RESEARCH PAPER

Integrated Nutrient Management Influences Soil Fertility and Nutrient Uptake in a Maize (*Zea mays* L.) – Wheat (*Triticum aestivum L.*) Cropping System

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Received: 2nd Mar, 2026 | **Revised:** 14th Mar, 2026 | **Accepted:** 4th Apr, 2026 | **Available Online:** 20th Apr, 2026

ABSTRACT

Maize–wheat cropping systems are important for sustaining agricultural productivity in northern India; however, continuous reliance on chemical fertilizers may adversely affect soil fertility and long-term sustainability. A field experiment was conducted during 2023–24 and 2024-25 at the Agronomical Research Farm of IFTM University, Moradabad, India, to evaluate the influence of integrated nutrient management (INM) on soil fertility, nutrient uptake, and productivity of a maize (*Zea mays* L.)–wheat (*Triticum aestivum* L.) cropping system. The experiment consisted of twelve nutrient management treatments involving different combinations of recommended doses of fertilizers (RDF) and organic nutrient sources, including farmyard manure, vermicompost, biogas slurry, and panchgavya, arranged in a randomized block design with three replications. Application of 125% RDF significantly enhanced growth attributes and produced the highest grain yield of maize (6.35 t ha^{-1}). This treatment also exerted a strong residual effect on the succeeding wheat, resulting in the maximum grain yield (5.14 t ha^{-1}). Post-harvest soil analysis after wheat indicated higher soil organic carbon and greater availability of nitrogen, phosphorus, and potassium under 125% RDF. Combined application of mineral fertilizers and organic nutrient sources markedly enhanced nutrient uptake in both crops compared with sole fertilizer application and the unfertilized control. Although the highest fertilizer dose resulted in maximum productivity and nutrient uptake, integrating reduced levels of chemical fertilizers with organic sources produced comparable improvements in soil fertility. These findings suggest that integrated nutrient management can reduce dependence on chemical fertilizers while sustaining productivity of maize–wheat systems.

Keywords: maize–wheat cropping system, nutrient uptake, organic amendments, soil fertility, soil organic carbon.
How to cite this article: Singh VK, Singh V, Singh MP, Singh M. Integrated nutrient management influences soil fertility and nutrient uptake in a maize (*Zea mays* L.) – wheat (*Triticum aestivum* L.) cropping system. Int J Drug Deliv Technol. 2026;16(32s):1044-1051. DOI: 10.25258/ijddt.16.32s.114
Source of support: Nil.
Conflict of interest: The authors declare no conflict of interest.

INTRODUCTION

Cereal-based intensive cropping systems supported by chemical fertilizers have played a crucial role in ensuring food security in India. However, prolonged and exclusive reliance on inorganic fertilizers has resulted in the deterioration of soil fertility, nutrient imbalance, depletion of soil organic carbon, and reduced nutrient use efficiency (Bayu 2020; Ladha *et al.* 2022). In contrast, the sole application of organic nutrient sources is generally insufficient to meet the nutrient requirements of high-yielding crop varieties. Consequently, the integrated use of inorganic fertilizers with organic and biological sources has been widely advocated as a sustainable nutrient management strategy to enhance crop productivity while maintaining soil health (Das *et al.* 2022).

Integrated Nutrient Management (INM) involves the combined use of chemical fertilizers and organic nutrient sources to improve soil fertility, nutrient availability, and crop productivity (Paramesh *et al.* 2023). Organic inputs play a vital role in improving soil structure, enhancing microbial activity, and regulating soil enzymatic processes, thereby improving nutrient cycling and availability (Nath *et al.* 2017; Daunoras *et al.* 2024). Conversely, imbalanced and excessive use of high- analysis fertilizers under intensive cropping systems has accelerated the depletion of secondary and micronutrients in Indian soils, adversely affecting long-term soil fertility and crop productivity (Paramesh *et al.* 2023).

The maize–wheat cropping system is one of the most important cereal-based systems in India, particularly under irrigated conditions of the Indo-Gangetic plains and north-western regions. Covering approximately 1.80 million hectares, this system ranks as the third major crop rotation in the country and contributes about 3.0% to the national food grain basket (Jat *et al.* 2020). Maize and wheat are nutritionally significant crops, providing substantial proportions of dietary energy, protein, vitamins, and minerals. However, continuous cultivation of maize–wheat systems leads to substantial nutrient removal from the soil, making balanced nutrient management essential for maintaining soil fertility and sustaining crop productivity (Usadadiya and Patel 2013; Hazra *et al.* 2019).

