

International Journal of Plant & Soil Science

Volume 38, Issue 11, Page 627-637, 2026; Article no.IJPSS.170872
ISSN: 2320-7035

Effect of Natural, Organic and Integrated Nutrient Management Practices on Growth, Productivity and Physico-Chemical Properties of Direct-Seeded Rice (*Oryza sativa* L.)

Anil Kumar [a++*], A. K. Pant [a#], Jai Paul [a#], Veer Singh [a#], Shri Ram [a#] and Sunita T. Panday [b#]

[a] Department of Soil Science, Govind Ballabh Pant University of Agriculture and Technology, Pantnagar, U.S. Nagar, Uttarakhand, India.
[b] Department of Agronomy, Govind Ballabh Pant University of Agriculture and Technology, Pantnagar, U.S. Nagar, Uttarakhand, India.

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: https://doi.org/10.9734/ijpss/2026/v38i116457

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://pr.sdiarticle5.com/review-history/170872

Original Research Article

Received: 18/09/2026
Accepted: 23/11/2026
Published: 27/11/2026

Abstract

A field experiment was conducted at the Norman E. Borlaug Crop Research Centre, Govind Ballabh Pant University of Agriculture and Technology, Pantnagar, Uttarakhand, to assess natural, organic and integrated nutrient management in direct-seeded rice (*Oryza sativa* L.). A randomised block design with six treatments and four replications was used to evaluate Pant Dhan-24. Treatments

[++] PhD Research Scholar; [#] Professor;
**Corresponding Email(s): anilsoil650@gmail.com;*

Contact Email(s): anilsoil650@gmail.com;

Cite as: *Kumar, A., Pant, A. K., Paul, J., Singh, V., Ram, S., & Panday, S. T. (2026). Effect of Natural, Organic and Integrated Nutrient Management Practices on Growth, Productivity and Physico-Chemical Properties of Direct-Seeded Rice (Oryza sativa L.). International Journal of Plant & Soil Science, 38(11), 627–637. https://doi.org/10.9734/ijpss/2026/v38i116457*

were T_1 absolute control, T_2 natural farming, T_3 AI-NPOF organic farming, T_4 INM with botanical pesticides, T_5 INM with chemical pesticides, and T_6 100% recommended dose of fertilisers (RDF). The recommended fertiliser treatment produced the highest plant height (113.4 cm), tiller density (404 m^{-2}), panicle density (400 m^{-2}), filled grains (120 $panicle^{-1}$), root biomass (8.0 g $plant^{-1}$), NDVI and SPAD readings. The highest grain yield (52.4 q ha^{-1}) was recorded under RDF, followed by INM with botanical pesticides (51.8 q ha^{-1}) and INM with chemical pesticides (50.4 q ha^{-1}), while the control yielded 21.8 q ha^{-1}. Grain, straw and biological yields responded significantly, whereas 1000-grain weight and harvest index did not. AI-NPOF recorded the highest soil organic carbon (0.87%) and lowest bulk density (1.32 Mg m^{-3}), although differences in physical properties and pH were non-significant. RDF recorded the highest available N (267.7 kg ha^{-1}), P (16.5 kg ha^{-1}) and K (183.7 kg ha^{-1}).
RDF maximised crop productivity, while organic-based management showed potential for improving soil organic carbon and soil health. INM treatments also maintained grain yields close to RDF, highlighting their potential as alternatives for productive rice cultivation under the *Tarai* conditions of Uttarakhand.

Keywords: Direct-seeded rice; natural farming; integrated nutrient management; soil fertility; sustainability; soil physicochemical properties.

1. Introduction

Rice (*Oryza sativa* L.) is a major food crop, particularly in South and Southeast Asia, and an important component of the Indo-Gangetic rice-wheat system. Intensification has increased reliance on fertilisers, pesticides, irrigation and labour-intensive establishment. Although these inputs have raised productivity, their excessive or imbalanced use can affect soil fertility, input-use efficiency and long-term sustainability (Bhatt *et al.*, 2023; Shah *et al.*, 2025). Direct-seeded rice (DSR) avoids nursery raising, puddling and transplanting, potentially reducing labour, water use and cultivation costs while enabling timely establishment and mechanisation (Bouman *et al.*, 2006; Kumar & Ladha, 2011). Sharma *et al*. (2021) also reported lower water use and shorter crop duration under direct seeding. However, DSR performance depends on effective nutrient, weed, water and crop-protection management. Balanced nitrogen, phosphorus and potassium supply supports vegetative growth, tillering, panicle development, grain filling and yield. Continued reliance on chemical fertilisers can contribute to nutrient imbalance and soil degradation when not managed judiciously (Bhatt *et al.*, 2023; Mishra *et al.*, 2024). Organic nutrient management uses materials such as farmyard manure (FYM), compost and vermicompost, which supply nutrients and add organic matter, potentially improving soil physical, chemical and biological properties. Organic inputs can improve water-holding capacity and nitrogen supply (Korsaeth *et al.*, 2002; Rajni *et al.*, 2025), while beneficial effects on soil microbial properties and grain production have also been reported (Sah *et al*., 2018). Field studies in Odisha have shown that site-specific fertiliser recommendations can improve grain yield in direct-seeded rice compared with farmers' fertiliser practices (Chaudhary *et al*., 2025). The response of rice growth indices to nutrient management has also been demonstrated in field experiments comparing direct seeding and transplanting (Jamsheed *et al.*, 2026).

Natural farming emphasises locally available resources and reduced dependence on purchased inputs. Common practices include Beejamrit, Jeevamrit, Ghanjeevamrit and crop-residue mulching, intended to support biological activity and nutrient cycling. Darjee *et al*. (2024) discussed its potential to reduce external-input costs, while Koner and Laha (2024) highlighted regional variation in organic farming performance. However, evidence on natural farming under DSR remains limited. Integrated nutrient management (INM) combines organic and inorganic sources: organic inputs supply nutrients gradually and add organic matter, while fertilisers provide nutrients more readily in line with crop demand. This combination may improve nutrient and moisture use and support root growth (Bandyopadhyay *et al*., 2010). Organic amendments may also reduce bulk density, increase porosity and support microbial populations (Kaje *et al.*, 2018; Mishra *et al.*, 2024; Rajni *et al.*, 2025). FYM and vermicompost have been associated with improved microbial activity and grain output (Sah *et al*., 2018), while organic matter can influence pH, EC and nutrient retention (Diacono & Montemurro, 2011). In direct-seeded rice, combining green manure with mineral nitrogen has been shown to maintain grain yield comparable to that obtained with the full recommended nitrogen dose under the conditions studied (Sahil *et al.*, 2026). In aerobic rice, integrated treatments incorporating farmyard manure, vermicompost and inorganic fertilisers, together with other nutrient inputs, have also been associated with favourable soil biological indicators and grain yield (Sangothari *et al*., 2025).

Despite research on organic and integrated nutrient management, comparative evidence for natural farming, AI-NPOF organic farming, INM and recommended fertiliser management in DSR under the Tarai agro-ecology of Uttarakhand remains limited. In particular, the relative performance of these management practices in terms of crop productivity and post-harvest soil properties requires evaluation under comparable field conditions. Such a comparison is important for determining whether nutrient management practices that maintain rice yield also support soil fertility under local conditions.

This study therefore evaluated the effects of these practices on rice growth, yield attributes, productivity and soil physico-chemical properties at Pantnagar.

