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Effect of soil disturbance and nutrient supply on soil-plant NPK dynamics and profitability under DSR

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Abstract
A field experiment titled "Response of Direct Seeded Rice to Tillage and Nutrient Management" was carried out during the kharif season of 2024 at All India Coordinated Research Project, College of Agriculture, Nagpur. The study aimed to assess how various tillage methods and nutrient management practices affect the soil-plant NPK and economics of direct seeded rice. The research site was characterized by vertisols with flat topography and a slightly alkaline pH of 7.3. The soil profile showed moderate organic carbon content (0.63 %), low nitrogen availability (227.52 kg ha^{-1}), moderate phosphorus levels (23.54 kg ha^{-1}), and high potassium content (367.38 kg ha^{-1}). A split-plot design was used for the experiment. The main plots were assigned three different tillage treatments: T1- conventional tillage (ploughing fb single rotavator pass), T2 - reduced tillage (one pass using a cultivator), and T3 - zero tillage while sub-plots included four nutrient management treatments: N1- application of 100 % recommended dose of fertilizers (RDF); N2 - 100 % RDF along with seed treatment using a microbial consortium (Biomix); N3 - 100 % RDF combined with foliar sprays of PDKV Grade-II micronutrients at two critical growth phases (5 ml/l at flowering, 65-70 DAS and 10 ml/l at grain filling, 85-90 DAS) and N4 - an integrated approach using 100 % RDF, Biomix seed treatment, and both foliar applications. In total, the experiment comprised of 12 treatment combinations, each replicated thrice to ensure accuracy and statistical robustness. The findings demonstrated that conventional tillage (T1) significantly enhanced nutrient parameters in the plant, including nitrogen, phosphorus, and potassium levels. This tillage practice also increased the residual availability of NPK in the soil as well as improved gross and net monetary returns and the benefit-cost (B:C) ratio. Among the nutrient management strategies, the integrated approach (N4), which combined the recommended dose of fertilizers (RDF), microbial inoculants and specific micronutrient applications showed superior performance across all measured parameters. While both tillage practices and nutrient management had a significant individual influence on rice growth and yield, their combined interaction did not yield statistically significant effects on the evaluated traits.

Keywords: Paddy, Tillage practices, Nutrient management, NPK (Grain and Straw), NPK (Soil), Economics

Introduction
Rice is a fundamental staple food that supplies vital nutrients to more than half of the world's population. A member of the Poaceae family, rice flourishes in warm tropical and subtropical regions and is primarily cultivated in Asia, Africa and parts of Latin America. Its growth is typically confined to latitudes between 45°N and 40°S (Mohanty *et al.* 2014) [13].

On the global scale, rice stands as the second most important cereal crop after maize. Recent global harvest data reports that milled rice production surpassed 513 million metric tons. Asia remains the leading continent in rice cultivation, with China producing the highest quantity of paddy in 2022 over 208 million metric tons followed closely by India and Bangladesh.

In the Indian context, rice occupies approximately 46.38 million hectares, yielding about 130.29 million tonnes with an average productivity of 2809 kg/ha (Agricultural Statistics at a Glance). Maharashtra contributes to this production by cultivating rice on around 15.30 lakh hectares, generating approximately 34.48 lakh tonnes of paddy with a state average yield of 2253 kg/ha (First Advance Estimates 2023-24) [2]. Within the Nagpur division alone, rice is cultivated on 8.36 lakh hectares, with a total production of 18.27 lakh tonnes and an average yield of2184 kg/ha (First Advance Estimates 2023-24) [2].

Tillage and nutrient management are critical components of sustainable crop production. The conventional tillage supports seedbed preparation, its high dependence on labour, machinery and fuel that increases production costs. Alternatives like zero or reduced tillage help minimize input use while maintaining productivity. Reduced tillage practices, such as direct seeding and no till, promote soil health by preserving organic matter and minimizing soil disturbance, thereby improving nutrient retention and reducing soil erosion (Regmi, 1997; Derpsch *et al*. 2010) [16, 7]. No tillage systems often exhibit higher soil organic carbon and phosphorus accumulation in surface layers (Bolliger *et al*. 2006; Redel *et al*. 2007; Zamuner *et al*. 2008) [4, 15, 24]. Moreover, tillage influences soil physical properties such as bulk density, aggregate stability, and penetration resistance, directly impacting crop growth and yield (Carman, 1997; Devi and Singh, 2020) [5, 8]. Alongside tillage, site-specific nutrient management is essential. Excessive use of fertilizers deteriorates soil health and escalates costs, while underuse hampers yield. Hence, tailored fertilizer recommendations for different tillage systems are necessary to enhance resource use efficiency and ensure long-term soil sustainability (Noroozisharaf and Kaviani 2018) [14].

