The Bioscan
AN INTERNATIONAL QUARTERLY JOURNAL OF LIFE SCIENCES

20(2): S2: 1076-1086, 2025 www.thebioscan.com

Wheat Productivity and Soil Physicochemical Response Under Organic vs. Chemical Fertilization

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DOI: 10.63001/tbs.2025.v20.i02.S2.pp1076-1086

KEYWORDS:
Wheat; Organic Fertilization; Chemical Fertilizers; Soil Fertility; Grain Yield; Nutrient Management; Sustainability.

Received on:

03-03-2025

Accepted on:

01-04-2025

Published on:

11-05-2025

ABSTRACT

Wheat is a major staple crop essential for global and national food security, and its productivity is strongly influenced by nutrient management practices. The present study was conducted to compare the effect of organic and chemical fertilization on growth performance, yield attributes, grain productivity and soil physicochemical properties of wheat (*Triticum aestivum* L.) variety HD-2189. Four nutrient management treatments were evaluated including control (no nutrients), recommended dose of chemical fertilizers (NPK), organic inputs (FYM + vermicompost) and integrated organic inputs combined with biofertilizers (FYM + vermicompost + PSB + *Azotobacter*). The results indicated that chemical fertilization promoted early vegetative growth and improved grain yield in the initial phase; however, organic fertilization and integrated nutrient management significantly enhanced tiller formation, thousand kernel weight, grain nutritional quality and soil fertility. The integrated organic treatment recorded the highest soil organic carbon, available macro and micronutrients, and superior grain protein and mineral content. In contrast, continuous chemical fertilization showed reduced soil organic carbon and limited improvement in grain quality. The findings suggest that integrated nutrient management practices offer a sustainable approach for maintaining wheat productivity while improving soil health and grain nutritional value over the long term.

1. Introduction

Wheat (*Triticum aestivum* L.) is one of the most important cereal crops globally and serves as a major source of calories, protein and essential nutrients for a large part of the human population. It is cultivated across a wide range of climatic zones due to its adaptability and agronomic versatility. Wheat plays a vital role in global food and nutritional security because of its high digestibility, good storage capacity and compatibility with numerous food preparations. In India, wheat is the second most widely grown staple crop after rice and is central to national food supply systems and farmer income stability. The consistent enhancement of wheat productivity is therefore essential for maintaining food security, rural livelihoods and sustainable agricultural growth [1, 2].

Globally, wheat contributes nearly one-fifth of the total dietary calorie and protein intake of humans. It holds significance in the economies of both developing and developed nations through its role in food markets, trade and agro-based industries. In India, wheat occupies approximately 30 to 32 million hectares of land with production exceeding 100 million tonnes annually. Major wheat-growing states such as Uttar Pradesh, Punjab, Haryana, Madhya Pradesh and Rajasthan contribute significantly to national grain availability. Wheat is also distributed through the Public Distribution System (PDS), ensuring affordable access to staple food for millions. The importance of wheat in fulfilling daily nutritional needs and national food security underscores the need for sustainable improvement in its production efficiency [3].

The growth and productivity of wheat depend directly on soil fertility and proper nutrient management. A balanced supply of macro and micro nutrients is essential to support photosynthesis, enzyme activation, grain filling and plant metabolic functions. Continuous cropping without replenishing soil nutrients leads to nutrient depletion, soil structural decline and reduced yield potential. Appropriate nutrient management practices, including organic, chemical and integrated nutrient strategies, are therefore essential to maintain soil health and ensure optimal wheat productivity across seasons [4].

Chemical fertilizers have contributed significantly to increased crop yields; however, their excessive use has resulted in several environmental and soil-related problems. Prolonged dependence on chemical fertilizers leads to soil acidification, loss of soil organic carbon, reduction in microbial biodiversity and imbalance in nutrient availability. These changes cause deterioration in soil structure and reduced nutrient use efficiency. Moreover, increasing fertilizer costs and declining soil productivity pose economic challenges for farmers. Continuous use of synthetic fertilizers has also been associated with a decline in grain quality, particularly in terms of protein and micronutrient levels, ultimately affecting nutritional value [5, 6].