2. Materials and Methods

The field experiment was conducted during the Kharif 2024-25 season at B-1, Norman E. Borlaug Crop Research Centre, Govind Ballabh Pant University of Agriculture and Technology, Pantnagar, Uttarakhand, India (29°N, 79°29′E; 243.84 m above mean sea level). The soil was a silty clay *Mollisol*. A randomised block design with six treatments and four replications was used. Pant Dhan-24 was grown under DSR and sown on 10 June 2024 at 40 kg seed ha^{-1} with 20 cm row spacing. Standard agronomic practices were followed according to the treatment schedule.

2.1 Treatment Details

Six nutrient-management treatments were evaluated (details are provided in the nutrient-source table below):

- **T_1 - Absolute Control:** No external nutrient source was applied; crop management was carried out without fertiliser application.
- **T_2 - Natural Farming:** Beejamrit seed treatment, Ghanjeevamrit and Jeevamrit, crop-residue mulching, and botanical preparations (Neemaster, Agniastra and Dashparni Ark) for pest management.
- **T_3 - AI-NPOF Organic Farming:** FYM, vermicompost and green manuring where applicable, with botanical/natural pest-management inputs.
- **T_4 - INM with Botanical Pesticides:** 50% of nutrients from FYM and vermicompost and 50% from inorganic fertilisers, with Neemaster, Agniastra and Dashparni Ark.
- **T_5 - INM with Chemical Pesticides:** the same 50:50 organic–inorganic nutrient supply as T4, with recommended chemical pesticides.
- **T_6 - 100% RDF:** 120:60:30 kg ha^{-1} N: P_2O_5: K_2O from inorganic fertilisers, with recommended crop-protection practices.

Chart 1. Details of nutrient sources used in the study

S. No.	Treatments	Kharif (Rice)
1.	Control	NIL
2.	Natural Farming	Basal Ghanjeevamrit (250 kg ha^{-1}), foliar application (15 DAI), Jeevamrit (500 L)
3.	Organic Farming	Basal FYM (10 t ha^{-1}), VC (2.5 t ha^{-1})
4.	INM + Botanical pesticides	**1.** 50% organic source of N: FYM (5 t ha^{-1}), VC (1.25 t ha^{-1}). **2.** 50 % inorganic source (NPK Mixture 12:32:16 93.75 Kg ha^{-1} and Urea 106 Kg ha^{-1})
5.	INM + Chemical pesticides	**1.** 50% organic source of N: FYM (5 t ha^{-1}), VC (1.25 t ha^{-1}). **2.** 50 % inorganic source (NPK Mixture 12:32:16 93.75 Kg ha^{-1} and Urea 106 Kg ha^{-1})
6.	RDF	100 % inorganic source (NPK Mixture 12:32:16 187.5 Kg ha^{-1} and Urea 212 Kg ha^{-1})

2.2 Growth Parameters, Yield Attributes and Yield

Growth parameters were recorded at harvest. Plant height was measured from ground level to the tip of five randomly selected, tagged plants per plot and expressed in centimetres, while tillers were counted within a representative 1 m^{-2} area per plot at each observation stage and expressed as tillers m^{-2}. At physiological maturity, yield attributes, including total panicles m^{-2}, filled grains $panicle^{-1}$, unfilled grains $panicle^{-1}$, 1000-grain weight and root biomass, were recorded. Total panicles were counted within a representative 1 m^2 area per plot and expressed as panicles m^{-2}. Ten representative panicles were sampled from each plot to determine the number of filled and unfilled grains, which were expressed as the average number of grains per panicle. The 1000-grain weight was determined by weighing 100 fully developed grains and multiplying the recorded weight by ten. Root biomass was measured by uprooting representative plants, washing and separating the roots, and oven-drying them at 65 ± 5°C to constant weight; the results were expressed as g $plant^{-1}$. At physiological maturity, the net plot was harvested manually, and the produce from each plot was dried, weighed and threshed separately. Grain yield was determined by weighing the grains obtained from each net plot and converting the values to q ha^{-1}. Straw yield was calculated by subtracting grain yield from biological yield and expressed as q ha^{-1}. The harvest index (%) was calculated as the ratio of grain yield to biological yield multiplied by 100.

2.3 Soil Analysis

Soil samples collected before sowing and after harvest were air-dried, ground, and passed through a 2-mm sieve before analysis. Bulk density, particle density, and porosity were determined following Baver (1956). Soil pH was measured using a glass-electrode pH meter, EC by conductometry, and organic carbon by the modified Walkley-Black method (Walkley & Black, 1934). Available nitrogen was determined by the alkaline $KMnO_4$ method (Subbiah & Asija, 1956), phosphorus by Olsen's method (Olsen et al., 1954), and potassium by neutral ammonium acetate extraction (Jackson, 1973). The initial soil of the experimental field had a bulk density of 1.34 Mg m^{-3}, particle density of 2.65 Mg m^{-3}, and porosity of 49.43%. Soil pH and EC were 7.37 and 0.28 dS m^{-1}, respectively, with an organic carbon content of 0.83%. Available N, P and K were 222.4, 11.1, and 164.4 kg ha^{-1}, respectively.

2.4 Statistical Analysis

All the recorded data were analysed by ANOVA for a randomised block design. Treatment means were compared using the critical difference (CD) at the 5 % probability level; standard errors of the mean (SEm±) were also calculated.

3. Results and Discussion

3.1 Growth Parameters

3.1.1 Plant Height and Number of Tillers

Nutrient management significantly affected plant height and tiller density (Table 1). At harvest, T_6 recorded the maximum height (113.4 cm) and tiller density (404 m^{-2}), followed by T_4 (110.8 cm; 395 m^{-2}); T_1 had the lowest values (94.6 cm; 335 m^{-2}). Readily

available nutrients, particularly N, likely supported cell division, leaf development and tillering under RDF. T_4 may have benefited from the combination of immediately available fertiliser nutrients and organic inputs. Similar rice growth and tillering responses to INM were reported by Durai Singh *et al.* (2021), while G. S. Yadav *et al*. (2013) found benefits from partial substitution of mineral N with organic sources. Jaipaul *et al.* (2014) also examined yield attributes and nutrient recycling under residue management in a rice–wheat sequence. Findings for wheat provide indirect support (A. Tiwari *et al.*, 2023).

3.2 Yield Attributes and Root Biomass

Yield attributes and root biomass differed among treatments (Table 1, Fig. 1). Panicle density ranged from 302 m^{-2} in T_1 to 400 m^{-2} in T_6, with 369 m^{-2} under T_4. Filled grains increased from 89 to 120 $panicle^{-1}$, while unfilled grains declined from 20 to 10 $panicle^{-1}$. Root biomass was highest under T_6 (8.0 g $plant^{-1}$), followed by T_4 (6.8), compared with 5.0 under T_1. Adequate nutrient availability during reproductive growth likely supported panicle formation, root development and grain filling; N supports canopy and assimilate production, while P and K contribute to root function, reproductive growth and assimilate transport. The complementary organic and inorganic nutrient supply under T_4 may also have supported crop development. Similar responses were reported by Durai Singh *et al.* (2021) and Sangothari *et al.* (2025).

