



Synergistic effects of organic and inorganic fertilizers on potato yield and soil nutrient status

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ABSTRACT

Potato, a nutrient-exhaustive crop, depends heavily on external nutrient inputs, and the prolonged use of chemical fertilizers has raised serious concerns regarding soil degradation and environmental sustainability. In this context, the present study evaluated the efficacy of organic nutrient management as a sustainable alternative by examining its effects on potato productivity, nutrient uptake, and soil nutrient availability. The experiment revealed that the integrated application of rice residue incorporation (5 t ha⁻¹), biofertilizers (*Azotobacter*, phosphate-solubilizing bacteria, and *Trichoderma viride* @ 5 kg ha⁻¹), and vermicompost (7.5 t ha⁻¹) significantly enhanced the number of tubers per plant compared to sole chemical fertilization. Notably, the organic treatment produced tuber yields statistically comparable to those obtained with 100% recommended dose of fertilizers (RDF), indicating its potential to substitute conventional inputs without compromising productivity. In addition, organic nutrient management improved the uptake of essential nutrients, particularly nitrogen, phosphorus, and potassium, and increased their availability in soil, reflecting enhanced nutrient cycling and soil fertility. The synergistic effects of organic inputs likely promoted better soil structure, microbial activity, and sustained nutrient release. Overall, the findings demonstrate that integrated organic nutrient management can maintain potato yield while improving soil health, thereby offering a viable and environmentally sustainable alternative to chemical fertilization in intensive cropping systems.

Key words: Biofertilizer, organic fertilization, nutrients availability, rice residue, vermicompost, potato yield.

INTRODUCTION

Potato (*Solanum tuberosum* L.) is one of the most important food crops globally and plays a crucial role in ensuring food and nutritional security, particularly in developing countries. It is a highly productive crop with a short growth duration and the ability to produce more food per unit area and time compared to many cereals (Mushtaq *et al.*, 9). Nutritionally, potato is a rich source of carbohydrates (primarily starch), high-quality protein with a good balance of essential amino acids, dietary fiber, vitamins such as vitamin C, B-complex (B1, B3, B6), and minerals including potassium, phosphorus, and magnesium (Dupuis and Liu, 3). It also contains several bioactive compounds such as phenolics and antioxidants, contributing to its health-promoting properties (Xu *et al.*, 22). Due to its versatility in culinary uses and its role in processing industries, potato is often referred to as the king of vegetables (Patel and Pundir, 14).

Being a heavy nutrient feeder, potato requires a substantial quantity of nutrients for optimum growth and tuber development. The crop has a shallow root system and high biomass production, which necessitates frequent and adequate nutrient supply. Conventionally, this demand has been met through the application of chemical fertilizers. However, continuous and excessive use of chemical fertilizers has led to several adverse effects, including soil degradation, nutrient imbalance, decline in soil organic matter, reduced microbial activity, and environmental pollution (Behera *et al.*, 1). These concerns have raised questions about the long-term sustainability of intensive fertilizer-based production systems. In contrast, organic fertilizer management focuses on maintaining soil fertility, enhancing biological activity, and sustaining agricultural productivity while minimizing environmental risks (Diacono and Montemurro, 2). Organic inputs such as crop residues, farmyard manure, compost, and vermicompost contribute to improved soil structure, water-holding capacity, cation exchange capacity, and nutrient cycling. In India, approximately 500–550 million tonnes of agricultural residues are generated annually, of which about 34% originate from rice cultivation (NAAS, 10). These residues, often underutilized or

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burned, represent a valuable resource for sustainable agriculture. Incorporation of crop residues into soil not only recycles nutrients but also enhances soil organic carbon and microbial activity, thereby improving soil health (Sarkar *et al.*, 16).