Organic fertilizers such as farmyard manure, compost, vermicompost and biofertilizers improve soil physical properties, enhance organic matter content and increase microbial population and activity. These inputs promote gradual and sustained nutrient release, improve nutrient use efficiency and enhance soil structure and water-holding capacity. Organic sources encourage biological nitrogen fixation, nutrient mineralization and better root development. They maintain ecological balance by improving soil porosity, aeration and cation exchange capacity, which collectively contribute to improved plant growth and better grain nutritional quality [7, 8].

Both organic and chemical fertilizer-based nutrient management systems influence wheat growth and soil health differently. Chemical fertilizers often increase yields rapidly, whereas organic fertilizers enhance long-term soil fertility and environmental sustainability. The performance of these nutrient management systems varies across soil types, climatic conditions and management practices. Therefore, a comparative evaluation is necessary to determine their relative efficiency in improving wheat productivity and maintaining soil quality over time [9].

The present study aims to evaluate the effect of organic and chemical fertilization on wheat growth, yield and soil physicochemical properties. The specific objectives are to assess the differences in growth and yield parameters of wheat under organic and chemical nutrient management regimes, to analyze the changes in soil fertility indicators such as pH, electrical conductivity, organic carbon content and macro and micro nutrient levels after cultivation, and to determine the suitability of organic nutrient inputs in promoting sustainable wheat production.

2. Materials and Methods

2.1 Experimental Site

The field experiment was conducted at the research farm during the rabi cropping season. The site is characterized by a semi-arid tropical climate with hot summers and mild winters. The average annual rainfall is primarily received during the monsoon months, while the rabi season remains predominantly dry, requiring supplemental irrigation. The soil of the experimental field is classified as medium to deep black clay loam, moderately fertile, with good moisture retention capacity. Prior to sowing, initial soil samples were collected and analyzed to determine baseline physicochemical properties including pH, electrical conductivity, organic carbon and available macro and micronutrients. The experimental site map and field layout are presented to provide spatial context and geographical details.

Figure 1: Experimental Field Site Showing Location and Layout

2.2 Crop Material

The test crop selected for the study was wheat (*Triticum aestivum* L.), using the widely grown and regionally adapted variety **HD-2189**. This cultivar is known for its stable yield performance, good adaptability, disease tolerance and suitability for irrigated conditions. The seed used for sowing was obtained from an authenticated agricultural research station to ensure varietal purity. The seeds were sown at a recommended seed rate and spacing to maintain uniform plant population across treatments.

2.3 Treatment Structure

The experiment included four nutrient management treatments to compare the effects of organic and chemical fertilizer sources on wheat productivity and soil properties. The first treatment consisted of a control condition without the application of any external nutrient inputs. The second treatment involved the application of chemical fertilizers based on the recommended dose of nutrients (RDF), typically supplied through urea, diammonium phosphate and muriate of potash. The third treatment involved the application of organic nutrient sources, mainly farmyard manure and vermicompost, applied in quantities based on nitrogen equivalence. The fourth treatment combined organic nutrient sources with microbial biofertilizers such as phosphate solubilizing bacteria and Azotobacter to enhance nutrient availability and biological activity within the soil. These treatments were designed to allow a clear assessment of the differences in growth response, yield performance and soil fertility changes between organic and chemical nutrient management practices.

2.4 Experimental Design

The experiment was laid out in a Randomized Block Design (RBD) with three replications to minimize experimental error and ensure statistical validity. Each treatment was assigned to uniformly sized plots with recommended spacing between rows and plants. Standard agronomic practices such as irrigation, weeding and plant protection were followed uniformly across all treatments to ensure that observed differences were primarily due to nutrient management practices.