Table 1. Effect of different nutrient management practices on the rice plant height, Number of tillers, yield attributes and root biomass

Treatments	Plant Height (cm)	Number of Tillers m^{-2}	Total Panicles m^{-2}	Filled grains $panicle^{-1}$	Unfilled grains $panicle^{-1}$	Root biomass (g $plant^{-1}$)
T_1 Absolute Control	94.6	335	302	89	20	5.0
T_2 (Natural Farming)	100.2	372	332	99	17	5.7
T_3 (AI-NPOF)	104.5	384	350	105	15	6.1
T_4 (INM + Neemaster + Agniastra + Dashparni Ark)	110.8	395	369	111	12	6.8
T_5 (INM + Chemical Pesticide)	107.6	390	361	109	12	6.6
T_6 (100% RDF)	113.4	404	400	120	10	8.0
SE(m)±	**3.31**	**13.64**	**15.35**	**4.60**	**0.62**	**0.28**
CD at 5%	**9.92**	**40.91**	**46.02**	**13.78**	**1.87**	**0.83**

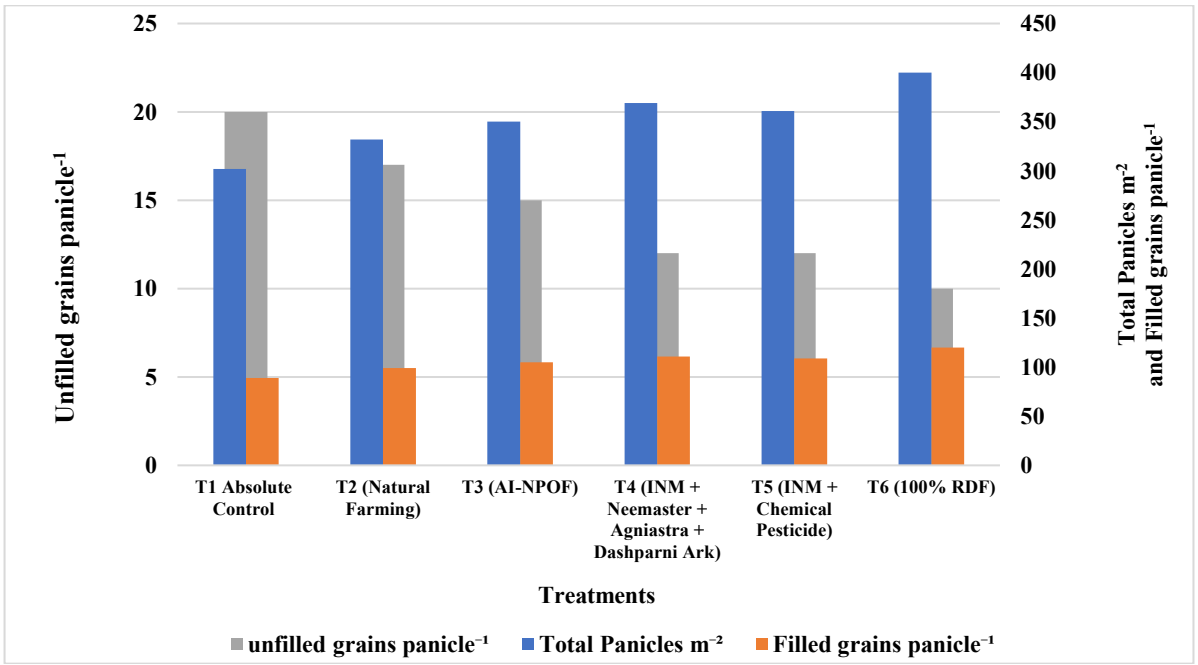


Fig. 1. Effect of different nutrient management practices on the unfilled grains^{-1} panicle, total panicles m^{-2} and filled grain panicles^{-1} of rice

3.3 NDVI and SPAD Values

NDVI and SPAD were affected by nutrient management (Table 2). Both increased from 30 to 60 DAS and declined slightly at 90 DAS. T_6 recorded the highest NDVI (0.68, 0.84 and 0.78) and SPAD (43.40, 49.40 and 46.60) at 30, 60 and 90 DAS, respectively; T_1 recorded the lowest values. Higher NDVI indicates greater canopy vigour, while SPAD generally reflects leaf chlorophyll and plant N status. The RDF response is consistent with readily available nutrients supporting chlorophyll synthesis and photosynthesis;

T_4's relatively high readings may reflect complementary organic and inorganic nutrient supply. Esfahani *et al.* (2008) identified SPAD as an indicator of rice N status, **Maiti *et al.* (2004)** reported higher SPAD with increasing N availability, and Didal *et al.* (2022) found that N management influenced SPAD and NDVI in rice.

Table 2. Effect of different nutrient management practices on the NDVI and SPAD values of rice at different stages

Treatments	NDVI Value			SPAD Value		
	30 days	60 days	90 days	30 days	60 days	90 days
T_1 Absolute Control	0.42	0.55	0.50	28.50	32.50	30.10
T_2 (Natural Farming)	0.55	0.72	0.68	34.70	40.70	38.50
T_3 (AI-NPOF)	0.61	0.76	0.72	37.68	43.40	41.70
T_4 (INM + Neemaster + Agniastra + Dashparni Ark)	0.65	0.81	0.76	41.70	47.40	44.40
T_5 (INM + Chemical Pesticide)	0.63	0.79	0.74	39.10	45.60	43.63
T_6 (100% RDF)	0.68	0.84	0.78	43.40	49.40	46.60
SE(m)±	**0.02**	**0.04**	**0.03**	**0.69**	**0.61**	**0.71**
CD at 5%	**0.07**	**0.11**	**0.09**	**2.08**	**1.84**	**2.14**

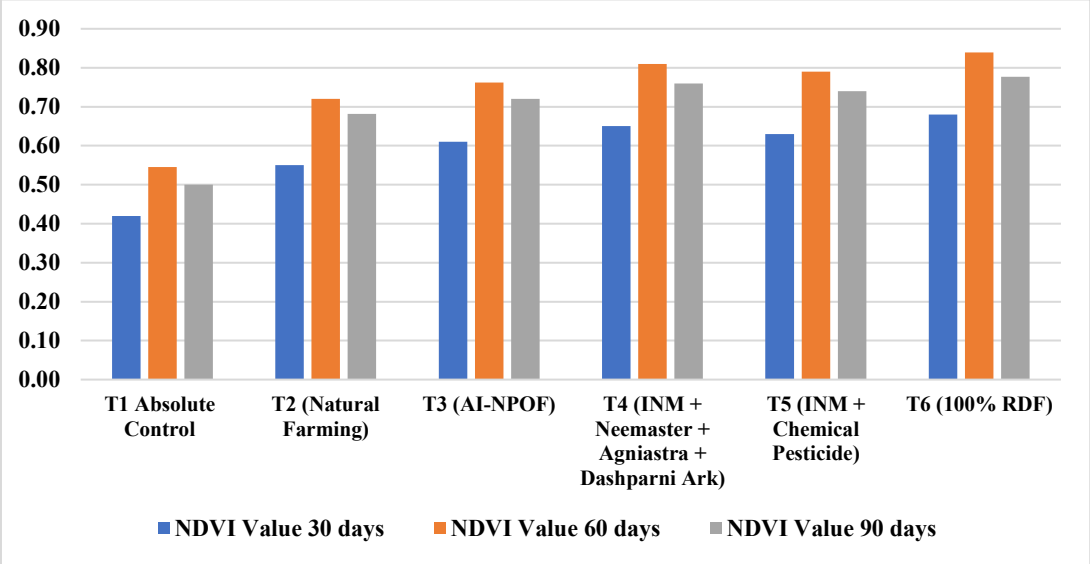


Fig. 2. Effect of different nutrient management practices on the NDVI and SPAD values of rice

