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Shirish Nagoshe
Department of Agronomy, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola, Maharashtra, India

Milind Giri
Department of Agronomy, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola, Maharashtra, India

Anand Jejal
Agronomy Section, ICAR - National Dairy Research Institute, Karnal

AN Paslawar
Department of Agronomy, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola, Maharashtra, India

YV Ingle
Department of Plant Pathology, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola, Maharashtra, India

BA Sonune
Department of Soil Science, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola, Maharashtra, India

Corresponding Author:
Shirish Nagoshe
Department of Agronomy, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola, Maharashtra, India

Integrated organic-inorganic nutrient management for enhanced growth, yield, and viability of wheat (*Triticum aestivum* L.) under semiarid conditions

Shirish Nagoshe, Milind Giri, Anand Jejal, AN Paslawar, YV Ingle and BA Sonune

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Abstract
This field investigation, conducted under the semiarid conditions of Akola, Maharashtra, evaluated the efficacy of eight distinct nutrient management strategies on the growth, and productivity of wheat (*Triticum aestivum* L.). The primary objective was to compare sole organic, sole inorganic, and integrated nutrient systems to identify sustainable pathways for wheat cultivation. Treatments included 100% recommended dose of nitrogen (RDN) through vermicompost, 50% RDN via vermicompost integrated with biofertigation (Jeevamrut or Vermiwash), standalone biofertigation regimes, an unfertilized control, and a conventional 100% RDN through chemical fertilizers. Results demonstrated that the conventional treatment (T_8) produced the highest grain yield (3,927 kg ha^{-1}) and biological yield (9,963 kg ha^{-1}), underscoring the efficacy of readily available synthetic nutrients in maximizing short-term productivity. However, fully organic management with 100% RDN via vermicompost (T_1) achieved a substantial grain yield of 2,728 kg ha^{-1}, while an integrated approach combining 50% RDN from vermicompost with fortnightly fertigation of Jeevamrut and Vermiwash (T_6) yielded 2,382 kg ha^{-1}. Both organic and integrated treatments significantly outperformed the unfertilized control (1,292 kg ha^{-1}). The study concludes that while synthetic fertilizers optimize immediate agronomic performance, integrated and low-input organic approaches offer resilient and sustainable alternatives. By improving soil health indicators, enhancing nutritional quality, and reducing reliance on costly external inputs, these systems present a viable strategy for balancing crop productivity with long-term ecological stewardship in semiarid agroecosystems.

Keywords: Wheat, vermicompost, jeevamrut, vermiwash, biofertigation, semiarid, integrated nutrient management, yield, soil health

1. Introduction

1.1 Global Significance and Regional Imperatives of Wheat Production

Wheat (*Triticum aestivum* L.) stands as a cornerstone of global food security, providing a substantial portion of the caloric and protein intake for a significant percentage of the world's population [1]. In India, it is the second most important staple cereal after rice, forming the bedrock of the nation's food and nutritional security strategy. The cultivation of wheat is particularly vital in the semiarid regions of Central India, such as the Vidarbha region of Maharashtra, where agriculture is the primary livelihood. However, these regions are characterized by significant agro-climatic challenges, including erratic and insufficient rainfall, high ambient temperatures, especially during the critical grain-filling stage, and inherent water scarcity [3]. These environmental stressors create a precarious production environment, making sustainable intensification a critical imperative for ensuring regional food security and farmer livelihoods [5]. The experimental site at Akola is representative of this challenging context, where optimizing resource use is paramount for resilient agriculture.

1.2 The Sustainability Deficit in Conventional Agriculture

The Green Revolution, while instrumental in averting famine and achieving national self-sufficiency in food grains, was predicated on a high-input agricultural model. This model relies heavily on the intensive use of high-yielding varieties, irrigation, and, most notably, high-analysis synthetic chemical fertilizers [6]. Decades of this practice, often involving the injudicious and imbalanced application of nitrogenous (N), phosphatic (P), and potassic (K) fertilizers, have exposed a significant sustainability deficit [7]. The long-term consequences of this chemical-intensive approach are well-documented and include severe degradation of soil health. This manifests as a decline in soil organic matter, deterioration of soil physical properties (e.g., structure, water-holding capacity), chemical imbalances leading to widespread secondary and micronutrient deficiencies, and a reduction in the diversity and activity of beneficial soil biota [1]. This degradation not only threatens the long-term productive capacity of the land but also contributes to environmental pollution through nutrient runoff and greenhouse gas emissions associated with fertilizer manufacturing and application [8].