2.5 Data Collection and Observations

During the crop growth period, observations on plant height, number of tillers, leaf count and other growth parameters were recorded at regular intervals. At maturity, wheat plants were harvested and yield attributes including number of grains per spike, thousand kernel weight, grain yield and straw yield were measured. Soil samples from each plot were collected after harvest and analyzed for pH, electrical conductivity, organic carbon and nutrient status. All data were subjected to statistical analysis using analysis of variance to determine the significance of treatment effects.

3. Results and Discussion

3.1 Growth Performance of Wheat

The growth parameters of wheat were significantly influenced by the different nutrient management treatments. Wheat plants under chemical fertilization (T2) showed rapid initial growth due to the immediate availability of nitrogen and other essential nutrients, which promoted early shoot elongation. However, as the crop advanced towards tillering and heading stages, the treatments receiving organic and integrated nutrient management (T3 and T4) outperformed chemical fertilization.

The organic treatments, especially the integrated organic treatment with biofertilizers (T4), sustained nutrient release throughout the crop period, improving root proliferation, nutrient uptake efficiency and physiological activity. The combined application of FYM, vermicompost, phosphate solubilizing bacteria and *Azotobacter* enhanced soil biological activity and nutrient mineralization, resulting in higher tiller formation. In contrast, T1 (control) recorded the lowest growth due to nutrient deficiency.

These findings are consistent with earlier reports that organic amendments improve soil structure, microbial biomass and the rate of nutrient release, thereby enhancing tiller production and plant stature over time [1, 2].

Table 2. Effect of Nutrient Management Treatments on Plant Height and Tiller Number in Wheat

Treatment	Plant Height (cm)	Tiller Number per Plant
T1 (Control)	78.4	3.1

T2 (Chemical Fertilizer)	89.6	4.4
T3 (Organic: FYM + Vermicompost)	93.2	5.0
T4 (Organic + Biofertilizers: FYM + VC + PSB + *Azotobacter*)	96.8	5.6