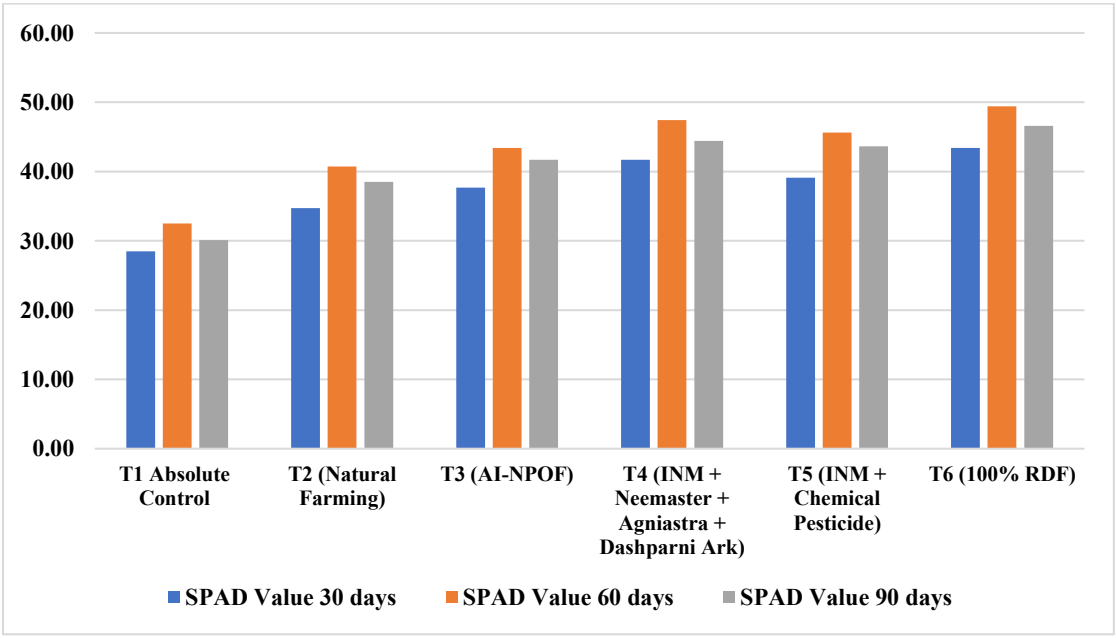


Fig. 3. Effect of different nutrient management practices on the SPAD values of rice

3.4 Yield

Grain, straw and biological yields were significantly affected by nutrient management, whereas 1000-grain weight and harvest index were not (Table 3, Fig. 4). Thousand-grain weight ranged from 26.4 g in T_1 to 27.8 g in T_6; harvest index ranged from 40.3% to 43.9%, with the highest numerical values under T_4 and T_5. Although the difference was non-significant, the higher grain weight under RDF may reflect adequate N and K supply during grain filling. The numerical harvest-index response under INM suggests greater partitioning to grain, but treatment differences were not significant.

Grain yield increased from 21.8 q ha^{-1} in T_1 to 52.4 q ha^{-1} in T_6, followed by T_4 (51.8) and T_5 (50.4 q ha^{-1}). T_6 also produced the highest straw (69.8 q ha^{-1}) and biological yield (122.2 q ha^{-1}), followed by T_4 (66.6 and 118.4 q ha^{-1}). Balanced, readily available N, P and K likely promoted productive tillers, panicle development and biomass accumulation under RDF. The near-RDF yields under T_4 and T_5 indicate that combining fertiliser nutrients with organic inputs can sustain productivity through complementary nutrient supply and cycling. Comparable rice productivity responses were reported by Sahil *et al.* (2026) and Sangothari *et al.* (2025). Evidence from wheat and soybean–maize intercropping also indicates productivity responses to integrated management (A. Tiwari *et al.*, 2023; H. Tiwari *et al.*, 2024).

Yields under T_2 and T_3 were lower than under T_4, T_5 and T_6, potentially because organic nutrient sources require decomposition and mineralisation, which may not synchronise fully with peak crop demand. Balanced nutrient supply and its effects on productivity have also been discussed by Prasad *et al.* (2026). Significant yield differences alongside non-significant 1000-grain weight and harvest index suggest that treatments affected total biomass and crop productivity more than individual grain mass or the proportion allocated to grain. Yield responses to balanced or integrated nutrient management in rice were reported by Chaudhary *et al.* (2025), Durai Singh *et al.* (2021) and Sahil *et al.* (2026). Long-term assessment of soil health, nutrient-use efficiency and costs remains necessary (Foley *et al.,* 2011).

Table 3. Effect of different nutrient management practices on the 1000-grain weight, grain straw yield, biological yield and harvest index of rice

Treatments	1000-grain wt. (g)	Grain yield (q ha^{-1})	Straw yield (q ha^{-1})	Biological Yield (q ha^{-1})	Harvest Index (%)
T_1 Absolute Control	26.4	21.8	32.2	54.0	40.3
T_2 (Natural Farming)	26.8	43.1	59.4	102.5	42.1
T_3 (AI-NPOF)	27.1	44.2	60.1	104.3	42.3
T_4 (INM + Neemaster + Agniastra + Dashparni Ark)	27.6	51.8	66.6	118.4	43.9
T_5 (INM + Chemical Pesticide)	27.3	50.4	64.4	114.8	43.9
T_6 (100% RDF)	27.8	52.4	69.8	122.2	42.9
SE(m)±	**1.31**	**1.89**	**2.84**	**3.03**	**1.75**
CD at 5%	**NS**	**5.68**	**8.53**	**9.09**	**NS**

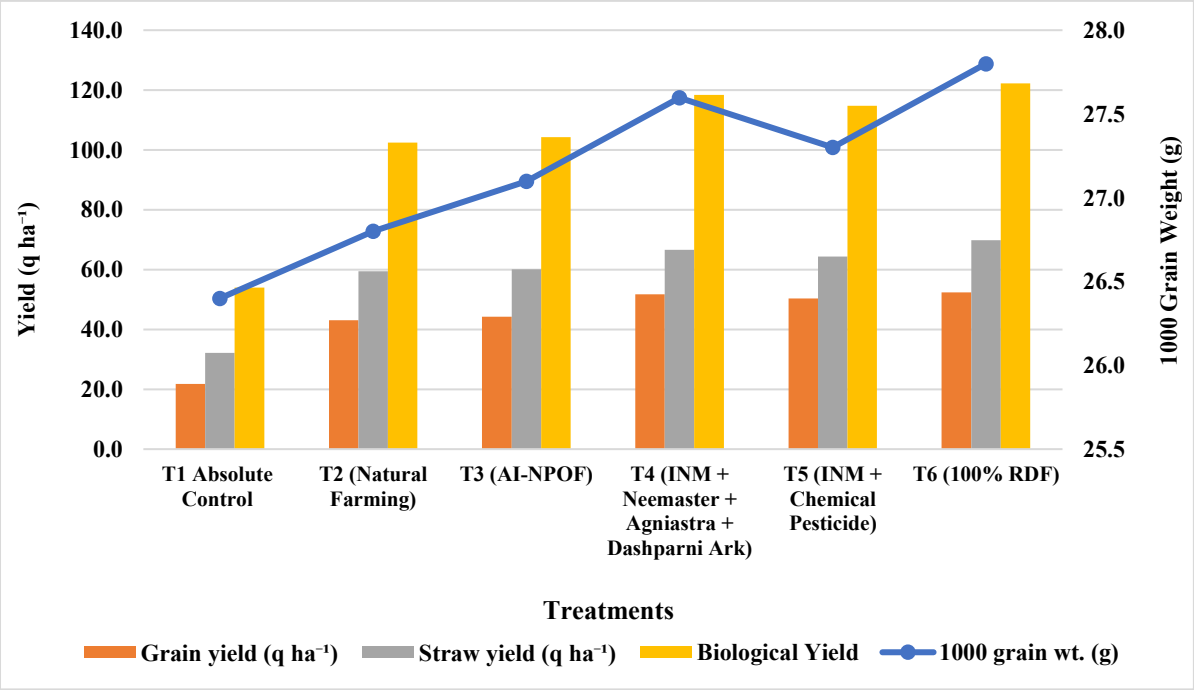


Fig. 4. Effect of different nutrient management practices on the 1000-grain weight, grain straw yield and biological yield of rice