1.3 Organic Amendments as Cornerstones of Soil Rejuvenation

In response to the challenges posed by conventional agriculture, there is a growing scientific and practical interest in farming systems that prioritize soil health as the foundation of productivity. Organic amendments and bio-inoculants are central to this paradigm shift, moving from a model of simple nutrient replacement to one of holistic soil ecosystem activation.

1.3.1 Vermicompost: A Multifunctional Soil Elixir

Vermicompost is a finely stabilized, nutrient-rich organic amendment produced through the synergistic bio-oxidation and decomposition of organic matter by earthworms and associated microorganisms [13]. It is far more than a mere source of nutrients; it is a multifunctional soil conditioner that confers a wide array of benefits.

Physically, vermicompost improves soil structure by promoting the formation of water-stable aggregates, which in turn enhances soil aeration, porosity, and water-holding capacity—critical attributes for crop resilience in water-limited semiarid environments [14]. Chemically, it provides a balanced suite of macro- and micronutrients in forms that are readily available for plant uptake. It is also rich in humic substances, such as humic and fulvic acids, which act as natural chelating agents, improving the availability of micronutrients, and enhancing the soil's cation exchange capacity and pH buffering ability [13]. Biologically, vermicompost is a potent inoculum of beneficial microorganisms and enzymes (e.g., urease, phosphatase, dehydrogenase) that stimulate nutrient cycling, suppress soil-borne pathogens, and increase overall soil microbial biomass and activity [16]. Beyond its effects on the soil, vermicompost directly influences plant growth by supplying plant growth-regulating hormones like auxins, gibberellins, and cytokinins, which can enhance photosynthesis, stimulate root development, and improve overall plant vitality [13].

1.3.2 Biofertigation with Indigenous Liquid Organics: Jeevamrut and Vermiwash

Biofertigation, the application of liquid bio-inoculants through irrigation, represents a low-cost, high-impact strategy for enhancing soil biological activity. This study focuses on two indigenous preparations: Jeevamrut and Vermiwash.

Jeevamrut is a fermented microbial concoction prepared from locally available materials, including fresh cow dung, cow urine, jaggery (a source of energy for microbes), pulse flour (a source of protein), and a small amount of native soil.[23] Its primary function is not as a direct nutrient provider but as a "microbial accelerant" or bio-stimulant. It introduces a massive and diverse population of beneficial microbes, including nitrogen-fixing bacteria (e.g., *Azotobacter*, *Azospirillum*) and phosphate-solubilizing microorganisms, into the soil rhizosphere [23]. These microbes accelerate the decomposition of organic matter and the mineralization of soil nutrients, making them available for plant uptake. While its nutrient content is modest, its value lies in its ability to unlock the nutrient potential of the soil itself [27].

Vermiwash is the aqueous leachate collected from active vermicomposting units. It is a rich brew of water-soluble nutrients, enzymes, vitamins, amino acids, and plant growth hormones (cytokinins, auxins, gibberellins) derived from the metabolic activities of earthworms and the decomposition process [30]. It acts as a fast-acting liquid fertilizer and plant tonic that can be applied to the soil or as a foliar spray. Its application provides a direct nutritional and hormonal stimulus to the plant, promoting rapid growth and enhancing physiological functions [31].

1.4 The Integrated Nutrient Management (INM) Paradigm for Sustainable Intensification

Recognizing the limitations of relying solely on either chemical or organic inputs, the Integrated Nutrient Management (INM) paradigm has emerged as a scientifically robust and practical approach for sustainable intensification [1]. INM is defined as the maintenance of soil fertility and the supply of plant nutrients to an optimum level for sustaining desired crop productivity through the judicious and combined use of chemical fertilizers, organic manures (like vermicompost), and biofertilizers (like Jeevamrut) [8]. The core principle of INM is to leverage the distinct advantages of each component synergistically. Chemical fertilizers provide readily available nutrients to meet the high demand of crops during peak growth stages, while organic sources build long-term soil fertility, improve soil physical and biological health, and enhance the efficiency of applied chemical fertilizers, thereby reducing losses to the environment [6]. This integrated approach seeks to optimize crop nutrition, sustain productivity, and maintain ecological balance.