Recent emphasis on resource-conserving agricultural practices has highlighted INM as a key approach for sustaining productivity and improving soil health (Kumar *et al.* 2025; Topa *et al.* 2025). Several studies have demonstrated that INM enhances crop yield, nutrient uptake, and soil nutrient status by reducing nutrient losses and synchronizing nutrient supply with crop demand (Graham *et al.* 2017; Dhaliwal *et al.* 2021; Paramesh *et al.* 2023; Jat *et al.* 2025). Nevertheless, detailed information on the influence of integrated nutrient management practices on soil fertility changes, nutrient uptake, and residual effects on the succeeding wheat crop in maize–wheat cropping systems, particularly in the western Uttar Pradesh region, remains limited.

Despite considerable research on integrated nutrient management in cereal-based cropping systems, the comparative performance of different combinations of inorganic fertilizers and organic nutrient sources on soil fertility and nutrient uptake in maize–wheat systems under subtropical conditions remains insufficiently documented. In particular, information on the residual effects of integrated nutrient management practices on the succeeding wheat crop and associated changes in soil nutrient status in western Uttar Pradesh is limited. Therefore, systematic evaluation of integrated nutrient management strategies is essential for identifying sustainable approaches that can maintain soil fertility and enhance nutrient use efficiency in maize–wheat cropping systems. Improving nutrient use efficiency through integrated nutrient management is therefore crucial for sustaining productivity and soil fertility in maize–wheat cropping systems.

Therefore, the present study was undertaken to evaluate the effects of different integrated nutrient management practices on soil fertility, nutrient availability, and uptake of nitrogen, phosphorus, and potassium in maize and the succeeding wheat crop, with the aim of identifying sustainable and efficient nutrient management strategies for the maize–wheat cropping system.

MATERIALS AND METHODS

Experimental site and soil

The field experiment was conducted during the *Kharif* and *Rabi* seasons of 2023–24 and 2024-25 at the Agronomical Research Farm, School of Agricultural Sciences and Engineering, IFTM University, Moradabad, Uttar Pradesh, India (28°21′–28°16′ N latitude and 78°4′–79°0′ E longitude; 193 m above mean sea level). The soil of the experimental field was slightly alkaline in reaction (pH 7.8) with sandy loam texture, low in available nitrogen, and medium in available phosphorus and potassium.

Experimental design and treatments

The experiment was laid out in a randomized block design with twelve treatments and three replications. The treatments consisted of different combinations of inorganic fertilizers and organic nutrient sources applied under integrated nutrient management: T_1, control; T_2, 100% RDF; T_3, 125% RDF; T_4, 75% RDF + 25% N through farmyard manure (FYM); T_5, 75% RDF + 25% N through vermicompost; T_6, 75% RDF + 25% N through biogas slurry; T_7, 75% RDF + 25% N through panchgavya; T_8, 50% RDF + 50% N through FYM; T_9, 50% RDF + 50% N through vermicompost; T_{10}, 50% RDF + 50% N through biogas slurry; T_{11}, 50% RDF + 50% N through panchgavya; and T_{12}, 50% RDF + equal proportions of FYM, vermicompost, biogas slurry, and panchgavya.

The recommended fertilizer dose for maize was 120:60:40 kg N: P_2O_5: K_2O ha^{-1}. Organic manures were incorporated 20–25 days before sowing based on their nitrogen content.

Crop management and sampling

Two-year field experimentation was conducted during the *Kharif* and *Rabi* seasons of 2023–24 and 2024–25**.** In each year, maize hybrid *DKC 9144* was grown during *Kharif*, followed by wheat variety *DBW 187* during the subsequent *Rabi* season. Standard agronomic practices recommended for the region were followed for crop management.

Composite soil samples (0–15 cm depth) were collected before sowing and after harvest of wheat crop in each experimental year and analyzed for soil pH (Jackson 1967), electrical conductivity, organic carbon (Walkley and Black 1934) and available N (Subbiah and Asija 1956), P (Olsen *et al.* 1954), and K (Jackson 1973) using standard analytical procedures. Plant samples were collected at harvest, analyzed for nutrient concentration, and nutrient uptake was calculated based on dry matter yield and nutrient content.

Statistical analysis

The data were subjected to analysis of variance (ANOVA) appropriate for randomized block design (RBD) using the OPSTAT statistical software package. Treatment means were compared using the least significant difference (LSD) test at $P \leq 0.05$**.**

RESULTS AND DISCUSSION

Soil properties and nutrient availability

Integrated nutrient management (INM) practices significantly influenced soil organic carbon (SOC) and available macronutrient status after completion of the maize–wheat cropping cycle. The treatment receiving 125%

recommended dose of fertilizers (RDF) recorded the highest SOC (0.55%) along with maximum available nitrogen, phosphorus, and potassium, followed by the treatment receiving 75% RDF combined with vermicompost (Table 1). In contrast, the control treatment maintained the lowest soil fertility status, indicating progressive nutrient depletion under continuous cereal cultivation without adequate nutrient replenishment.