3.5 Soil Physical Properties

Bulk density ranged from 1.32 to 1.35 Mg m^{-3}, with the minimum under T_3 and the maximum under T_1 and T_6. Particle density ranged from 2.63 to 2.66 Mg m^{-3}, while porosity ranged from 48.9 to 49.8% (Table 4, Fig. 5). Differences among treatments were non-significant. The numerically lower bulk density and greater porosity under T_2 and T_3 may reflect organic inputs promoting aggregation, structural stability and pore formation, alongside microbial activity and root growth. Similar effects of organic amendments were reported by Kaje *et al.* (2018) and Ramulu *et al.* (2024); FYM and other organic materials may also help maintain soil structure under rice–wheat cultivation (Bhatt *et al*., 2023; Rajni et al., 2025). The numerical changes were not sufficient to establish significant treatment effects during this study.

Table 4. Effect of different nutrient management practices on soil bulk density, particle density and porosity of rice

Treatments	BD (Mg m^{-3})	PD (Mg m^{-3})	Porosity (%)
T_1 Absolute Control	1.35	2.66	49.1
T_2 (Natural Farming)	1.33	2.64	49.2
T_3 (AI-NPOF)	1.32	2.63	49.8
T_4 (INM + Neemaster + Agniastra + Dashparni Ark)	1.34	2.64	49.3
T_5 (INM + Chemical Pesticide)	1.34	2.65	49.2
T_6 (100% RDF)	1.35	2.65	48.9
SE(m)±	**0.04**	**0.07**	**2.09**
CD at 5%	**NS**	**NS**	**NS**

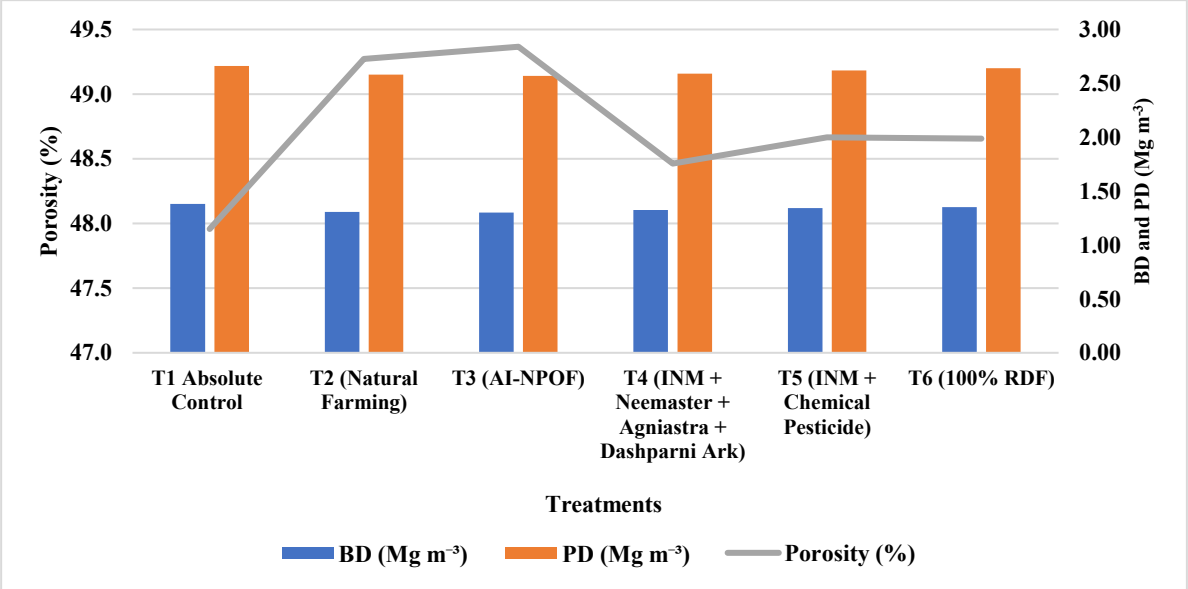


Fig. 5. Effect of different nutrient management practices on soil bulk density, particle density and porosity of rice during 2024

3.6 Soil Chemical Properties

3.6.1 Soil pH

Soil pH ranged from 7.23 under T_3 to 7.38 under T_1, but treatment differences were non-significant (Table 5, Fig. 6). Slightly lower pH under organic treatments may be related to organic-acid and CO_2 release during decomposition and H^+ release during ammonium nitrification. These processes can gradually moderate alkalinity and influence nutrient availability (Singh & Saini, 2022). Mishra *et al*. (2024) and Darjee *et al*. (2024) likewise reported relatively stable pH under different farming practices.

3.6.2 Soil Electrical Conductivity (EC)

Soil EC ranged from 0.275 dS m^{-1} under T_1 to 0.330 dS m^{-1} under T_6. The highest EC was recorded under T_6, which was significantly higher than all other treatments, while the lowest value was recorded under T_1. Higher EC under RDF may reflect fertiliser dissolution and increased soluble ions; however, values remained low across treatments, indicating no substantial salt accumulation during the study. Variation may also reflect nutrient release, crop uptake and ion movement. Limited changes in EC under different management systems were reported by Mishra *et al*. (2024) and Darjee *et al.* (2024).

3.6.3 Soil Organic Carbon (OC)

Soil organic carbon ranged from 0.79% under T_1 to 0.87% under T_3, followed by T_2 (0.86%). Treatment T_3 was statistically at par with T_2, T_4 and T_5, but significantly higher than T_1 and T_6. Similarly, T_2 was significantly higher than T_1, while T_4 was also significantly superior to T_1. Higher OC under organic treatments may reflect carbon supplied through amendments and crop residues, which support microbial transformation and organic matter formation. Some decomposition products become stabilised through association with minerals and soil aggregates; roots, exudates and decaying roots provide additional below-ground carbon. Lower OC under T_1 may reflect limited external carbon inputs and residue returns. Increased SOC under combined organic and inorganic management was reported by Majumder *et al*. (2008), while Mithlesh *et al*. (2019) reported improvements under organic-based farming. Carbon accumulation depends on amendment quality, decomposition, soil properties and management duration. Under INM, FYM inputs, microbial activity, crop growth and root biomass may increase carbon inputs, with part of the carbon stabilised in soil.

3.6.4 Available Nitrogen, Phosphorus and Potassium

Available N (Table 5, Fig. 5) ranged from 198.7 kg ha^{-1} under T_1 to 267.7 kg ha^{-1} under T_6, followed by T_4 (261.7 kg ha^{-1}) and T_5 (255.5 kg ha^{-1}). Treatment T_6 was statistically at par with T_4 and T_5, but significantly superior to T_3, T_2 and T_1. Treatment T_4 was also significantly higher than T_3, T_2 and T_1. RDF supplied readily available mineral N, whereas T_4 combined fertiliser N with gradual mineralisation of organic N. Organic inputs provide substrates for microbes that convert organically bound N into plant-available forms. The low value under T_1 may reflect the absence of external nutrients and removal through crop uptake and other loss pathways. Darjee *et al.* (2024) and Mithlesh *et al*. (2019) discussed the contribution of organic inputs and microbial mineralisation to N availability; Ramulu *et al*. (2024) similarly linked INM to combined nutrient supply and microbial conversion. Thus, RDF supported immediate N availability, while INM provided mineral and potentially mineralisable organic N.

