosphorus (16.4 kg/ha) and potassium (276.4 kg/ha). Prior to the start of this experiment, the field was under rice-wheat cropping system, with both the crops fertilized at recommended rates. In every plot, the inorganic fertilizers urea, Single Super Phosphate (SSP) and Muriate of Potash (MOP) were used @60:30:30 kg N:P:K, respectively/ha when rice was planted. The entire amount of potassium and phosphorus was applied during the time of sowing, but nitrogen was split equally into two portions, viz. one for planting and the other for tillering. Among all the treatments, except for natural farming, butachlor was applied at a rate of 1.5 kg/ha to control weeds. In the rice fields, weeds were mechanically removed. Wheat residue was administered @3 t/ha for both the natural farming and reduced tillage regimens. According to Mr. Subhash Palekar, a natural farming expert, the natural farming treatment was conducted in accordance with the complete recommendations that are unique to this form of cultivation (Palekar 2011). The practices implemented in this treatment were: Applied *Ghanjeevamrit* @500 kg/ha prior to sowing; Soaked rice seeds in *Beejamrit* solution for half an hour before sowing; Dissolved 25 litres of *Jeevamrit* in 500 litres of water and applied it to a 1 ha area 1-month after sowing; Conducted a second spray of *Jeevamrit* three weeks after the initial spray, using a mixture of 50 litres of *Jeevamrit* in 500 litres of water per hectare; Administer a third spray of *Jeevamrit* three weeks following the second application, again using 50 litres of *Jeevamrit* dissolved in 500 litres of water per hectare; Three weeks subsequent to the final *Jeevamrit* application, sprayed a mixture of 25 litres of buttermilk dissolved in 500 litres of water over 1 ha.

The data on different yields (grain and straw), nutrient concentration and uptake were recorded using standardized procedures. To estimate the input energy, it was classified into direct, indirect, renewable, and non-renewable categories (Hatirli *et al.* 2006). According to Singh *et al.* (2007), diesel, electricity and human labour are the sources of direct energy, while seeds, farm equipment, fertilizers and herbicide are the sources of indirect energy. The energy inputs and their corresponding energy equivalents were determined using the per-unit energy equivalency factors provided by Babu *et al.* (2014). The energy input (in MJ/ha) was calculated by adding the energy requirement for machinery, herbicide, human labour, fertilizers and seeds of different varieties. To assess the farm's energy output, both grain and straw yields were converted into energy terms by multiplying the crop yields by their respective energy equivalents per unit. Using these energy equivalents for both inputs and outputs, several metrics were calculated to assess energy efficiency and productivity. These metrics included:

Energy use efficiency = Gross energy output (MJ/ha)/ Energy input (MJ/ha)

Energy productivity (kg/MJ) = Total output (grain + straw) (kg/ha)]/Total energy input (MJ/ha)

Net energy output (MJ/ha) = Gross energy output (MJ/ha) – Energy input (MJ/ha)

Energy intensity in physical terms (MJ/kg) = Total energy input (MJ/ha)/Total output (grain + straw) (kg/ha)

Energy profitability (rupee/ha) = Net returns/Crop duration

Statistical analysis: The data recorded in both trials were subjected to analysis of variance (ANOVA) using the method described by Gomez and Gomez (1984).

RESULTS AND DISCUSSION

Effect of tillage systems on yield of rice genotypes: The grain and straw yield of rice was significantly influenced by both tillage systems and genotypes (Table 1 and Fig. 1). Among the tillage systems, conventional tillage produced the highest grain and straw yields, followed by reduced tillage and zero tillage treatments. The natural farming treatment resulted in the lowest grain and straw yields.

In conventional tillage systems, greater grain yields may be attributed to more favourable values of key agronomic traits or yield attributes. Conventional tillage practices result in a softer soil structure during field preparation, which facilitates better root growth compared to zero and reduced tillage methods. Enhanced root development under conventional tillage allows for more efficient nutrient uptake from the soil, helping in promoting improved crop growth and higher yields. On the other hand, because of the enhanced nitrogen immobilisation in low tillage systems, crop residues on the soil surface may hinder the initial growth of seedlings. It can have a detrimental effect on the yield results in the end. These results are in corroboration with the findings of Seth *et al.* (2019), Seth *et al.* (2020), Seth and Manuja (2022), Ankit *et al.* (2022a), Ankit *et al.* (2022c), Saini *et al.* (2022), Saini *et al.* (2023) and Saini *et al.* (2024).