Biofertilizers further complement organic nutrient management by facilitating nutrient availability and uptake. Microorganisms such as *Azotobacter* can fix atmospheric nitrogen, while phosphate-solubilizing bacteria (PSB) enhance phosphorus availability by converting insoluble phosphates into plant-available forms. Similarly, *Trichoderma* spp. not only contribute to nutrient mineralization but also act as biocontrol agents, improving plant health and resilience (Meena *et al.*, 8). The combined use of crop residues, biofertilizers, and organic manures offers a promising alternative to chemical fertilizers by providing a balanced and sustained nutrient supply. Previous studies have demonstrated that organic amendments can significantly improve crop productivity and soil fertility (Nongmaithem and Pal, 11). Enhanced availability and uptake of essential nutrients such as nitrogen (N), phosphorus (P), and potassium (K) under organic management have been widely reported (Singh *et al.*, 17). Moreover, organic inputs have been shown to improve soil physical, chemical, and biological properties, leading to better crop performance over time. However, most of the existing research has focused on the individual effects of specific organic amendments, such as vermicompost or biofertilizers, rather than their combined or interactive effects.

Despite the recognized benefits of organic nutrient sources, there remains a significant knowledge gap regarding the synergistic interactions between crop residues, organic manures, and biofertilizers, particularly in potato cultivation systems. Limited information is available on how these components collectively influence tuber yield, nutrient uptake, soil nutrient dynamics, and economic returns. Furthermore, comparative evaluations of organic and inorganic nutrient management strategies under similar conditions are scarce, especially in the context of sustainable intensification. Considering these gaps, the present investigation was undertaken to evaluate the effects of organic and inorganic fertilizer management on potato productivity and soil nutrient availability. The study specifically aimed to assess tuber yield and yield attributes under different nutrient management practices, evaluate nutrient uptake (N, P, and K) by the crop, determine changes in soil nutrient status, and analyze the profitability of different treatments. The ultimate objective was to develop a sustainable and efficient nutrient management

strategy that can reduce dependence on chemical fertilizers while maintaining or enhancing potato productivity and soil health.

MATERIALS AND METHODS

The field experiment was conducted during the winter season of 2020–2021 at the research farm of Dr. Rajendra Prasad Central Agricultural University, Pusa, Bihar. The region receives an average annual rainfall of 1633 mm. The experimental soil was classified as an Entisol with a sandy loam texture. It was slightly alkaline in reaction (pH 8.31), low in organic carbon (0.47%) and available nitrogen (254 kg ha⁻¹), and medium in available phosphorus (17.4 kg ha⁻¹) and potassium (129.3 kg ha⁻¹).

Eight treatments were evaluated in a randomized block design with three replications. Potato (cultivar 'Kufri Lalit') was planted at a spacing of 60 cm × 20 cm. The treatments included: (i) control, (ii) 100% recommended dose of fertilizer (RDF), (iii) 50% RDF, (iv) rice residue incorporation (RRI) @ 5 t ha⁻¹ + biofertilizers, (v) RRI + biofertilizers + farmyard manure (FYM) @ 25 t ha⁻¹, (vi) RRI + biofertilizers + vermicompost @ 7.5 t ha⁻¹, (vii) RRI + biofertilizers + neem cake @ 5 t ha⁻¹, and (viii) RRI + biofertilizers + poultry manure @ 3 t ha⁻¹. The nutrient composition of organic sources varied: rice straw contained 0.56% N, 0.11% P, and 1.18% K; FYM contained 0.51% N, 0.23% P, and 0.54% K; vermicompost contained 1.80% N, 1.49% P, and 1.23% K; neem cake contained 5.01% N, 1.02% P, and 1.44% K; and poultry manure contained 2.63% N, 2.04% P, and 1.35% K.

The gross plot size was 4.8 m × 4.0 m (19.2 m²). The recommended chemical fertilizer dose was 150 kg N, 90 kg P, and 100 kg K ha⁻¹. The full dose of phosphorus and potassium, along with half of the nitrogen, was applied as basal, while the remaining nitrogen was applied in two equal splits at 25 and 45 days after planting.

Dehauling was carried out 20 days prior to harvest to ensure proper tuber maturity, followed by harvesting of potato tubers. Five plants from each plot were randomly selected for recording various growth parameters. Dry matter accumulation (g plant⁻¹) was determined after oven drying the samples for 72 hours. The tuber bulking rate was calculated by dividing the difference in tuber weight between two successive stages by the number of days between intervals and expressed as g day⁻¹ plant⁻¹. The number of tubers per plant was recorded after proper cleaning. Grade-wise tuber yield (t ha⁻¹) was determined by weighing tubers of different grades (>75 g). Total tuber yield was estimated by harvesting all tubers from the

net plot area and recording their weight to compute final yield (t ha^{-1}).