Nutrient management emphasizes supplying plants with essential nutrients in a timely manner. The combined application of organic manures and chemical fertilizers proves more beneficial than using either source alone (Kumar *et al*. 2008) [11]. Given the limited availability of organic manures and their relatively slower impact during early crop growth stages compared to chemical fertilizers (Deka *et al*. 1996) [6], a balanced nutrient strategy integrating organic, chemical and microbial inputs is recommended to maintain optimal yields and enhance residual soil fertility (Mohanty *et al*. 2014) [13].

Considering the above facts, a field experiment was carried out to study the effect of tillage and nutrient management on nutrient content, uptake and residual nutrient availability and profitability of rice production under DSR.

Material and Methods

A field study was conducted during the *kharif* season of 2024 under the All India Coordinated Research Project on Linseed at the College of Agriculture, Nagpur. The principal objective was to evaluate the influence of different tillage systems and nutrient management strategies on the soil-plant NPK dynamics and rice farm profitability and yield performance of direct seeded rice. The experimental site featured soil that was slightly alkaline (pH 7.3), with low available nitrogen (227.52 kg ha^{-1}), moderate levels of phosphorus (23.54 kg ha^{-1}) and organic carbon (0.63 %), and a very high content of available potassium (367.38 kg ha^{-1}). The experiment followed a split plot design with three replications, encompassing twelve treatment combinations. Tillage practices were assigned to the main plots and included: (T_1) conventional tillage, involving ploughing followed by one rotavator pass; (T_2) reduced tillage, with a single cultivator pass; and (T_3) zero tillage. Sub-plots were allocated four nutrient management treatments: (N_1) 100 % recommended dose of fertilizers (RDF); (N_2) RDF in combination with a microbial consortium (Biomix) applied as a seed treatment; (N_3) RDF along with foliar application of PDKV Grade-II micronutrients applied at 5 ml/l during the flowering stage (65-70 DAS) and 10 ml/l during the grain filling stage (85-90 DAS) and (N_4) an integrated approach consisting of RDF, Biomix seed treatment, and both foliar micronutrient applications as described. Split dose of the nitrogen, along with the complete dose of phosphorus and potassium, was applied at sowing while the remaining nitrogen was top dressed 30 days after sowing. Fertilizers were applied through row placement, wherein shallow furrows were manually opened adjacent to the seed lines and subsequently covered with soil. Growth observations were recorded periodically at various crop growth stages where five plants selected randomly from each net plot. The crop duration extended from July to October, during which the experimental site received a total rainfall of 1179.6 mm. An economic analysis was carried out based on the prevailing market price of paddy to determine the total cultivation cost and returns. The nutrient content of grain and straw was estimated by following standard analysis process and then uptake was calculated. The collected data were analyzed statistically using procedures outlined for split plot designs by Gomez and Gomez (1984). Treatment differences were evaluated using the F-test at the 5 % significance level, and where applicable, the critical difference (CD) was calculated to determine statistically significant variations among treatments.

Results and Discussion

Plant analysis

Effect of tillage practices

The content (%) and uptake (kg ha^{-1}) of nitrogen (N), phosphorus (P), and potassium (K) in grain and straw were significantly greater under conventional tillage (ploughing *fb* rotavator once) (T_1), with reduced tillage (cultivator once) (T_2) showing comparatively lower values. Elevated nitrogen content plays a crucial role in the mineralization process, which transforms organic nitrogen into readily available forms to plants in direct seeded rice (DSR) systems. This process is supported by the enhanced activity of soil enzymes such as β-glucosidase and N-acetyl-β-glucosaminidase, which facilitate the decomposition and mobilization of organic nitrogen compounds. Consequently, the stimulation of these enzymatic pathways improves nitrogen mineralization, thereby increasing its availability for rice uptake and growth. Furthermore, the rise in potassium content under T_1 which enhances soil structure and aeration, encouraging the development of deeper and more extensive root systems that can access potassium from a wider soil profile. Similar trends have been documented by Saini *et al.* (2022) and Tang *et al.* (2022) [17, 20].