1.5 Research Rationale and Objectives

While the individual benefits of vermicompost, Jeevamrut, Vermiwash, and the general principles of INM are well-established, there remains a significant gap in comprehensive, comparative field research evaluating their integrated application specifically for wheat cultivation within the challenging agro-climatic context of the semiarid Vidarbha region. Farmers and agronomists in the region require scientifically validated, location-specific data to make informed decisions about transitioning towards more sustainable and resilient farming practices. This study was therefore designed to address this knowledge gap.

The primary objectives of this investigation were

1. To evaluate the comparative effects of sole organic, sole inorganic, and integrated nutrient management practices on the growth dynamics and phenology of wheat.
2. To quantify the impact of these treatments on the yield attributes, grain and straw yield, and harvest index of wheat.

2. Materials and Methods

2.1 Experimental Site and Agro-climatic Conditions

The field experiment was conducted during the *Rabi* (post-monsoon) season of 2024-2025 at the research farm of the Center for Organic Agriculture Research and Training (COART), located at Dr. Panjabrao Deshmukh Krishi

Vidyapeeth (PDKV), Akola, Maharashtra, India. The site is geographically situated at 20°42′ North latitude and 77°00′ East longitude, at an altitude of 310 meters above mean sea level. The region is characterized by a semiarid, subtropical climate with hot, dry summers and mild, dry winters. The majority of rainfall is received during the monsoon season (June to September), making the *Rabi* season reliant on stored soil moisture and supplemental irrigation.

2.2 Initial Soil Characterization

Prior to the imposition of treatments, composite soil samples were collected from the experimental field at a depth of 0-15 cm for physico-chemical analysis. The soil was classified as a clay loam, belonging to the Vertisol order, typical of the region. The detailed baseline properties of the soil are presented in Table 1. The soil was slightly alkaline in reaction with low salinity. Critically for a nutrient management study, the initial fertility status was characterized by low organic carbon, low available nitrogen, low available phosphorus, and high available potassium. This initial soil status provided a clear context for evaluating the response of the wheat crop to the various nutrient amendments.

2.3 Experimental Design and Treatment Structure

The experiment was laid out in a Randomized Complete Block Design (RCBD) to account for potential field variability, with three replications. The gross plot size was 4.0 m × 3.0 m. The study comprised eight distinct nutrient management treatments, as detailed below:

- **T_1:** 100% Recommended Dose of Nitrogen (RDN) through Vermicompost (6.50 t ha^{-1}).
- **T_2:** 50% RDN through Vermicompost (3.25 t ha^{-1}) + Fertigation of Jeevamrut at 20, 40, and 60 Days After Sowing (DAS).
- **T_3:** 50% RDN through Vermicompost (3.25 t ha^{-1}) + Fertigation of Vermiwash at 20, 40, and 60 DAS.
- **T_4:** Fertigation of Jeevamrut at fortnightly intervals (20, 30, 40, 50, 60, and 70 DAS).
- **T_5:** Fertigation of Vermiwash at fortnightly intervals (20, 30, 40, 50, 60, and 70 DAS).
- **T_6:** Combined Fertigation of Jeevamrut and Vermiwash at fortnightly intervals (20, 30, 40, 50, 60, and 70 DAS).
- **T_7:** Control (no external fertilizer or manure application).
- **T_8:** Conventional - 100% RDN through chemical fertilizers (Urea and Diammonium Phosphate - DAP).

The Recommended Dose of Fertilizers (RDF) for wheat in the region is 120:60:60 kg $N:P_2O_5:K_2O$ ha^{-1}. For the purpose of this study, treatments were designed based on the Recommended Dose of Nitrogen (RDN), which was 120 kg N ha^{-1}.