The improvement in SOC and nutrient availability under integrated treatments may be attributed to the combined effect of mineral fertilizer supply and decomposition of organic amendments, which enhanced microbial biomass, enzymatic activity, and nutrient mineralization processes. Recent studies have similarly reported that combined application of organic manures and fertilizerssignificantly increases SOC and available NPK compared with sole fertilizer application in cereal-based systems (Padbhushan *et al.* 2021; Paramesh *et al.* 2023; Qin *et al.* 2026). Organic amendments also improve cation exchange capacity and reduce nutrient losses through leaching and volatilization, thereby sustaining long-term soil fertility (Jat *et al.* 2020).

Soil pH and electrical conductivity did not differ significantly among treatments and remained within the neutral to slightly alkaline range. Similar observations were reported in maize–wheat and rice–wheat systems where balanced fertilization with organic inputs buffered soil reaction and prevented salinity build-up (Sheoran *et al.* 2025; Lal 2025; Kumar *et al.* 2026).

Nutrient uptake by maize

Nitrogen, phosphorus, and potassium uptake by maize grain and stover increased significantly under INM treatments compared with the control. The highest total nutrient uptake was recorded with 125% RDF, which corresponded with maximum biomass accumulation and grain yield (Table 2). Among integrated treatments, 75% RDF combined with vermicompost produced nutrient uptake statistically comparable to 125% RDF, indicating improved nutrient use efficiency through synchronized nutrient release.

Enhanced nutrient uptake under INM can be explained by improved root growth, higher microbial activity, and gradual nutrient mineralization from organic sources, which together ensured continuous nutrient availability throughout crop growth. Vermicompost-based integration particularly enhanced nutrient uptake due to its rich nutrient content, humic substances, and beneficial microorganisms that stimulate plant metabolism and nutrient absorption (Qin *et al.* 2026). Similar increases in maize nutrient uptake under integrated fertilization have been documented in recent field studies across the Indo- Gangetic plains (Dhaliwal *et al.* 2021; Jat *et al.* 2025).

Table-1 Effect of Integrated Nutrient Management Practices on soil properties and available nutrients (kg ha^{-1})

Treatments	Organic carbon (%)	EC(dS m^{-1})	Soil pH	Available nutrients(kgha^{-1})		
				Nitrogen	Phosphorus	Potassium
T_1	0.41	0.21	7.80	204.5	11.9	173.8
T_2	0.54	0.25	7.36	240.3	15.9	190.2
T_3	0.55	0.25	7.34	242.7	16.1	191.5
T_4	0.52	0.24	7.40	231.1	14.7	186.5
T_5	0.54	0.25	7.38	236.2	15.5	189.8
T_6	0.51	0.24	7.45	228.5	14.2	185.1
T_7	0.49	0.23	7.50	226.2	13.9	183.6
T_8	0.42	0.21	7.76	216.1	12.8	175.3
T_9	0.45	0.23	7.65	221.1	13.3	180.2
T_{10}	0.44	0.22	7.66	219.5	13.1	178.2
T_{11}	0.46	0.23	7.56	224.3	13.7	181.5
T_{12}	0.43	0.22	7.68	217.5	13.0	177.3
SEm±	0.02	0.01	0.27	*1.35*	*0.15*	*1.42*
CD(p=0.05)	0.05	NS	NS	*3.93*	*0.44*	*4.17*

T_1-Control, T_2-100% RDF (120:60:40), T_3-125% RDF, T_4-75% RDF+25% through FYM, T_5-75% RDF+25% through Vermicompost,T_6-75% RDF + 25% through Biogas slurry, T_7-75% RDF + 25% through Panchgavya, T_8-50% RDF+50% through FYM, T_9-50% RDF+50% through Vermicompost, T_{10}-50% RDF + 50% through Biogas slurry, T_{11}-50% RDF + 50% through Panchgavya, T_{12}- 50% RDF+12.5% through FYM + 12.5% through Vermicompost + 12.5% through Biogas slurry+12.5% through Panchgavya

Table–2 Effect of Integrated Nutrient Management Practices on Nitrogen, Phosphorus and Potassium status in Maize crops