Effect of nutrient management

The content (%) and uptake (kg ha^{-1}) of nitrogen (N), phosphorus (P), and potassium (K) in both grain and straw were significantly enhanced by the application of RDF (100%) combined with seed treatment using Biomix, along with foliar application of the micronutrient formulation PDKV Grade-II at critical growth stages specifically, at flower initiation (65-70 DAS) at 5 ml/liter of water, and at the grain filling stage (85-90 DAS) at 10 ml/liter (N_4). This was closely followed by RDF (100 %) supplemented with foliar sprays of the same micronutrient at identical stages and concentrations. Elevated nitrogen content is pivotal in the mineralization process, converting organic nitrogen into plant available forms within direct seeded rice (DSR) systems. The increased nitrogen in grain and straw supports enhanced metabolic activities, improving plant nutrition and biomass quality. Likewise, increased phosphorus content and uptake promote ATP synthesis, facilitating essential physiological functions such as photosynthesis, respiration, and nutrient absorption in DSR. Furthermore, the rise in potassium content and uptake activates key enzymes and aids in the translocation of photosynthates, resulting in higher potassium concentrations in grain and straw.

This nutrient enrichment leads to the development of stronger grains and more robust straw, characteristics typical of rice cultivated under high potassium regimes. Comparable observations have been reported by Tang *et al*. (2022), Liang *et al.* (2014) and Atapattu *et al.* (2018) [20, 12, 3].

Soil analysis

Initial and residual N, P and K in soil

Effect of tillage practices

Zero tillage (T_3) was significantly increased the availability of soil nitrogen, phosphorus, and potassium, with reduced tillage (cultivator once) (T_2) showing the next highest levels. The enhancement of soil microbial activity and the accelerated decomposition of organic matter under zero tillage contribute to elevated levels of available nitrogen in the top soil, particularly following direct seeded rice cultivation. Additionally, the retention of crop residues in zero tillage systems promotes microbial activity and facilitates organic phosphorus mineralization, resulting in increased concentrations of exchangeable and available phosphorus, especially within the surface soil layers. Potassium levels in the surface soil are also significantly elevated due to the decomposition of retained crop residues, which release potassium and thereby increase its availability and exchangeability after harvest in direct seeded rice. These findings align with similar observations reported by Issaka *et al.* (2019) [10], Liang *et al.* (2014) [12].

Table 1: NPK content (%) and uptake (kg ha^{-1}) of DSR as influenced by various treatments