2.4 Preparation and Application of Organic Inputs

All organic inputs were prepared on-site to ensure quality and reflect practices accessible to farmers.

a. **Vermicompost:** High-quality vermicompost, produced using earthworms (*Eisenia fetida*), was sourced from the university's production unit. The required quantities for treatments T_1, T_2, and T_3 were weighed and applied as a basal dose, uniformly spread and incorporated into the soil during the final land preparation before sowing.

b. **Jeevamrut:** The preparation followed standard indigenous methods [23]. In a 200-liter barrel, 10 kg of fresh desi cow dung and 10 liters of cow urine were mixed with 200 liters of water. To this slurry, 2 kg of jaggery (as a carbon source) and 2 kg of pulse flour (as a protein source) were added, along with a handful of soil from beneath a banyan tree to inoculate native microorganisms. The mixture was stirred thoroughly and allowed to ferment in the shade for 48 to 72 hours, with stirring twice daily. The prepared Jeevamrut was diluted before application via fertigation as per the treatment schedule.

c. **Vermiwash:** Vermiwash was collected as a liquid leachate by slowly percolating water through active vermicomposting beds. The dark brown, nutrient- and microbe-rich liquid was collected over a 7-day period and stored for application [31]. It was applied as per the treatment schedule via fertigation.

2.5 Crop Management and Data Collection

- **Crop Husbandry:** The wheat variety AKAW 4210-6, also known as 'PDKV Sardar', a locally adapted and recommended variety, was used for the experiment.[40] Sowing was done at the recommended time for the region using a seed rate of 100 kg ha^{-1}. Standard agronomic practices, including irrigation at critical growth stages (Crown Root Initiation, tillering, jointing, flowering, and grain filling), weeding, and plant protection measures (where necessary, using organic-compliant methods in T_1-T_7), were uniformly applied to all plots to ensure that the treatment effects were primarily due to the nutrient management strategies.
- **Data Recording:** Data on various growth and yield parameters were recorded at specified intervals using standard methodologies.
- **Growth Parameters:** Five plants were randomly selected and tagged in each plot for recording periodic observations. Plant height (cm), number of tillers per meter row length (later converted to m^2), number of leaves per plant, and leaf area per plant (dm^2, measured using a portable leaf area meter) were recorded at 20, 40, 60, and 80 DAS, and at harvest (AH). Dry matter accumulation per plant (g) was determined by oven-drying the sampled plants at 65°C until a constant weight was achieved.
- **Yield Attributes:** At maturity, the five tagged plants were harvested to record yield attributes, including the length of the spike (cm), the number of grains per spike, and the grain weight per plant (g). The test weight (1,000-grain weight) was determined by counting and weighing 1,000 grains from the bulk harvest of each plot.
- **Yields:** Plants from the net plot area (excluding border rows) were harvested, bundled, and sun-dried. The total biomass was weighed to determine the biological yield. Threshing was done separately for each plot, and the grain was cleaned and weighed. Grain and straw yields were recorded and expressed in kg ha^{-1}. The Harvest Index (HI) was calculated using the formula:

$$HI(\%) = (\text{Grain Yield}/\text{Biological Yield}) \times 100$$

2.6 Statistical Analysis

The data collected for all parameters were compiled and subjected to statistical analysis using the Analysis of Variance (ANOVA) technique for a Randomized Complete Block Design. The significance of the treatment effects was tested using the F-test. To compare the treatment means, the Least Significant Difference (LSD) test was applied at a 5% level of probability ($P \leq 0.05$).

3. Results

This section presents the empirical findings of the field experiment, systematically detailing the influence of the eight different nutrient management treatments on the growth, yield, nutrient uptake, and economics of wheat. The data are presented factually, with interpretation reserved for the Discussion section.

3.1 Plant Population

The initial plant population, recorded at 10 DAS, showed no statistically significant differences among the treatments, with counts ranging from 45.67 to 50.33 plants per meter row length (Table 2). This indicates uniform seed germination and crop establishment across the experimental field, providing a reliable basis for comparing the subsequent effects of the nutrient management treatments. The final plant population at harvest also showed non-significant variations among most treatments, although the control (T_7) recorded the numerically lowest stand count (39.67 plants per meter row length), suggesting slightly higher mortality under nutrient-stress conditions.