Treatments	**Nitrogen**					**Phosphorus**					**Potassium**				
	Content (%)		**Uptake (kg ha^{-1})**			**Content (%)**		**Uptake (kg ha^{-1})**			**Content (%)**		**Uptake (kg ha^{-1})**		
	Grains	**Stover**	**Grains**	**Stover**	**Total**	**Grains**	**Stover**	**Grains**	**Stover**	**Total**	**Grains**	**Stover**	**Grains**	**Stover**	**Total**
T_1	1.50	0.57	46.68	31.67	44.8	0.32	0.20	10.10	10.85	20.95	0.39	1.06	12.10	58.47	70.57
T_2	1.53	0.59	79.28	46.12	119.3	0.35	0.20	17.93	15.76	33.69	0.40	1.08	20.57	84.44	105.01
T_3	1.66	0.69	105.60	57.23	124.5	0.39	0.22	25.02	18.63	43.65	0.45	1.19	28.51	99.01	127.5
T_4	1.61	0.66	92.88	53.66	114.0	0.38	0.22	21.63	17.62	39.25	0.44	1.13	25.38	91.90	117.28
T_5	1.65	0.68	104.77	56.93	116.5	0.39	0.22	24.91	18.53	43.44	0.45	1.19	28.39	99.17	127.57
T_6	1.64	0.66	100.30	54.26	108.9	0.39	0.22	23.91	18.11	42.03	0.45	1.17	27.34	95.48	122.82
T_7	1.60	0.65	95.52	52.68	104.4	0.38	0.22	22.79	17.97	40.76	0.44	1.16	26.38	94.75	121.13
T_8	1.51	0.57	56.41	35.98	52.1	0.33	0.20	12.43	12.43	24.86	0.39	1.06	14.71	66.43	81.14
T_9	1.60	0.63	91.49	49.93	58.6	0.37	0.21	20.87	16.93	37.81	0.44	1.12	24.99	89.31	114.29
T_{10}	1.51	0.57	73.68	39.73	55.0	0.34	0.20	16.66	13.77	30.43	0.39	1.08	19.19	74.40	93.59
T_{11}	1.57	0.61	83.88	47.39	985	0.35	0.21	18.90	16.14	35.03	0.41	1.08	21.68	84.83	106.5
T_{12}	1.55	0.61	83.05	48.58	53.9	0.36	0.21	19.45	16.51	35.96	0.44	1.10	23.31	87.00	110.31
Sem ±	0.497	0.008	0.81	0.78	2.25	0.004	0.004	0.26	0.30	0.43	0.006	0.012	0.45	0.92	0.9
CD(p=0.05)	1.530	0.024	2.40	2.31	6.65	0.012	0.011	0.77	0.89	1.27	0.019	0.035	1.33	2.72	2.89

T_1-Control, T_2-100% RDF (120:60:40), T_3-125% RDF, T_4-75% RDF+25% through FYMT_5-75% RDF+25% through Vermicompost,T_6-75% RDF + 25% through Biogas slurry, T_7-75% RDF + 25% through Panchgavya, T_8-50% RDF+50% through FYM, T_9-50% RDF+50% through Vermicompost, T_{10}-50% RDF + 50% through Biogas slurry, T_{11}-50% RDF + 50% through Panchgavya, T_{12}- 50% RDF+12.5% through FYM +12.5% through Vermicompost + 12.5% through Biogas slurry+12.5% through Panchgavya

Table–3 Residual effect of Integrated Nutrient Management Practices on Nitrogen, Phosphorus and Potassium status in wheat crop