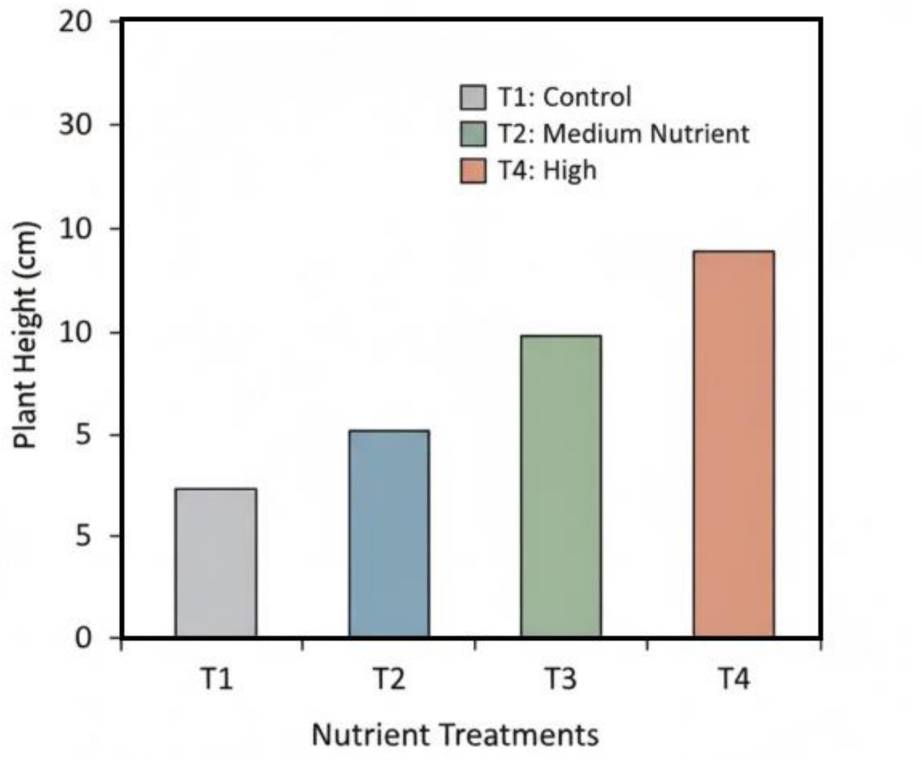

Figure 2. Plant Height Variation Under Different Nutrient Management Treatments

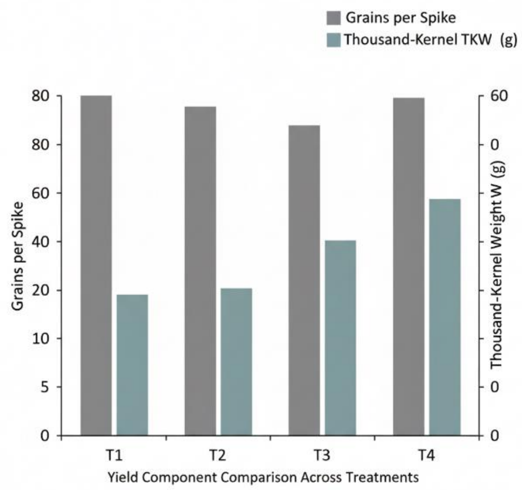

Figure 3. Tiller Count per Plant Across Treatments

The highest plant height (96.8 cm) and number of tillers per plant (5.6) were recorded under T4 (Organic + Biofertilizers), followed by T3, indicating the beneficial effects of organic nutrient sources in improving growth performance. T2 (Chemical Fertilizer) resulted in moderate tiller formation, while T1 (Control) recorded the lowest values. The superiority of T4 can be attributed to enhanced microbial activity, improved soil aeration, increased organic carbon and better nutrient uptake. Meanwhile, the chemical fertilizer treatment provided a quick nutrient supply but lacked the sustained soil-building benefits observed under organic systems.

3.2 Yield Attributes and Productivity

The yield-attributing characteristics of wheat varied significantly among the different nutrient management treatments. The treatment receiving chemical fertilizers (T2) recorded a higher grain yield during the early season due to the rapid release and immediate availability of nutrients, especially nitrogen, which accelerated vegetative growth and spike development. However, the treatments under organic nutrient management, particularly T4 (FYM + Vermicompost + PSB + *Azotobacter*), demonstrated superior performance in terms of grains per spike, thousand kernel weight (TKW) and overall biomass accumulation.

Organic nutrient inputs improved soil structure, enhanced water-holding capacity and supported microbial mineralization, leading to better grain filling and improved kernel weight. In contrast, although T2 initially increased plant vigor, the nutrient supply declined in the later stages due to lower nutrient buffering capacity and reduced soil organic matter. The integrated organic treatment (T4) produced the highest yield attributes, followed by T3, while the control treatment (T1) recorded the lowest productivity due to insufficient nutrient availability. These results indicate that organic nutrient sources contribute to stabilized and sustained productivity over time.

Table 3. Effect of Treatments on Yield Components of Wheat

Treatment	Grains per Spike	Thousand Kernel Weight (TKW, g)
T1 (Control)	34.2	35.6
T2 (Chemical Fertilizer)	41.8	38.9
T3 (Organic: FYM + Vermicompost)	44.6	41.3
T4 (Organic + Biofertilizers: FYM + VC + PSB + *Azotobacter*)	47.3	43.8

Grain yield and straw yield followed a similar pattern. Chemical fertilizer (T2) promoted higher grain yield early due to rapid nutrient uptake; however, the integrated organic treatment (T4) recorded the highest final grain and straw yields due to improved soil nutrient holding capacity and balanced nutrient supply throughout the growing season. The control (T1) consistently showed the lowest yield due to nutrient deficiency.