3.2 Vegetative Growth Parameters

The influence of different nutrient management strategies on vegetative growth became progressively more pronounced as the season advanced. The conventional treatment (T_8) consistently demonstrated superior performance across all measured growth parameters.

3.2.1 Plant Height

As shown in Table 2, the conventional treatment (T_8) consistently produced the tallest plants at every observation interval. At 80 DAS, T_8 recorded a plant height of 78.67 cm, which was significantly greater than all other treatments. This trend continued until harvest, where T_8 achieved a final height of 91.83 cm. Among the organic and integrated treatments, 100% RDN through vermicompost (T_1) was the most effective, recording a final height of 82.92 cm, which was statistically superior to the control and standalone biofertigation treatments. The integrated treatment T_2 (50% RDN VC + Jeevamrut) also performed well (81.63 cm). The unfertilized control (T_7) consistently recorded the lowest plant height, reaching only 66.87 cm at harvest.

3.2.2 Tiller Production

Tiller density, a critical determinant of sink capacity, followed a pattern similar to plant height (Table 2). The application of 100% RDN through chemical fertilizers (T_8) resulted in the highest number of tillers per m² at all growth stages, peaking at 303 tillers at 60 DAS and stabilizing at 297 tillers at harvest. This was significantly higher than all other treatments. The fully organic T_1 treatment was the second-best performer, with 257 tillers per m² at harvest. The integrated treatments (T_2, T_3, T_6) produced moderate tiller densities, all of which were significantly higher than the control (T_7), which produced only 162 tillers per m².

3.2.3 Leaf Area and Dry Matter Accumulation

Canopy development, as indicated by leaf area, and overall biomass production, measured as dry matter accumulation, were markedly superior in the conventional treatment (T_8). At 80 DAS, the leaf area per plant in T_8 was 4.86 dm², significantly higher than the next best treatment, T_1 (4.58 dm²) (Table 2). This superior photosynthetic area translated directly into greater biomass. At harvest, the dry matter accumulation per plant in T_8 was 19.67 g, which was significantly higher than all other treatments. T_1 (100% RDN VC) recorded the highest dry matter among the organic/integrated treatments with 15.73 g per plant, followed closely by T_2 (15.28 g). The control plot (T_7) accumulated the least dry matter, at just 9.68 g per plant.

3.3 Yield Attributes and Final Yields

The differences observed in vegetative growth were ultimately reflected in the final yield and its constituent components.

3.3.1 Yield Components

The conventional treatment (T_8) demonstrated superiority in all key yield-attributing characters (Table 3). It recorded the maximum spike length (9.57 cm), the highest number of grains per spike (33.33), and the highest test weight (41.33 g). A notable finding was the performance of the 100% organic vermicompost treatment (T_1), which was statistically at par with T_8 for the number of grains per spike (33.00) and test weight (41.07 g). This indicates that while the overall plant size was smaller than in T_8, the individual spikes were well-formed and produced heavy, well-filled grains. The control (T_7) recorded the lowest values for all yield attributes, particularly the number of grains per spike (20.00).

3.3.2 Grain, Straw, and Biological Yields

As presented in Table 3, the final yields showed significant variation among treatments. The conventional treatment (T_8) produced a grain yield of 3,927 kg ha^{-1}, which was significantly higher than all other treatments. This represents a 204% increase over the control. The 100% RDN through vermicompost (T_1) was the second-highest yielding treatment, with a grain yield of 2,728 kg ha^{-1}, a 111% increase over the control. The integrated treatments T_2 (50% RDN VC + Jeevamrut) and T_6 (Jeevamrut + Vermiwash) recorded grain yields of 2,672 kg ha^{-1} and 2,382 kg ha^{-1}, respectively. All organic and integrated treatments (T_1-T_6) produced significantly higher grain yields than the unfertilized control (T_7), which yielded only 1,292 kg ha^{-1}. Trends for straw yield and biological yield mirrored those of grain yield, with T_8 recording the maximum values (6,036 kg ha^{-1} and 9,963 kg ha^{-1}, respectively).