Net return was calculated by subtracting the cost of cultivation from the gross return using the following equation: Net return (₹ ha^{-1}) = Gross return (₹ ha^{-1}) – Cost of cultivation (₹ ha^{-1}).

Soil available nitrogen Subbiah and Asija (18), phosphorus Jackson (4), and potassium Jackson (5) were determined using standard analytical methods. Nutrient concentrations in plant and tuber samples were estimated using the Kjeldahl method for nitrogen, the vanado-molybdate yellow color method for phosphorus, and flame photometry for potassium (Subbiah and Asija 18). Nutrient uptake was calculated by multiplying the dry matter yield of tubers/haulms with the corresponding nutrient concentration. Statistical analysis was performed using the “F” test at a 5% level of significance ($p \leq 0.05$).

RESULTS AND DISCUSSION

Organic nutrient management comprising rice residue incorporation (RRI) @ 5 t ha^{-1} + biofertilizers + vermicompost @ 7.5 t ha^{-1} significantly improved crop growth and yield attributes of potato. This treatment recorded 4% higher plant dry weight compared to 100% recommended dose of fertilizers (RDF), indicating enhanced biomass accumulation under organic nutrient supply (Table 1). Similarly, the number of tubers per plant increased by 3% over 100% RDF, reflecting better tuber initiation and development under integrated organic inputs. However, no significant difference was observed between organic fertilization and 100% RDF with respect to tuber bulking rate, suggesting that both nutrient sources were equally effective in supporting tuber growth during the bulking phase. The improved

performance under organic fertilization may be attributed to the synergistic effects of crop residue, biofertilizers, and vermicompost, which together enhanced nutrient availability, microbial activity, and soil physical conditions. The gradual mineralization of organic inputs likely ensured a sustained release of nutrients, thereby supporting continuous plant growth and efficient accumulation of photosynthates (Meena *et al.*, 8). In addition, biofertilizers such as *Azotobacter* and phosphate-solubilizing bacteria might have improved nitrogen fixation and phosphorus availability, further contributing to enhanced crop performance. With respect to yield, the organic fertilization treatment (RRI + biofertilizer + vermicompost) recorded a remarkable 115.8% increase in grade-wise tuber yield over the control, demonstrating the effectiveness of organic inputs in improving both yield and tuber quality (Table 2). Notably, the tuber yield under this treatment was statistically at par with 100% RDF, indicating that organic nutrient management can successfully substitute chemical fertilizers without compromising productivity. The higher yield under organic amendments can be ascribed to the continuous and balanced supply of essential nutrients through mineralization processes, improved soil structure, and enhanced root growth (Zaman *et al.*, 23). Despite comparable yields, economic analysis revealed that 100% RDF resulted in 28.9% higher net returns than organic fertilization (Fig.1). This was primarily due to the higher cost associated with the application and handling of bulky organic manures such as vermicompost and crop residues (Verma *et al.*, 20). Therefore, while organic nutrient management offers clear advantages in terms of sustainability, soil health, and environmental safety, its economic feasibility may depend on reducing input costs or integrating it with partial chemical fertilization.

Table 1: Effect of organic and inorganic nutrient sources on growth parameters of potato.

Treatment	Dry matter accumulation at 75 DAS (g plant^{-1})	Number of tubers plant^{-1} at 75 DAS	Tuber bulking rate at 75 DAS ($\text{g day}^{-1} \text{ plant}^{-1}$)
Control	32.8 ^{e*}	4.59 ^d	3.20 ^f
100% recommended dose of fertilizer	52.9 ^{ab}	8.47 ^a	7.46 ^a
50% recommended dose of fertilizer	40.8 ^{cd}	5.99 ^c	5.42 ^d
Rice residue incorporation (RRI) + biofertilizer	36.3 ^{de}	5.17 ^d	4.07 ^e
RRI + biofertilizer + FYM	51.4 ^{ab}	8.13 ^a	6.96 ^{ab}
RRI + biofertilizer + vermicompost	54.9 ^a	8.70 ^a	7.48 ^a
RRI + biofertilizer + neem cake	49.2 ^b	7.15 ^b	6.62 ^{bc}
RRI + biofertilizer + poultry manure	42.6 ^c	6.26 ^c	6.19 ^c

DAS = Days after sowing; *within a column, numbers followed by different lowercase letters are significantly different between treatment at $p \leq 0.05$; Biofertilizers = *Azotobacter*, Phosphate solubilizing bacteria, *Trichoderma viridae*.