Treatments	Nitrogen			Phosphorus			Potassium		
	Nitrogen uptake (kg/ha) (Nitrogen content %)			Phosphorus uptake (kg/ha) (Phosphorus content %)			Potassium uptake (kg/ha) (Potassium content %)		
	Grain	Straw	Total	Grain	Straw	Total	Grain	Straw	Total
Main plot treatments- Tillage Practices (T)									
T_1-Conventional tillage (ploughing fb by rotavator once)	55.21 (1.23)	45.73 (0.74)	100.94	12.53 (0.28)	11.63 (0.18)	24.16	34.34 (0.77)	84.83 (1.38)	119.17
T_2 - Reduced tillage (cultivator once)	48.73 (1.19)	36.73 (0.65)	85.46	9.94 (0.24)	9.17 (0.16)	19.11	27.26 (0.67)	75.41 (1.34)	92.54
T_3- Zero tillage	42.50 (1.18)	28.90 (0.58)	71.40	7.81 (0.22)	7.84 (0.15)	15.65	22.40 (0.62)	65.14 (1.32)	87.54
SE (m) ±	0.79	0.55	1.34	0.45	0.21	0.65	1.95	1.39	1.39 3.34
CD at 5 %	3.11	2.17	5.28	1.76	0.84	2.60	7.65	5.46	5.46 13.11
Sub plot treatments- Nutrient management (N)									
N_1-RDF (100%)	44.29 (1.17)	32.05 (0.61)	76.34	8.49 (0.22)	7.69 (0.14)	16.18	24.86 (0.65)	68.94 (1.32)	93.80
N_2-RDF+ Seed treatment with microbial consortium (Biomix)	46.79 (1.19)	35.43 (0.65)	82.09	9.41 (0.24)	8.67 (0.16)	18.08	26.53 (0.67)	71.96 (1.33)	998.49 (1.33)
N_3- RDF + Foliar application of micronutrient (PDKV Grade-II) at flower initiation (65-70 DAS) @5 ml/ lit of water & grain filling stage (85-90 DAS) @10 ml/ lit of water	50.79 (1.21)	38.82 (0.67)	89.13	10.56 (0.25)	10.22 (0.17)	20.78	29.08 (0.69)	77.48 (1.35)	106.56
N_4- RDF+ Seed treatment (Biomix)+ Foliar application of micronutrient (PDKV Grade-II) at flower initiation (65-70 DAS) @5 ml/ lit of water & grain filling stage (85-90 DAS) @10 ml/ lit of water	53.88 (1.24)	42.17 (0.70)	96.05	11.90 (0.27)	11.60 (0.19)	23.50	31.52 (0.72)	82.13 (1.37)	113.65
SE (m) ±	0.73	0.69	1.42	0.23	0.28	0.51	3.31	0.91	0.91 4.22
C.D. at 5 %	2.25	2.12	4.37	0.70	0.86	1.56	10.20	2.80	2.80 13.00
Interaction (T x N)									
SE (m) ±	1.26	1.19	2.45	0.39	0.48	0.87	5.73	1.58	7.31
CD at 5 %	NS	NS	NS	NS	NS	NS	NS	NS	NS
GM	48.82	37.12	85.94	10.09	9.55	19.64	28.00	75.10	103.10

(Parentheses indicate the percentage of nitrogen, phosphorus and potassium content)

Effect of nutrient management

According to the results, an increase in available nitrogen, phosphorus and potassium was associated with the application of RDF+ Seed treatment with Biomix + Foliar application of micronutrient (PDKV Grade-II) at flower initiation (65-70 DAS) @ 5ml/ lit of water and grain filling stage (85-90 DAS) @ 10 ml/ lit of water (N_4) and was followed by the application of RDF + Foliar application of micronutrient (PDKV Grade-II) at flower initiation (65-70 DAS) @ 5 ml/ lit of water & grain filling stage (85-90 DAS) @ 10 ml/ lit of water (N_3). The increased availability of nitrogen in the post-harvest soil may be attributed to the soil application of the recommended dose of nitrogen, which can supply the nutrient in quantities exceeding the crop's immediate requirements. This excess leads to higher residual nitrogen levels after harvest. Similarly, the application of the recommended dose of fertilizers (RDF) may result in a surplus supply of phosphorus, causing an accumulation of unabsorbed phosphorus and thereby enhancing phosphorus availability in post-harvest soil. In the case of potassium, the application of RDF in potassium rich black cotton soils contributes to increased potassium availability after harvest. These soils naturally contain high levels of native potassium, and the addition of fertilizers further enriches the exchangeable and water-soluble potassium fractions. These outcomes are consistent with the findings reported by Thind *et al.* (2018) [22], Singh N. (2021) [19], and Atapattu *et al.* (2018) [3].

Table 2: Soil available nutrients after harvest of DSR as influence by various treatments