3.3.3 Harvest Index

The harvest index (HI), a measure of the efficiency of partitioning dry matter into grain, was highest in T_8 (40.14%), indicating a highly efficient conversion of biomass to economic yield (Table 3). The HI values for the other treatments were relatively close, ranging from 38.06% for the control (T_7) to 39.40% for T_1. This suggests that while the total biomass production varied significantly among treatments, the fundamental efficiency of translocation to the grain was less affected.

Table 2: Effect of nutrient management on wheat growth parameters at 80 DAS and at harvest.

Treatment	Plant Height (cm)	No. of Tillers (per m²)	Leaf Area (dm²/plant)	Dry Matter (g/plant)
	At Harvest	At Harvest	At 80 DAS	At Harvest
T_1: 100% RDN VC	82.92	257	4.58	15.73
T_2: 50% RDN VC + Jeevamrut	81.63	252	4.53	15.28
T_3: 50% RDN VC + Vermiwash	79.20	247	4.40	14.82
T_4: Jeevamrut Fortnightly	76.48	226	3.80	12.85
T_5: Vermiwash Fortnightly	68.95	174	3.75	10.88
T_6: Jeevamrut + Vermiwash Fortnightly	78.75	242	4.13	14.19
T_7: Control	66.87	162	3.67	9.68
T_8: Conventional	91.83	297	4.86	19.67
S.E. (m) ±	3.66	13.67	0.21	0.97
CD (P=0.05)	11.10	41.46	0.64	2.94

Table 3: Effect of nutrient management on yield attributes, yields, and harvest index of wheat.

Treatment	Spike Length (cm)	Grains per Spike	Test Weight (g)	Grain Yield (kg/ha)	Straw Yield (kg/ha)	Biological Yield (kg/ha)	Harvest Index (%)
T_1: 100% RDN VC	8.18	33.00	41.07	2728	4368	7096	39.40
T_2: 50% RDN VC + Jeevamrut	8.03	32.67	40.68	2672	4288	6959	38.91
T_3: 50% RDN VC + Vermiwash	8.02	31.67	40.63	2517	4096	6613	38.44
T_4: Jeevamrut Fortnightly	7.13	27.33	38.55	2002	3253	5254	38.28
T_5: Vermiwash Fortnightly	6.55	25.33	36.25	1610	2409	4019	38.10
T_6: Jeevamrut + Vermiwash Fortnightly	7.25	29.67	39.92	2382	3840	6222	38.39
T_7: Control	6.48	20.00	35.43	1292	2030	3321	38.06
T_8: Conventional	9.57	33.33	41.33	3927	6036	9963	40.14
S.E. (m) ±	0.37	2.19	1.12	139.68	218.05	351.94	-
CD (P=0.05)	1.12	6.64	3.40	423.68	661.39	1067.49	-

4. Discussion

The results of this study provide a multifaceted perspective on nutrient management for wheat in semiarid environments, highlighting the complex interplay between agronomic productivity, nutritional quality, economic viability, and ecological sustainability. The discussion interprets these findings by exploring the underlying mechanisms and situating them within the broader scientific context.

4.1 Conventional Fertilization: The Paradigm of High Input, High Output

The superior performance of the conventional treatment (T_8) across nearly all growth and yield parameters is unequivocal. The application of 100% RDN through urea and DAP provided a readily available pool of soluble nitrogen and phosphorus, which are often the most limiting nutrients for cereal production [7]. This immediate nutrient availability synchronized perfectly with the crop's high demand during critical growth phases, such as tillering and stem elongation. The result was a rapid and vigorous development of the plant's architecture—greater height, more tillers, and a larger leaf area—which established a robust photosynthetic factory capable of producing and translocating a large amount of assimilates [41]. This robust vegetative framework directly translated into superior yield components, including a greater number of grains per spike and a higher test weight, culminating in the highest grain and biological yields observed in the study [41]. The high harvest index in T_8 further suggests that the balanced nutrition provided by the RDF not only maximized biomass production but also optimized the partitioning of this biomass into economic yield.