Available P ranged from 10.3 kg ha^{-1} under T_1 to 16.5 kg ha^{-1} under T_6, followed by T_4 (15.8 kg ha^{-1}). Treatment T_6 was statistically at par with T_4 but significantly superior to T_5, T_3, T_2 and T_1. Treatment T_4 was significantly higher than all remaining treatments except T_6. The RDF result reflects direct supply of soluble fertiliser P. Under INM, organic matter decomposition, microbial mineralisation and organic acids may affect P sorption and mobilisation; phosphate-solubilising microorganisms may also convert less-available forms. Similar variation under different farming practices was reported by Mishra *et al*. (2024). Majumder *et al*. (2008) highlighted integrated amendments in rice-wheat systems, while Jaipaul *et al.* (2014) examined nutrient recycling and soil biological indicators. Fertiliser application provided the highest available P in this study, while organic inputs may contribute to biological P cycling.

Available K ranged from 160.6 kg ha^{-1} under T_1 to 183.7 kg ha^{-1} under T_6, followed by T_4 (178.6 kg ha^{-1}) and T_5 (176.4 kg ha^{-1}). Treatment T_6 was statistically at par with T_4, T_5 and T_3, but significantly superior to T_2 and T_1. Treatment T_4 was also significantly higher than T_1, while it remained statistically at par with T_2, T_3 and T_5. Higher K under RDF reflects fertiliser supply; INM combines inorganic K with contributions from organic materials. Decomposition of amendments and residues can release K, while organic matter may improve cation retention. Lower K under T_1 may reflect the absence of external inputs and crop removal. Mishra *et al*. (2024) reported variations in available K under different farming practices. Greater residue recycling may support K balance under organic management, whereas crop removal exceeding fertiliser replenishment can draw on non-exchangeable soil K (D. S. Yadav *et al*., 2009).

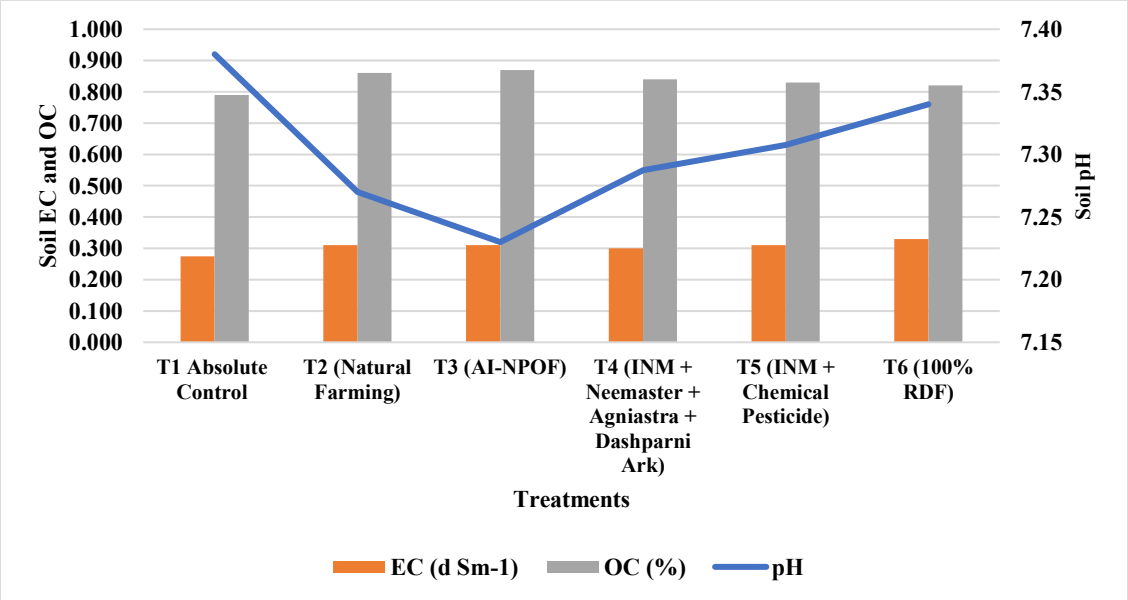


Fig. 6. Effect of different nutrient management practices on the soil pH, EC and OC cropped with rice

Table 5. Effect of different nutrient management practices on the soil chemical properties of rice during 2024

Treatments	pH	EC (d Sm^{-1})	OC (%)	N (kg h^{-1})	P (kg h^{-1})	K (kg h^{-1})
T_1 Absolute Control	7.38	0.275	0.79	198.7	10.3	160.6
T_2 (Natural Farming)	7.27	0.310	0.86	235.5	12.4	168.3
T_3 (AI-NPOF)	7.23	0.310	0.87	240.1	13.9	171.9
T_4 (INM + Neemaster + Agniastra + Dashparni Ark)	7.29	0.300	0.84	261.7	15.8	178.6
T_5 (INM + Chemical Pesticide)	7.31	0.310	0.83	255.5	14.7	176.4
T_6 (100% RDF)	7.34	0.330	0.82	267.7	16.5	183.7
SE(m)±	**0.17**	**0.006**	**0.016**	**7.08**	**0.34**	**4.19**
CD at 5%	**NS**	**0.019**	**0.048**	**21.22**	**1.01**	**12.57**

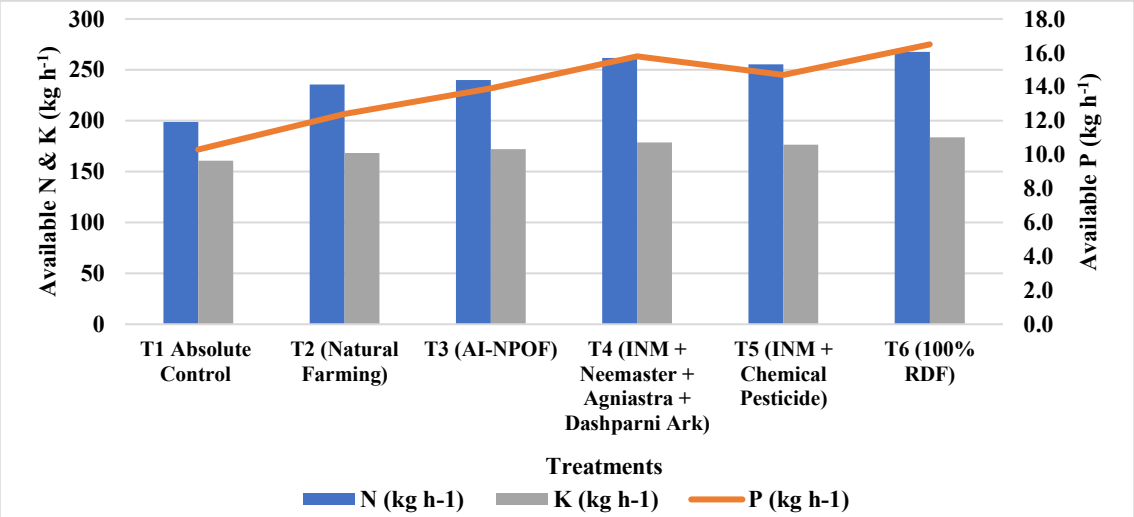


Fig. 7. Effect of different nutrient management practices on the soil available NPK of rice

4. Conclusion

Nutrient-management practices influenced growth, physiological traits, yield and soil fertility of direct-seeded rice. RDF produced the highest grain (52.4 q ha^{-1}), straw (69.8 q ha^{-1}) and biological yield (122.2 q ha^{-1}), along with superior growth and yield attributes. INM with botanical pesticides gave a comparable grain yield (51.8 q ha^{-1}), demonstrating the potential of combining organic and inorganic nutrient sources.