Table 2: Effect of organic and inorganic nutrient sources on yield attributing character, yield and net return in potato.

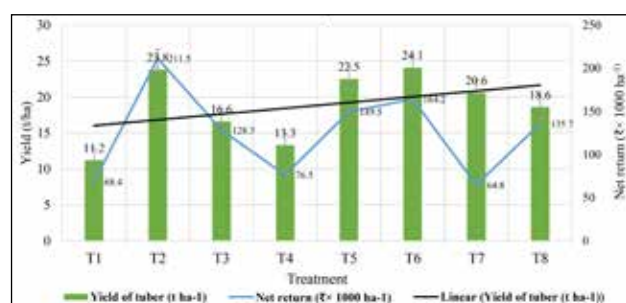
Treatment	Graded tuber (> 75 g) yield (t ha ⁻¹)	Yield of tuber (t ha ⁻¹)	Net return (₹ × 1000 ha ⁻¹)
Control	1.90 ^e	11.2 ^f	68.4 ^d
100% recommended dose of fertilizer	4.05 ^a	23.8 ^a	211.5 ^a
50% recommended dose of fertilizer	2.81 ^d	16.6 ^d	128.3 ^c
Rice residue incorporation (RRI) + biofertilizer	2.27 ^e	13.3 ^{ef}	76.5 ^d
RRI + biofertilizer + FYM	3.83 ^{ab}	22.5 ^{ab}	149.5 ^{bc}
RRI + biofertilizer + vermicompost	4.10 ^a	24.1 ^a	164.2 ^b
RRI + biofertilizer + neem cake	3.51 ^{bc}	20.6 ^{bc}	64.8 ^d
RRI + biofertilizer + poultry manure	3.16 ^{cd}	18.6 ^{cd}	135.7 ^{bc}

*Within a column, numbers followed by different lowercase letters are significantly different between treatment at $p \leq 0.05$; Biofertilizers = Azotobacter, Phosphate solubilizing bacteria, *Trichoderma viridae*.

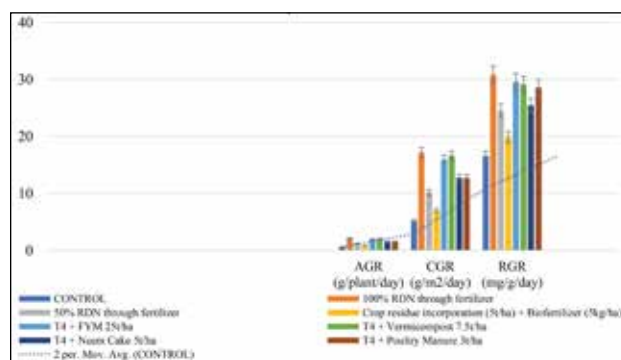
Table 3: Effect of organic and inorganic nutrient sources on growth indices.

Treatment	AGR (g/plant/day)	CGR (g/m ² /day)	RGR (mg/g/day)
Control	0.62 ^{d*}	5.18 ^c	16.56 ^a
100% recommended dose of fertilizer	2.06 ^a	17.19 ^a	30.80 ^a
50% recommended dose of fertilizer	1.22 ^{bc}	10.15 ^b	24.50 ^a
Rice residue incorporation (RRI) + biofertilizer	0.84 ^{cd}	7.01 ^{bc}	19.88 ^a
RRI + biofertilizer + FYM	1.9 ^a	15.94 ^a	29.58 ^a
RRI + biofertilizer + vermicompost	2.00 ^a	16.63 ^a	29.12 ^a
RRI + biofertilizer + neem cake	1.53 ^{ab}	12.74 ^{ab}	25.44 ^a
RRI + biofertilizer + poultry manure	1.52 ^{ab}	12.67 ^{ab}	28.57 ^a

*Within a column, numbers followed by different lowercase letters are significantly different between treatment at $p \leq 0.05$; Biofertilizers = Azotobacter, Phosphate solubilizing bacteria, *Trichoderma viridae*.