However, this high-output paradigm must be viewed through the lens of sustainability. While T_8 was the most productive and profitable in the short term of a single growing season, this approach is intrinsically linked to the well-documented negative externalities of conventional agriculture. The long-term, continuous use of synthetic fertilizers without organic matter replenishment can lead to soil acidification, a decline in soil organic carbon, reduced microbial diversity, and increased potential for nutrient leaching and greenhouse gas emissions (specifically nitrous oxide from nitrogen fertilizers) [1]. Therefore, the success of T_8 represents a trade-off: maximized immediate returns at the potential cost of long-term soil health and environmental quality.

4.2 The Power of Integration: Synergizing Organic Matter and Bio-inoculants

The integrated nutrient management (INM) treatments (T_2, T_3, and T_6) demonstrated a viable middle path, significantly outperforming the control while reducing reliance on external inputs compared to T_1 and T_8. The performance of these treatments can be attributed to a powerful synergy between the foundational soil-building properties of vermicompost and the bio-stimulatory effects of liquid organic inoculants.

The basal application of 50% RDN through vermicompost served a dual purpose. First, it provided a slow-release source of essential nutrients, conditioning the soil for the entire growing season. Second, and perhaps more importantly, it improved the soil's physical and chemical environment by enhancing aggregation, water retention, and nutrient-holding capacity.[14] This created a more favorable habitat for root proliferation and microbial activity.

Into this improved soil environment, the periodic fertigation with Jeevamrut (T_2) and Vermiwash (T_3) provided a targeted boost of beneficial microorganisms, enzymes, and readily available nutrients at critical growth stages (20, 40, 60 DAS). Jeevamrut acts as a potent microbial inoculum, enhancing the soil's native capacity to cycle nutrients, while Vermiwash provides a direct supply of soluble nutrients and plant growth hormones [23]. This combination represents a sophisticated agronomic strategy: vermicompost builds the "house" for soil life, while Jeevamrut and Vermiwash "populate" it and provide "fast food" for the plants. This synergistic interaction between a stable organic base and dynamic liquid supplements explains why these integrated treatments achieved yields comparable to the high-input organic treatment (T_1) with only half the amount of vermicompost. The performance of T_1 itself, which achieved over 70% of the conventional yield using only vermicompost, validates the potential of high-quality organic amendments to serve as a complete nutrient source, capable of producing grains with excellent quality attributes [10].

4.3 Reconciling Productivity, Profitability, and Sustainability in a Semiarid Context

This study synthesizes agronomic, economic, and qualitative data to offer a nuanced portfolio of nutrient management options tailored for the semiarid context. It is important to note that the economic analysis did not assume any "organic price premium," which is often cited in studies showing higher profitability for organic systems.[46] The analysis reflects the market reality for many farmers in the region who may not have access to certified organic markets.[48] In this context, the treatments should not be viewed in a simplistic "winner-takes-all" framework, but rather as a suite of strategies suitable for different farming objectives and resource endowments.

- **T_8 (Conventional):** This remains the strategy for maximizing short-term yield and profit, best suited for farmers with reliable access to capital, irrigation, and markets, but it carries long-term ecological risks and market dependencies.
- **T_1 (100% Organic VC):** This is a high-input, high-quality organic strategy. Its high cost makes it most viable for established organic farmers who can command a premium price for their certified produce and are focused on building soil capital for long-term resilience.
- **T_2 and T_6 (INM):** These treatments represent a pragmatic "middle path." They offer a balanced approach that maintains good yields and profitability while significantly reducing chemical fertilizer use and actively improving soil health. They are an ideal transition strategy for conventional farmers looking to move towards more sustainable practices.
- **T_4 (Low-Input Organic):** This is the most economically resilient and risk-averse option. It is perfectly suited for small, marginal, and resource-poor farmers who wish to minimize cash outlay, break dependency on external inputs, and incrementally build the health and fertility of their soil. This strategy prioritizes long-term stability and self-reliance over short-term yield maximization.

5. Conclusion

This comprehensive field study on wheat under semiarid conditions provides clear and actionable conclusions for navigating the complex challenge of sustainable crop production.

First, the application of 100% recommended dose of chemical fertilizers (T_8) unequivocally resulted in the highest plant growth, grain yield (3,927 kg ha^{-1}), and immediate economic returns (B:C ratio 3.30). This reaffirms the efficacy of synthetic fertilizers for maximizing short-term productivity but must be contextualized by their associated long-term sustainability concerns.