AI-NPOF recorded the highest soil organic carbon (0.87%) and lowest bulk density (1.32 Mg m^{-3}), although differences in bulk density, particle density, porosity and pH were non-significant. The recommended dose of fertiliser maintained the highest available N, P and K, while organic treatments had higher organic carbon contents, highlighting a balance between immediate crop productivity and selected soil-property improvements.

INM may combine high rice productivity with organic-resource use. Longer-term experiments are needed to assess sustainability, soil health, nutrient-use efficiency and production economics under the *Tarai* conditions of Uttarakhand.

5. Limitations

The study was conducted during a single cropping season at a specific location using one rice variety. Consequently, the findings primarily represent short-term crop and soil responses under the prevailing agroecological conditions of Pantnagar. Long-term, multi-location investigations across different soil types and rice varieties would provide a more comprehensive understanding of the cumulative effects of nutrient management practices on crop productivity, soil fertility and the sustainability of direct-seeded rice cultivation.

Acknowledgement

The authors are grateful for the facilities provided by the Department of Soil Science and the College of Agriculture, GBPUAT, Pantnagar, Uttarakhand.

Declaration of AI Use

This manuscript was prepared through the intellectual contributions of the author(s) to the study design, data analysis, interpretation of results, and scholarly content. ChatGPT, Claude and Perplexity were used solely to assist with grammatical refinement and reference formatting during manuscript revision. The author(s) accept full responsibility for the accuracy, integrity, and final content of the manuscript.

Competing Interests

Authors have declared that no competing interests exist.

References

Bandyopadhyay, K. K., Misra, A. K., Ghosh, P. K., & Hati, K. M. (2010). Effect of integrated use of farmyard manure and chemical fertilizers on soil physical properties and productivity of soybean. *Soil and Tillage Research*, *110*(1), 115-125. https://doi.org/10.1016/j.still.2010.07.007

Baver, L. D. (1956). *Soil physics* (3rd ed.). John Wiley & Sons. https://trid.trb.org/View/125290

Bhatt, M. K., Singh, D. K., Raverkar, K. P., Chandra, R., Pareek, N., Dey, P., Pramanick, B., Joshi, H. C., Kumar, M., Gaber, A., Alsuhaibani, A. M., & Hossain, A. (2023). Effects of varied nutrient regimes on soil health and long-term productivity in a rice-wheat system: Insights from a 29-year study in the *Mollisols* of the Himalayan Tarai region. *Frontiers in Sustainable Food Systems*, *7*, Article 1206878. https://doi.org/10.3389/fsufs.2023.1206878

Bouman, B. A. M., Yang, X., Wang, H., Wang, Z., Zhao, J., & Chen, B. (2006). Performance of aerobic rice varieties under irrigated conditions in North China. *Field Crops Research*, *97*(1), 53-65. https://doi.org/10.1016/j.fcr.2005.08.015

Chaudhary, A., Mishra, A. K., Venkatramanan, V., & Sharma, S. (2025). Enhancing yield and GHG mitigation through site-specific nutrient management for transplanted and direct-seeded rice in Odisha, India. *Frontiers in Sustainable Food Systems, 9*, Article 1571263. https://doi.org/10.3389/fsufs.2025.1571263

Darjee, S., Singh, R., Dhar, S., Pandey, R., Dwivedi, N., Sahu, P. K., Rai, M. K., Alekhya, G., Padhan, S. R., Ramalingappa, P. L., & Shrivastava, M. (2024). Empirical observation of natural farming inputs on nitrogen uptake, soil health, and crop yield of rice–wheat cropping system in the organically managed *Inceptisol* of the Trans-Gangetic Plain. *Frontiers in Sustainable Food Systems*, *8*, Article 1324798. https://doi.org/10.3389/fsufs.2024.1324798

Diacono, M., & Montemurro, F. (2011). Long-term effects of organic amendments on soil fertility. In E. Lichtfouse, M. Hamelin, M. Navarrete, & P. Debaeke (Eds.), *Sustainable Agriculture* (Vol. 2, pp. 761–786). Springer. https://doi.org/10.1007/978-94-007-0394-0_34

Didal, V. K., Vidyasagar, G. E. C., Kumar, R. M., Surekha, K., Reddy, S. N., & Brijbhooshan. (2022). Effect of nitrogen management practices on SPAD values and NDVI readings of rice crop. *The Pharma Innovation Journal*, *11*(2), 367-371. https://www.thepharmajournal.com/archives/2022/vol11issue2/PartF/11-1-399-395.pdf

Durai Singh, R., Hussainy, S. A. H., Paulpandi, V. K., Nandhini, R., Lavanya, A., & Prema, M. (2021). Effect of integrated nutrient management on the growth, phyllochron, tillering and yield of rice (Oryza sativa). *Crop Research*, *56*(6), 281–286. https://doi.org/10.31830/2454-1761.2021.045

Esfahani, M., Abbasi, H. R. A., Rabiei, B., & Kavousi, M. (2008). Improvement of nitrogen management in rice paddy fields using chlorophyll meter (SPAD). *Paddy and Water Environment*, *6*(2), 181–188. https://doi.org/10.1007/s10333-007-0094-6

Foley, J. A., Ramankutty, N., Brauman, K. A., Cassidy, E. S., Gerber, J. S., Johnston, M., Mueller, N. D., O'Connell, C., Ray, D. K., West, P. C., Balzer, C., Bennett, E. M., Carpenter, S. R., Hill, J., Monfreda, C., Polasky, S., Rockström, J., Sheehan, J., Siebert, S., & Zaks, D. P. M. (2011). Solutions for a cultivated planet. *Nature*, *478*, 337-342. https://doi.org/10.1038/nature10452

Jackson, M. L. (1973). *Soil chemical analysis*. Prentice Hall of India. https://spices.res.in/opac/cgi-bin/koha/opac-detail.pl?biblionumber=179

Jaipaul, Dixit, A. K., Sharma, A. K., & Kumar, V. (2014). Nutrient recycling and its relationship with biofertility indicators of soil health and nutrient uptake in a rice (Oryza sativa L.)-wheat (Triticum aestivum L. emend. Fiori & Paol) cropping sequence. *Agroecology and Sustainable Food Systems*, *38*(4), 445-459. https://doi.org/10.1080/21683565.2013.870628

Jamsheed, B., Saxena, A., Bhat, T. A., Nazeer, A., Nazir, A., Sharma, A., Wani, F. J., Dar, K. A., Parray, U. Y., Saad, A. A., Khan, I. M., Mir, A. H., Kubrevi, S. S., & Meena, S. R. (2026). Effect of precision nutrient management on growth indices of rice under different establishment methods. *Journal of Biology and Nature, 18*(2), 241–256. https://doi.org/10.56557/joban/2026/v18i210854

Kaje, V. V., Sharma, D. K., Shivay, Y. S., Jat, S. L., Bhatia, A., Purakayastha, T. J., Bandyopadhyay, K. K., & Bhattacharyya, R. (2018). Long-term impact of organic and conventional farming on soil physical properties under rice (Oryza sativa)-wheat (*Triticum aestivum*) cropping system in north-western Indo-Gangetic plains. *The Indian Journal of Agricultural Sciences*, *88*(1), 107-113. https://doi.org/10.56093/ijas.v88i1.79635

Koner, N., & Laha, A. (2024). Measuring the progress of organic farming in Indian states: Are there any agro-climatic implications? *Tekirdağ Ziraat Fakültesi Dergisi*, *21*(1), 64-80. https://doi.org/10.33462/jotaf.1233377