Table 4. Grain and Straw Yield of Wheat Under Different Nutrient Management Treatments

Treatment	**Grain Yield (kg/ha)**	**Straw Yield (kg/ha)**
T1 (Control)	2450	3100
T2 (Chemical Fertilizer)	3510	4130
T3 (Organic: FYM + Vermicompost)	3745	4380
T4 (Organic + Biofertilizers: FYM + VC + PSB + *Azotobacter*)	3980	4625

The highest values for grains per spike, kernel weight and final grain yield were observed in T4, followed by T3, demonstrating the beneficial role of organic nutrient sources in enhancing yield quality and soil productivity. T2 showed comparatively high grain yield in the early stage but did not match the stability and grain filling improvements observed under organic treatments. These findings align with earlier reports indicating that organic nutrient management fosters sustainable yield improvement by enhancing soil fertility and microbial nutrient cycling.

3.3 Soil Physicochemical Properties

The soil physicochemical parameters showed noticeable variation among the nutrient management treatments, reflecting the influence of organic and chemical fertilization practices on soil health. Organic treatments (T3 and T4) significantly improved soil organic carbon (OC), microbial activity and micronutrient availability when compared to chemical fertilization and the control. The combined organic and biofertilizer treatment (T4) recorded the highest organic carbon content due to the incorporation of decomposed organic matter and enhanced microbial biomass. The presence of phosphate solubilizing bacteria and *Azotobacter* further contributed to the mineralization of nutrients and improved nutrient turnover in the soil.

In contrast, the chemical fertilizer treatment (T2) increased the availability of nitrogen in the short term but did not contribute to building soil organic matter. Long-term dependence on chemical fertilizers can lead to soil structural degradation and a decline in microbial diversity. The control treatment (T1) exhibited the lowest values due to the absence of nutrient supplementation. These results indicate that organic nutrient sources support sustained soil fertility improvement, while chemical fertilizers supply nutrients rapidly but may reduce soil health over time.

Table 5. Soil Properties Before Sowing (Baseline)

Parameter	Value
pH	7.6
EC (dS/m)	0.42
Organic Carbon (%)	0.48
Available N (kg/ha)	212
Available P (kg/ha)	17.5
Available K (kg/ha)	289
Fe (mg/kg)	4.8
Zn (mg/kg)	0.68

Table 6. Soil Properties After Harvest Under Different Treatments

Parameter	T1 (Control)	T2 (Chemical)	T3 (Organic)	T4 (Organic + Biofertilizers)
pH	7.6	7.5	7.4	7.3
EC (dS/m)	0.43	0.49	0.45	0.46
Organic Carbon (%)	0.44	0.41	0.57	0.63
Available N (kg/ha)	205	254	239	262
Available P (kg/ha)	15.9	18.4	21.6	24.7
Available K (kg/ha)	276	282	307	319
Fe (mg/kg)	4.6	4.2	5.1	5.5
Zn (mg/kg)	0.61	0.57	0.72	0.79

Organic treatments resulted in a marked improvement in soil organic carbon and micronutrient availability, particularly in T4. The slight reduction in pH under organic treatments indicates increased microbial decomposition and organic acid formation, contributing to enhanced nutrient solubility. The chemical fertilizer treatment (T2) increased nitrogen availability but showed a decline in soil organic carbon, suggesting nutrient exhaustion without structural replenishment. These findings confirm that organic nutrient management promotes soil fertility restoration, while chemical fertilization alone supports short-term nutrient supply but is less effective in sustaining soil health.

3.4 Nutritional Quality of Wheat Grain

The nutritional composition of wheat grains was influenced significantly by the different nutrient management treatments. Organic and integrated organic treatments improved grain quality parameters such as protein content, crude fiber, ash and micronutrient levels. The highest protein content was recorded in the treatment receiving combined organic manures and biofertilizers (T4), followed by the organic treatment (T3). This could be attributed to the slow and sustained release of nutrients and enhanced microbial activity, which promoted efficient nitrogen uptake and assimilation during the grain filling stage. The chemical fertilizer treatment (T2) exhibited moderate protein levels due to rapid nutrient release but lacked the buffering effect of organic matter required to maintain long-term nutrient availability. The control (T1) recorded the lowest protein and mineral content due to nutrient deficiency.