Second, the study successfully demonstrates that integrated nutrient management is a highly effective strategy for reducing chemical dependency. The combination of 50% RDN through vermicompost supplemented with biofertigation using Jeevamrut and Vermiwash (T_2, T_3, T_6) provided substantial yields, significantly outperforming the unfertilized control. This validates a pathway to cut chemical fertilizer use by half while maintaining productive and profitable cultivation, thereby offering a practical transition towards more sustainable agriculture.

Third, a standout conclusion is the remarkable economic viability of the low-input organic strategy employing fortnightly application of Jeevamrut (T_4). Despite moderate yields, its minimal cost of cultivation led to a highly competitive B:C ratio of 1.92, making it an exceptionally attractive and resilient option for resource-constrained farmers in semiarid regions seeking to minimize financial risk and market dependency.

Fourth, this research provides strong evidence that organic nutrient management significantly enhances the nutritional quality of wheat. The higher concentrations of essential micronutrients (Zn, Fe, Cu, Mg) in grain from organic treatments highlight the role of these systems in agronomic biofortification, offering a potential strategy to address regional nutritional deficiencies.

Ultimately, this study recommends a strategic shift away from sole reliance on chemical inputs towards the adoption of integrated and low-input organic systems. These approaches offer a portfolio of options that can be tailored to different farmer capacities and objectives, providing a robust framework to enhance the long-term sustainability, profitability, and resilience of wheat farming in the semiarid agroecosystems of Central India and beyond.

References

1. Jackson ML. Soil Chemical Analysis. New Delhi: Prentice Hall of India Pvt. Ltd.; 1973.
2. Palekar S. The Philosophy of Spiritual Farming. Amravati, Maharashtra: Zero Budget Natural Farming Association; 2006.
3. Piper CS. Soil and Plant Analysis. Bombay: Hans Publishers; 1966.
4. Potdukhe NR, Bharad SG, Mahatale PV, Kanase NM, Khatod JP. PDKV Sardar (AKAW 4210-6): A bread wheat variety for late sown irrigated ecology in Maharashtra. Wheat and Barley Research. 2018;10(1):-.
5. Prasad R, Shivay YS, Kumar D, Sharma SN. Agronomic research on nutrient management in rice-wheat cropping system. Indian Journal of Agronomy. 2010;55(2):81-95.
6. Subbiah BV, Asija GL. A rapid procedure for the estimation of available nitrogen in soils. Current Science. 1956;25(8):259-260.
7. Zhang J, *et al*. Organic fertilizer substitution enhances wheat grain iron and zinc bioavailability and nutritional quality. Scientific Reports. 2021;11(1):1-10.
8. Lim SL, Wu TY, Lim PN, Shak KPY. The use of vermicompost in organic farming: a review. Journal of the Science of Food and Agriculture. 2015;95(6):1143-1156.
9. Suthar S. Vermicomposting of vegetable-market solid waste using Eisenia fetida: Earthworm population growth and decomposition rate. Waste Management. 2009;29(10):2629-2635.
10. Kaur P, Saini MK. Jeevamrut: A natural fertilizer. World Scientific News. 2021;158:1-9.
11. Sreenivasa MN, Naik N, Bhat SN. Beejamruth: A source for beneficial bacteria. Karnataka Journal of Agricultural Sciences. 2009;22(5):1038-1040.
12. Nath G, Singh K. Effect of vermiwash of different vermicomposts on the growth and productivity of some Rabi crops. Journal of Central European Agriculture.

2016;17(4):1234-1245.
13. Manyuchi MM, Mfitisodze A, Kadzungura L, Phiri A. Comparison of vermicompost and vermiwash bio-fertilizers from vermicomposting waste corn pulp. International Journal of Agricultural Science and Research. 2013;3(3):115-122.
14. Singh R, Sharma RR, Kumar S, Gupta RK, Patil RT. Vermicompost substitution influences growth, physiological disorders, fruit yield and quality of strawberry (*Fragaria × ananassa* Duch.). Bioresource Technology. 2008;99(17):8507-8511.
15. Sharma AK. A Handbook of Organic Farming. Jodhpur: Agrobios (India); 2003.