**Fig. 1.** Comparative analysis of tuber yield and economic profitability of potato crop.

Different nutrients sources significantly influenced the AGR and CGR of the crop, whereas the effect on RGR was found to be non-significant (Table 3, Fig.2). Among all the treatments, application of 100% recommended dose of fertilizer (RDF) recorded the highest AGR (2.06 g plant⁻¹ day⁻¹) and CGR (17.19 g m⁻² day⁻¹), which was statistically at par with RRI + biofertilizer + vermicompost (2.00 g plant⁻¹ day⁻¹ and 16.63 g m⁻² day⁻¹) and RRI + biofertilizer + FYM (1.90

**Fig. 2.** Effect of organic and inorganic sources of nutrients on growth indices of potato.

g plant⁻¹ day⁻¹ and 15.94 g m⁻² day⁻¹). The lowest AGR (0.62 g plant⁻¹ day⁻¹) and CGR (5.18 g m⁻² day⁻¹) were observed under control treatment. Incorporation of rice residue along with biofertilizer alone recorded comparatively lower AGR (0.84 g plant⁻¹ day⁻¹) and CGR (7.01 g m⁻² day⁻¹), but these values improved substantially when organic sources such as FYM,

vermicompost, neem cake, and poultry manure were added along with biofertilizer.

Regarding RGR, numerical variations were observed among treatments, ranging from 16.56 to 30.80 mg g⁻¹ day⁻¹; however, the differences were statistically non-significant, indicating that the treatments did not exert a marked influence on relative growth rate. Overall, integrated nutrient management practices involving rice residue incorporation, biofertilizer, and organic amendments performed better than control and 50% RDF, and remained comparable with 100% RDF in promoting crop growth (Kumar *et al.*, 7).

Organic nutrient management and 100% recommended dose of fertilizers (RDF) exhibited statistically similar effects on nutrient concentration and uptake in potato plants (Table 3), indicating that organic sources were equally efficient in meeting crop nutrient requirements. Moreover, organic nutrient management recorded relatively higher soil nutrient availability, with increases of 3.4% in nitrogen, 34.3% in phosphorus, and 7.5% in potassium compared to chemical fertilization (100% RDF). However, the treatments RRI + biofertilizer + vermicompost and 100% RDF remained at par with respect to soil available N, P, and K, suggesting comparable nutrient-supplying capacity under both systems (Table 4). The improved nutrient availability under organic treatments may be attributed to reduced nutrient losses through leaching and volatilization, along with enhanced nutrient retention and gradual mineralization of organic matter, which contributes to building soil nutrient reserves over time (Wang *et al.*, 21). Although long-term experiments are generally more reliable for assessing sustainability trends Diacono and Montemurro, (2), short-term

studies such as the present investigation can still demonstrate meaningful improvements in soil nutrient dynamics when appropriate management practices are followed Kumar and Garhwal (6). While the application of inorganic fertilizers can substantially increase crop yields, their excessive and indiscriminate use has been associated with detrimental effects on soil health, including nutrient imbalance, decline in soil organic matter, and reduced microbial activity (Pahalvi *et al.*, 13). Additionally, prolonged reliance on chemical fertilizers may contribute to soil degradation, erosion, water pollution, and disruption of beneficial soil microbial communities (Behera *et al.*, 1). In contrast, organic inputs such as vermicompost improve soil structure and biological activity. The relatively balanced lignin-to-nitrogen ratio in vermicompost facilitates faster decomposition and nutrient release compared to raw plant biomass, making nutrients readily available for short-duration crops like potato (Thomas *et al.*, 19; Rehman *et al.*, 15). Furthermore, the combined application of vermicompost and biofertilizers enhances nutrient mineralization and availability, ensuring a steady nutrient supply throughout the crop growth period (Rehman *et al.*, 15). Biofertilizers can improve nutrient mineralization efficiency by approximately 10–30% in potato cultivation, thereby contributing to better nutrient use efficiency and crop performance (Nosheen *et al.*, 12). The organic nutrient management demonstrates strong potential to address the environmental and soil health concerns associated with excessive chemical fertilizer use. However, the economic feasibility of such systems may be constrained by the high cost and bulkiness of organic inputs when sourced externally. Therefore, for sustainable adoption, it is essential to promote