Treatments	Soil available nutrients (kg ha^{-1})		
	N	P	K
Main plot treatments- Tillage Practices (T)			
T_1-Conventional tillage ploughing *fb* by rotavator once)	241.52	23.56	362.26
T_2 - Reduced tillage (cultivator once)	243.50	23.79	368.02
T_3 - Zero tillage	246.35	26.67	371.86
SE (m) ±	0.78	0.35	1.10
CD at 5 %	3.08	1.36	4.33
Sub plot treatments- Nutrient management (N)			
N_1 - RDF	241.06	23.28	364.32
N_2- RDF+ Seed treatment with microbial consortium (Biomix)	243.01	24.29	366.52
N_3- RDF + Foliar application of micronutrient (PDKV Grade-II) at flower initiation (65-70 DAS) @5 ml/ lit of water & grain filling stage (85-90 DAS) @10 ml/ lit of water	244.44	25.09	368.45
N_4- RDF+ Seed treatment (Biomix)+ Foliar application of micronutrient (PDKV Grade-II) at flower initiation (65-70 DAS) @5 ml/ lit of water & grain filling stage (85-90 DAS) @10 ml/ lit of water	246.64	26.03	370.23
SE (m) ±	0.30	0.18	0.30
C.D. at 5 %	0.92	0.56	0.93
Interaction (Tx N)			
S.E. (m) ±	0.52	0.32	0.52
C.D. at 5 %	NS	NS	NS
GM	243.79	24.67	367.38
Initial nutrient status	227.52	23.54	338.83

Economics

Effect of tillage practices

Conventional tillage (ploughing *fb* rotavator once) (T_1) recorded the highest gross monetary returns, net monetary returns, and benefit-cost (B:C) ratio, showing a statistically significant advantage over other treatments. This was followed by reduced tillage (cultivator once) (T_2), while zero tillage (T_3) resulted in comparatively lower economic returns. Improved grain yield per hectare in conventional tillage might be due to enhanced root and shoot growth, which improves nutrient uptake and utilization. Tillage induced soil porosity supports root expansion and shoot vigor, promoting efficient photosynthesis and nutrient assimilation. This strengthens the source-sink relationship, leading to better grain filling and yield. The significant improvement in economic yield under conventional tillage contributed directly to enhanced gross and net monetary returns as well as a higher B: C ratio.

Effect of nutrient management

According to data on paddy economics, foliar application resulted in higher gross monetary returns, net monetary returns, and the B:C ratio. Application of RDF+ Seed treatment with Biomix + Foliar application of micronutrient (PDKV Grade-II) at flower initiation (65-70 DAS) @ 5ml/ lit of water and grain filling stage (85-90 DAS) @ 10 ml/ lit of water (N_4) recorded the maximum value according to an evaluation of treatments based on economic features. The B:C ratio, net monetary returns, and gross monetary returns were all considerably lowest when RDF (100 %) was applied. Application of RDF along with bioinoculant and micronutrient enhanced the crop growth and thereby increasing yield of DSR that resulted in a high GMR higher B: C ratio. Similar results were recorded by Anand *et al*. (2017) [1].

Table 3: Gross monetary returns (Rs. ha^{-1}), Net monetary returns (Rs. ha^{-1}) and B:C ratio of DSR as influenced by various treatments

Treatment	Gross monetary returns (Rs. ha^{-1})	Net monetary returns (Rs. ha^{-1})	B:C ratio
Main plot treatments- Tillage Practices (T)			
T_1-Conventional tillage ploughing *fb* by rotavator once)	112324	70783	2.70
T_2 - Reduced tillage (cultivator once)	102567	64326	2.68
T_3 - Zero tillage	90111	54369	2.52
S.E. (m) ±	2048	2048	-
C.D. at 5 %	8039	8039	-
Sub plot treatments- Nutrient management (N)			
N_1- RDF (100 %)	94999	57589	2.53
N_2- RDF+ Seed treatment with microbial consortium (Biomix)	98341	60481	2.59
N_3- RDF + Foliar application of micronutrient (PDKV Grade-II) at flower initiation (65-70 DAS) @5 ml/ lit of water & grain filling stage (85-90 DAS) @10 ml/ lit of water	104332	65030	2.65
N_4- RDF+ Seed treatment (Biomix)+ Foliar application of micronutrient (PDKV Grade-II) at flower initiation (65-70 DAS) @5 ml/ lit of water & grain filling stage (85-90 DAS) @10 ml/ lit of water	108997	69536	2.76
S.E. (m) ±	1240	1240	-
C.D. at 5 %	3821	3821	-
Interaction (T x N)			
S.E. (m) ±	2148	2148	-
C.D. at 5 %	NS	NS	-
GM	101667	63159	2.63

Interaction effect

The interaction impact of tillage and nutrient management did not significantly affect soil- plant NPK and economics of DSR (Table 1, 2 and 3).

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