Similarly, crude fiber and ash content were higher in the organically fertilized treatments, reflecting improved structural carbohydrate and mineral accumulation. Micro-nutrient concentrations, particularly iron (Fe) and zinc (Zn), were noticeably higher in T3 and T4, reinforcing the role of organic matter in enhancing micro-nutrient availability and chelation in the rhizosphere. These findings confirm that organic nutrient management not only enhances yield but also enriches the nutritional profile of wheat grains by improving soil biological activity and nutrient cycling.

Table 7. Nutritional Quality Parameters of Wheat Grain Under Different Treatments

Parameter	T1 (Control)	T2 (Chemical)	T3 (Organic)	T4 (Organic + Biofertilizers)
Protein (%)	9.3	10.4	11.2	11.8
Crude Fiber (%)	1.58	1.63	1.71	1.78
Ash (%)	1.41	1.46	1.54	1.62
Carbohydrates (%)	69.8	69.1	68.4	67.9
Fe (mg/100g)	3.4	3.7	4.3	4.8
Zn (mg/100g)	2.1	2.3	2.7	3.0

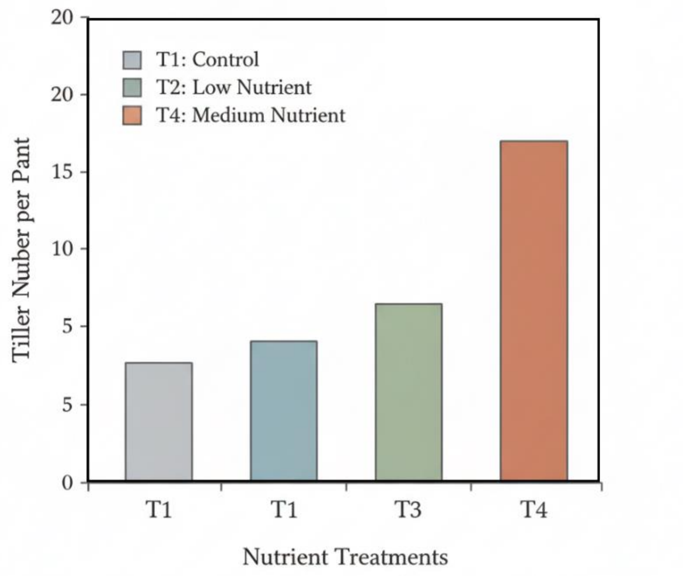

Figure 4. Variation in Protein Content (%) of Wheat Under Different Nutrient Management Treatments

The integrated organic treatment (T4) produced nutritionally superior grains due to enhanced nitrogen assimilation and micronutrient enrichment. Organic amendments improve soil organic carbon, microbial biomass and enzyme activity, which contribute to better nutrient transformation and uptake during grain development. The chemical fertilizer treatment improved yield but did not enhance micronutrient concentration to the same extent as organic sources. The control treatment consistently recorded the lowest values for all nutritional parameters due to inadequate nutrient supply. These results suggest that organic nutrient management systems offer significant advantages in producing high-quality wheat grains with greater nutritional value.

Conclusion

The results of the study demonstrated that nutrient management practices have a significant influence on wheat growth, yield performance, grain nutritional quality and soil physicochemical properties. Organic fertilization, particularly the combination of FYM, vermicompost and biofertilizers, improved soil organic carbon content, enhanced microbial activity and increased the availability of macro and micronutrients. This contributed to better tillering, superior kernel development and improved grain quality attributes such as higher protein and mineral content. Although chemical fertilization promoted rapid vegetative growth and resulted in higher early-season yield due to the swift availability of nutrients, it did not contribute to long-term soil health and showed a gradual decline in soil carbon and biological activity. Therefore, while chemical fertilizers may offer short-term productivity advantages, their continuous use can negatively affect soil sustainability. Based on the findings, integrated nutrient management, which combines organic manures with biofertilizers and, where necessary, minimal chemical inputs, is recommended as a balanced strategy to sustain wheat productivity, enhance soil fertility and ensure long-term agricultural sustainability.

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