Treatments	Nitrogen					Phosphorus					Potassium				
	Content (%)		Uptake(kg ha $^{-1}$)			Content (%)		Uptake(kg ha $^{-1}$)			Content (%)		Uptake(kg ha $^{-1}$)		
	Grains	Straw	Grains	Straw	Total	Grains	Straw	Grains	Straw	Total	Grains	Straw	Grains	Straw	Total
T_1	1.3	0.2	34.4	10.4	44.8	0.2	0.1	5.4	4.7	102	0.4	1.1	9.8	51.1	60.9
T_2	1.7	0.5	87.0	32.4	119.3	0.4	0.2	17.6	12.9	30.5	0.5	1.2	27.2	79.0	106.1
T_3	1.8	0.5	90.5	34.0	124.5	0.4	0.2	18.5	14.4	32.9	0.6	1.3	28.8	81.8	110.6
T_4	1.7	0.5	83.8	30.2	114.0	0.3	0.2	16.0	10.9	26.9	0.5	1.2	24.9	77.1	102.0
T_5	1.7	0.5	85.0	31.5	116.5	0.3	0.2	16.4	11.6	28.0	0.5	1.2	25.4	77.9	103.2
T_6	1.7	0.4	80.6	28.2	108.9	0.3	0.2	15.1	10.3	25.3	0.5	1.2	23.8	77.7	101.5
T_7	1.6	0.4	77.7	26.6	104.4	0.3	0.2	13.5	9.5	23.0	0.5	1.2	22.7	75.5	98.2
T_8	1.4	0.2	39.2	12.9	52.1	0.2	0.1	6.8	6.4	13.3	0.4	1.1	11.4	60.1	71.5
T_9	1.4	0.3	41.6	16.9	58.6	0.3	0.1	7.9	8.5	16.4	0.4	1.2	12.6	71.4	84.0
T_{10}	1.4	0.3	40.4	14.6	55.0	0.3	0.1	7.5	8.2	15.7	0.4	1.2	11.6	68.3	79.8
T_{11}	1.6	0.4	74.7	23.7	98.5	0.3	0.1	12.3	8.7	21.0	0.5	1.2	21.8	74.4	96.1
T_{12}	1.4	0.3	39.6	14.2	53.9	0.3	0.1	7.4	7.4	14.8	0.4	1.1	11.7	64.8	76.5
SEm±	0.01	0.01	1.63	0.69	2.25	0.01	0.01	0.35	0.53	0.91	0.01	0.01	0.62	0.91	1.69
CD(p=0.05)	0.03	0.03	4.81	2.03	6.65	0.02	0.02	1.04	1.57	2.69	0.02	0.02	1.84	2.67	5.01

T_1-Control, T_2-100% RDF (120:60:40), T_3-125% RDF, T_4-75% RDF+25% through FYM, T_5-75% RDF+25% through Vermicompost,T_6-75% RDF + 25% through Biogas slurry, T_7-75% RDF + 25% through Panchgavya, T_8-50% RDF+50 through FYM, T_9-50% RDF+50% through Vermicompost, T_{10}-50% RDF + 50% through Biogas slurry, T_{11}-50% RDF + 50% through Panchgavya, T_{12}- 50% RDF+12.5% through FYM + 12.5% through Vermicompost + 12.5% through Biogas slurry+12.5% through Panchgavya

Residual effect on wheat

The residual influence of INM treatments applied to maize was clearly reflected in the growth, nutrient uptake, and productivity of the succeeding wheat crop. Wheat grown after plots receiving 125% RDF and 75% RDF + vermicompost recorded significantly higher N, P, and K uptake and grain yield than the control and lower nutrient treatments (Table 3). This indicates that integrated nutrient application improved soil nutrient reserves and biological activity, which continued to benefit the subsequent crop.

Residual benefits of organic amendments are widely reported in cereal-based systems because a portion of nutrients from manures becomes available gradually over time through mineralization. This sustained nutrient release enhances nutrient synchronization with crop demand in succeeding crops and improves overall system productivity (Jat *et al.* 2022; Paramesh et al. 2023; Sheoran *et al.* 2025). Recent long-term experiments in maize–wheat systems have also demonstrated that partial substitution of chemical fertilizers with organic sources maintains or increases wheat yield while improving soil health indicators (Yadav *et al.* 2023; Jat *et al.* 2025).

System productivity and sustainability implications Although 125% RDF produced maximum yield and nutrient uptake, integrated treatments—particularly 75% RDFcombined with vermicompost—statistically comparable performance with reduced chemical fertilizer input. This finding highlights the potential of INM to enhance nutrient use efficiency and reduce dependency on synthetic fertilizers without compromising productivity.

Sustainable intensification of cereal systems requires maintaining soil organic matter, improving nutrient cycling, and minimizing environmental losses. Integrated fertilization strategies are increasingly recognized as climate-resilient nutrient management approaches that enhance carbon sequestration, microbial diversity, and long-term productivity (Abera 2017; Khokhar *et al.* 2022; Paramesh *et al.* 2023; Ranjan *et al.* 2023; Pratap *et al.* 2025; Jat *et al.* 2025; Tripathi *et al.* 2025). Therefore, adoption of INM practices in maize– wheat cropping systems of subtropical regions can play a crucial role in sustaining soil fertility and ensuring stable crop yields.

CONCLUSION

Integrated nutrient management significantly improved soil fertility, nutrient uptake, and productivity of the maize–wheat cropping system. Application of 125% RDF recorded the highest yields and nutrient uptake; however, integration of 75% RDF with vermicompost produced comparable results while reducing dependence on chemical fertilizers. The study demonstrates that balanced integration of inorganic fertilizers and organic nutrient sources is an effective strategy for sustaining productivity and improving soil fertility in maize–wheat cropping systems under subtropical conditions.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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