Among the genotypes investigated HPR 2795 recorded a significantly higher yield of grains and straw while a significantly lower yield of grains and straw was observed with HPR 2656 during both the years. The genotype's yield was substantially reduced in HPR 2656 as a result of the lower values of all yield components, whereas the higher yield in HPR 2795 was a direct consequence of these greater values.

Effect of tillage systems on energy dynamics of different rice genotypes: The rice crop's various energy indices were significantly impacted by the tillage system. The natural farming treatment had the lowest energy input, whereas the reduced tillage approach and conventional tillage method had the highest energy input (Table 2). In natural farming, the energy requirement was 75% lower than conventional tillage and reduced tillage respectively. Due to the lower energy demands associated with natural farming and zero tillage practices, the gross and net energy outputs for these methods were observed to be lower compared to conventional tillage. The increased energy requirements for conventional tillage are likely attributable to greater labour demands and more intensive ploughing and field preparation processes. Despite the higher energy inputs, natural farming demonstrated at 63.0% and 66.7% greater energy use efficiency compared to conventional and reduced tillage methods, respectively. Furthermore, natural farming achieved the highest energy productivity, measured as kilograms of rice grain produced per unit of energy invested, outperforming both zero and reduced tillage practices. Specifically, energy productivity in natural farming was 62.9% and 66.8% higher than that of conventional and reduced tillage methods, respectively. Conversely, when evaluating energy intensity in physical terms, a contrasting trend was observed. The greatest energy intensity was recorded under the reduced tillage treatment, with energy intensity being 10.7% and 17.3% lower in conventional and zero tillage methods compared to reduced tillage, respectively. Similarly, energy profitability was highest under conventional tillage and lowest in natural farming. Greater energy requirement, energy output, net energy and energy use efficiency in conventional tillage over zero tillage and natural farming in agricultural production systems was also reported by Seth and Manuja (2022) and Singh *et al.* (2015).

In addition, the energetics of rice production were substantially impacted by the various genotypes that were examined (Table 2). HPR 2795 exhibited substantially greater amount of gross energy output (112345 MJ/ha), net energy output (99657 MJ/ha), energy use efficiency (11.24 MJ/ha), and energy productivity (0.85 kg rice/MJ) than HPR 2656 and HPR 1156. In general, the efficacy of energy use is directly proportional to the increase in energy output. Nevertheless, genotype HPR 2795 exhibited the highest energy profitability (448.1 ₹/MJ) among all other genotypes. Genotype HPR 2795 maintained a minimal energy intensity in physical terms, which was 7.0 and 6.2% lower than that of HPR 2656 and HPR 1156, respectively. Given that biomass directly affects any production system's energy efficiency, this could be mediated through the increased amount of harvestable biomass.

Effect of tillage systems on nutrient concentration of rice genotypes: The rice crop's nutrient content was substantially influenced by various treatments. In both grain and straw, the conventional tillage treatment exhibited the maximum concentrations of nitrogen, phosphorus, and potassium, while the reduced tillage treatment followed suit. Alternatively, the natural farming treatment exhibited the lowest concentrations of nutrients in both grain and debris. The administration of the prescribed fertilizer dosage at planting is likely to have contributed to the increased nutrient concentrations in the grain and straw across various tillage treatments, which likely enhanced nutrient availability and absorption, particularly during the early growth stages of the crop. The roots could access a wider soil profile for nutrient uptake, leading to higher nutrient assimilation in both the grain and straw. Furthermore, the growth of a deep and extensive root system was facilitated by the increased administration of nitrogen, phosphate, and potassium at sowing, which in turn enhanced initial growth. In contrast, the natural farming treatment, characterized by minimal nutrient addition to the soil, did not meet the crop's nutritional requirements, leading to suboptimal growth and root development. Consequently, the reduced nutrient availability and less developed root system under natural farming conditions likely resulted in lower nutrient concentrations in both grain and straw. The results so obtained are in corroboration with the findings of Archana *et al.*