Table 4: Nitrogen (N), phosphorus (P) and potassium (K) content in whole plant of potato, their uptake and availability at harvest in soil under different inorganic and organic nutrient sources.

Treatment	Concentration of nutrients in plant (%)			Nutrient uptake by plant (kg ha ⁻¹)			Available nutrient in soil (kg ha ⁻¹)		
	N	P	K	N	P	K	N	P	K
Control	1.61 ^{d*}	0.16 ^f	1.51 ^e	55.0 ^f	5.57 ^f	51.3 ^e	200.9 ^c	10.3 ^d	99.6 ^d
100% recommended dose of fertilizer	2.06 ^a	0.35 ^a	2.02 ^a	139.7 ^a	23.8 ^a	135.2 ^a	239.6 ^{ab}	17.2 ^b	162.3 ^{ab}
50% recommended dose of fertilizer	1.76 ^{bc}	0.24 ^{de}	1.72 ^{cd}	84.0 ^d	11.5 ^d	81.6 ^c	226.0 ^b	14.1 ^c	138.6 ^c
Rice residue incorporation (RRI) + biofertilizer	1.69 ^{cd}	0.21 ^e	1.65 ^d	67.1 ^e	8.20 ^e	65.0 ^d	233.3 ^{ab}	16.4 ^{bc}	155.5 ^b
RRI + biofertilizer + FYM	2.05 ^a	0.28 ^{bc}	2.05 ^a	133.2 ^a	18.3 ^b	131.3 ^a	244.6 ^{ab}	20.7 ^a	168.4 ^{ab}
RRI + biofertilizer + vermicompost	2.07 ^a	0.37 ^a	2.08 ^a	142.7 ^a	25.4 ^a	140.4 ^a	247.7 ^a	23.1 ^a	174.4 ^a
RRI + biofertilizer + neem cake	1.85 ^b	0.26 ^{cd}	1.88 ^b	108.2 ^b	15.4 ^c	108.3 ^b	243.3 ^{ab}	16.9 ^b	159.8 ^b
RRI + biofertilizer + poultry manure	1.81 ^b	0.30 ^b	1.81 ^{bc}	95.9 ^c	16.3 ^{bc}	94.6 ^c	241.2 ^{ab}	17.5 ^b	160.0 ^b

*Within a column, numbers followed by different lowercase letters are significantly different between treatment at $p \leq 0.05$; Biofertilizers = Azotobacter, Phosphate solubilizing bacteria, *Trichoderma viridae*.

on-farm production of organic inputs and develop cost-effective strategies to ensure both environmental sustainability and economic viability (Verma *et al.*, 20).

Thus, the present study indicates that the integrated use of crop residues, biofertilizers, and organic manures/vermicompost (e.g., rice residue incorporation @ 5 t ha⁻¹ + biofertilizers + vermicompost @ 7.5 t ha⁻¹) can achieve potato yields comparable to those obtained with chemical fertilizers, while enhancing soil nutrient availability. These findings highlight the potential of organic nutrient management as a sustainable alternative to conventional fertilization practices. The study provides valuable insights for promoting environmentally sound and resource-efficient farming systems, particularly in regions where organic agriculture is gaining importance. Furthermore, the results contribute to the development of improved nutrient management strategies and support the wider adoption of organic amendments for long-term agricultural sustainability.

AUTHOR'S CONTRIBUTION

Conceptualization of research (SA,DK); Designing of the experiments (AK); Contribution of experimental materials (DK,B); Execution of lab experiments (DK,B); Analysis of data and interpretation (SA); Preparation of manuscript (DK, SA).

DECLARATION

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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