Korsaeth, A., Henriksen, T. M., & Bakken, L. R. (2002). Temporal changes in mineralization and immobilization of N during degradation of plant material: Implications for the plant N supply and nitrogen losses. *Soil Biology and Biochemistry*, *34*(6), 789-799. https://doi.org/10.1016/S0038-0717(02)00008-1

Kumar, V., & Ladha, J. K. (2011). Direct seeding of rice: Recent developments and future research needs. *Advances in Agronomy, 111*, 297–413. https://doi.org/10.1016/B978-0-12-387689-8.00001-1

Maiti, D., Das, D. K., Karak, T., & Banerjee, M. (2004). Management of nitrogen through the use of leaf color chart (LCC) and soil plant analysis development (SPAD) or chlorophyll meter in rice under irrigated ecosystem. *The Scientific World Journal*, *4*, 838-846. https://doi.org/10.1100/tsw.2004.137

Majumder, B., Mandal, B., Bandyopadhyay, P. K., Gangopadhyay, A., Mani, P. K., Kundu, A. L., & Mazumdar, D. (2008). Organic amendments influence soil organic carbon pools and rice–wheat productivity. *Soil Science Society of America Journal*, *72*(3), 775-785. https://doi.org/10.2136/sssaj2006.0378

Mishra, A. K., Maurya, P. K., & Sharma, S. (2024). Impact of different farming scenarios on key soil sustainability indicators driving soil carbon and system productivity of rice-based cropping systems. *Frontiers in Plant Science*, *15*, Article 1408515. https://doi.org/10.3389/fpls.2024.1408515

Mithlesh, Singh, S., Singh, L., & Kaur, S. (2019). Effects of long-term organic and conventional farming on physical and chemical properties of soil. *Journal of Krishi Vigyan*, *7*(2), 104-109. https://doi.org/10.5958/2349-4433.2019.00018.7

Olsen, S. R., Cole, C. V., Watanabe, F. S., & Dean, L. A. (1954). *Estimation of available phosphorus in soils by extraction with sodium bicarbonate*. U.S. Department of Agriculture, Circular 939. https://agris.fao.org/search/en/providers/122535/records/65dded244c5aef494fd7641c

Prasad, S., Choudhary, S. K., Kumar, R., Singh, M. K., Singh, P., Seema, & Sahu, J. (2026). Performance of rice-wheat cropping system under different methods of farming system in irrigated condition of Bihar, India. *Journal of Experimental Agriculture International*, *48*(9), 585-591. https://doi.org/10.9734/jeai/2026/v48i94492

Rajni, Gupta, N., Sharma, S., & Saini, K. S. (2025). Integrated effect of organic amendments and inorganic fertilizers on crop productivity and drivers of soil quality under rice–wheat cropping system in the Indo-Gangetic plains of India. *Discover Soil*, *2*, Article 126. https://doi.org/10.1007/s44378-025-00156-y

Ramulu, Ch., Shravan Kumar, R., Padmaja, G., & Uma Reddy, R. (2024). Effect of different nutrient management practices on Kharif rice yield, nutrient uptake and soil properties in Telangana. *Asian Journal of Soil Science and Plant Nutrition*, *10*(4), 62-70. https://doi.org/10.9734/ajsspn/2024/v10i4382

Sah, A. K., Singh, M., Pradhan, A. K., Prasad, S., Chatoopadhyaya, N., Behera, S. K., & Kiran, K. (2018). Effect of organic fertilizer and microbial inoculants on soil biological properties and yield of scented rice (Oryza sativa L.). *Journal of Applied and Natural Science*, *10*(3), 995-1002. https://doi.org/10.31018/jans.v10i3.1831

Sahil, Garhwal, R. S., Goyal, V., Kamboj, A., Shallni, & Kumar, S. (2026). Nutrient dynamics in direct-seeded rice: Balancing crop productivity and economic viability via integrated nutrient management. *Asian Journal of Soil Science and Plant Nutrition, 12*(1), 357–370. https://doi.org/10.9734/ajsspn/2026/v12i1665

Sangothari, A., Radhamani, S., & Gnanachitra, M. (2025). Effect of combined use of organic and inorganic sources of nutrients on soil biological indicators and yield in aerobic rice (*Oryza sativa*). *The Indian Journal of Agricultural Sciences, 95*(10), 1169–1175. https://doi.org/10.56093/ijas.v95i10.138400

Shah, S. S., van Dam, J., Singh, A., Kumar, S., Kumar, S., Bundela, D. S., & Ritsema, C. (2025). Impact of irrigation, fertilizer, and pesticide management practices on groundwater and soil health in the rice–wheat cropping system: A comparison of conventional, resource conservation technologies and conservation agriculture. *Environmental Science and Pollution Research*, *32*(2), 533-558. https://doi.org/10.1007/s11356-024-35661-0

Sharma, A., Sharma, S., Yadav, P. K., & Sodari, B. (2021). Direct seeded rice and its prospects in Nepal: A review. *Turkish Journal of Agriculture - Food Science and Technology*, *9*(12), 2355–2364. https://doi.org/10.24925/turjaf.v9i12.2355-2364.4383

Singh, P., & Saini, S. P. (2022). Micronutrients availability in soil–plant system as influenced by long-term integrated nutrient management under rice-wheat cropping. *Journal of Plant Nutrition*, *45*(3), 457-470. https://doi.org/10.1080/01904167.2021.1943680

Subbiah, B. V., & Asija, G. L. (1956). A rapid procedure for the estimation of available nitrogen in soils. *Current Science*, *25*(1), 259-260. https://eurekamag.com/research/013/939/013939242.php

Tiwari, A., Kumar, A., Pathak, R. K., Kumar, R., Sachan, R., Suryabhan, & Verma, H. (2023). Growth characteristics, yield components and yield of wheat (Triticum aestivum L.) as affected by integrated nutrient management under Central Plain Zone of Uttar Pradesh. *International Journal of Plant & Soil Science*, *35*(18), 2015-2022. https://doi.org/10.9734/ijpss/2023/v35i183557

Tiwari, H., Bhambri, M. C., & Kumar, S. (2024). Effect of natural farming, organic farming, and integrated crop management practices on yield attributes and productivity of soybean + maize intercropping system under unbunded *Vertisol* of Chhattisgarh plains. *International Journal of Research in Agronomy*, 7(Suppl. 7), 493-500. https://doi.org/10.33545/2618060X.2024.v7.i7Sg.1123

Walkley, A., & Black, I. A. (1934). An examination of Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. Soil Science, 37(1), 29–38. https://doi.org/10.1097/00010694-193401000-00003

Yadav, D. S., Kumar, V., & Yadav, V. (2009). Effect of organic farming on productivity, soil health and economics of rice (Oryza sativa)-wheat (Triticum aestivum) system. *Indian Journal of Agronomy*, *54*(3), 267-271. https://doi.org/10.59797/ija.v54i3.4801

Yadav, G. S., Datta, M., Babu, S., Debnath, C., & Sarkar, P. K. (2013). Growth and productivity of lowland rice (*Oryza sativa*) as influenced by substitution of nitrogen fertilizer by organic sources. *The Indian Journal of Agricultural Sciences*, 83(10), 1038–1042. https://doi.org/10.56093/ijas.v83i10.33663

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of the publisher and/or the editor(s). This publisher and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.

© Copyright (2026): Author(s). The licensee is the journal publisher. This is an Open Access article distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/4.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Peer-review history:

The peer review history for this paper can be accessed here: https://pr.sdiarticle5.com/review-history/170872