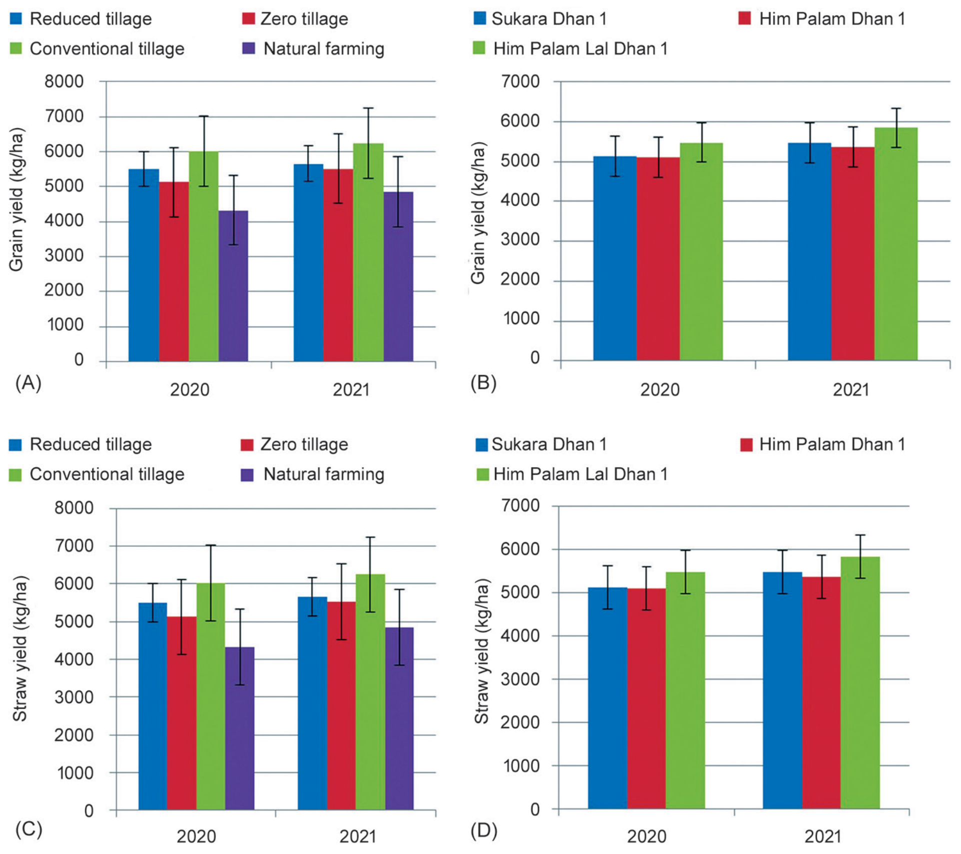

Fig. 1 Impact of different tillage systems on grain yield (A) and (B) and straw yield (C) and (D) of different rice genotypes.
SE is represented by error bars.

(2017), Thakur and Sidar (2017), Seth *et al.* (2020), Saini *et al.* (2022) and Saini *et al*. (2024).

Among the genotypes examined, the highest nitrogen concentration in grains was observed in HPR 2795, which exhibited comparable levels to HPR 2656 and was also on par with HPR 1156. In terms of nitrogen concentration in straw, HPR 1156 demonstrated significantly higher nitrogen content, whereas HPR 2795 exhibited the lowest nitrogen content across both the years of study. The genetic composition of the various genotypes can be mainly inferred from the observed variations in nitrogen content in both grain and straw. However, in case of phosphorus and potassium concentration in both grain and straw during both the years of study, significantly higher phosphorus and potassium concentration was recorded in HPR 2795 while lowest was observed in HPR 2656 for both grain and straw. The variations in phosphorus and potassium concentrations in grain and chaff among the genotypes may be attributed to internal or external mechanisms that facilitate increased soil phosphorus and potassium extraction and grain yield (Islam *et al*. 2008).

Effect of tillage systems on nutrient uptake of rice genotypes: Nutrient uptake by plants is a dynamic process influenced by various factors including climate, soil characteristics, the quantity and application methods of fertilizers, and the cultural practices employed. Nutrient uptake by rice indicated that rice tillage systems had a positive effect on nutrient uptake. Results showed that different treatments significantly influenced the nutrient uptake (nitrogen, phosphorus and potassium) by both grain and straw (Table 1). Significantly higher N (48.8 and 28.4 kg/ha), P (9.88 and 7.26 kg/ha) and K (8.0 and 71.6 kg/ha) uptake by grain and straw was noticed in conventional tillage which was followed by reduced tillage and zero tillage treatment during both the years of study, while significantly lower N (28.0 and 17.3 kg/ha), P (5.39 and 4.33 kg/ha) and K (4.5 and 46.1 kg/ha) uptake in both grain and straw was recorded in natural farming treatment. The significantly higher grain and straw yields of rice under conventional tillage, along with the increased concentrations of N, P, and K in both grain and straw, led to a markedly greater N uptake in conventional tillage systems. In contrast, the lower yields and reduced N, P, and K contents observed in natural farming practices resulted in a diminished nitrogen uptake under these conditions. These results are in accordance with the findings of Seth *et al.* (2020), Saini *et al.* (2022) and Saini *et al.* (2024).

Similarly, HPR 2795 exhibited a substantially higher N, P, and K uptake in both grain and straw than HPR 2656, while HPR 2656 exhibited a significantly lower N, P, and K uptake value. Since the nutrient uptake is a function of nutrient content and yield, the higher grain yield of HPR 2795 and the higher N, P, and K content in the grain and straw of this variety resulted in a higher N, P, and K uptake by the grain and straw. Furthermore, the genotype HPR 2656 exhibited a lower N, P, and K absorption in grain and straw due to its reduced yield and lower N, P, and K content.

For all the aforementioned parameters, including yield, nutrient content and uptake, and energy indices of the rice crop, no significant interaction was observed between the tillage systems and the genotypes.

In terms of attaining a superior rice crop yield, conventional tillage outperformed alternative tillage systems, as indicated by the results of the current study, which also enhanced nutrient content and increased nutrient uptake. Furthermore, among the various genotypes investigated, it was observed that HPR 2795, a recently introduced red rice variety, exhibited more favourable outcomes.

Table 1 Effect of different tillage systems on nutrient content and uptake of rice genotypes (Pooled over 2 years)

Treatment	N content (%)		P content (%)		K content (%)		N uptake (kg/ha)		P uptake (kg/ha)		K uptake (kg/ha)	
	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw
Tillage system												
Reduced tillage	1.41	0.47	0.274	0.115	0.226	1.176	42.8	25.4	8.34	6.22	6.9	63.8
Zero tillage	1.38	0.46	0.265	0.112	0.220	1.170	40.0	24.1	7.68	5.94	6.4	62.2
Conventional tillage	1.43	0.47	0.289	0.121	0.232	1.193	48.8	28.4	9.88	7.26	8.0	71.6
Natural farming	1.31	0.43	0.251	0.107	0.209	1.135	28.0	17.3	5.39	4.33	4.5	46.1
SEm ±	0.01	0.01	0.003	0.001	0.003	0.009	1.0	0.6	0.24	0.15	0.1	1.5
CD (P= 0.05)	0.03	0.02	0.010	0.004	0.012	0.028	3.1	1.8	0.73	0.46	0.4	4.5
Genotype												
Sukara Dhan 1 (HPR 1156)	1.38	0.47	0.268	0.115	0.221	1.167	39.6	23.7	7.73	5.84	6.4	59.6
Him Palam Dhan 1 (HPR 2656)	1.38	0.46	0.258	0.109	0.217	1.163	37.3	23.5	7.03	5.58	5.9	59.5
Him Palam Lal Dhan 1 (HPR 2795)	1.41	0.45	0.284	0.118	0.227	1.176	42.8	24.1	8.72	6.38	7.0	63.7
SEm ±	0.001	0.004	0.002	0.001	0.002	0.007	0.8	0.4	0.17	0.16	0.1	1.1
CD (P= 0.05)	NS	0.001	0.006	0.004	0.006	NS	2.4	1.2	0.49	0.45	0.3	3.1

Table 2 Effect of different tillage systems on yield and energetics of rice genotypes (Pooled over 2 years)

Treatment	Grain yield (kg/ha)	Straw yield (kg/ha)	Energy input (MJ/ha)	Gross energy output (MJ/ha)	Energy use efficiency (MJ/ha)	Net energy output (MJ/ha)	Energy productivity (kg rice/MJ)	Energy intensity in physical terms (MJ/kg)	Energy profitability (₹/ha)
Tillage system									
Reduced tillage	3041	5423	16529	112480	6.81	95951	0.51	1.96	339.7
Zero tillage	2894	5314	13649	108951	7.99	95303	0.60	1.67	337.7
Conventional tillage	3420	6010	16566	125400	7.57	108834	0.57	1.77	417.3
Natural farming	2134	4053	4008	82037	20.47	78029	1.54	0.66	173.7
SEm ±	68	139		2615	0.30	2615	0.03	0.04	11.7
CD (*P*=0.05)	206	420		7931	0.92	7931	0.07	0.09	35.5
Genotype									
Sukara Dhan 1 (HPR 1156)	2862	5091	12688	105692	10.58	93004	0.80	1.54	258.5
Him Palam Dhan 1 (HPR 2656)	2705	5108	12688	103615	10.30	90927	0.78	1.56	234.7
Him Palam Lal Dhan 1 (HPR 2795)	3050	5402	12688	112345	11.24	99657	0.85	1.45	448.1
SEm ±	59	68		1328	0.29	1328	0.02	0.03	11.9
CD (*P*=0.05)	171	196		3827	0.84	3827	0.04	0.06	34.3

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