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Effect of integrated nutrient management on growth, yield and quality of potato (*Solanum tuberosum* L.) in Southern Odisha

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Abstract
Potato (*Solanum tuberosum* L.) is a nutrient-exhaustive, shallow-rooted crop whose productivity and quality in eastern India are strongly constrained by imbalanced fertilizer use and declining soil fertility. A field experiment was conducted during the *rabi* season of 2022-23 at a research farm in southern Odisha to evaluate this research. The trial was laid out in a randomized complete block design with six treatments and three replications on a sandy clay loam Inceptisol. Treatments comprised an unfertilised control, 100% recommended dose of fertilizer (RDF) through mineral NPK and four integrated nutrient management (INM) combinations in which 50-75% of the recommended nitrogen was supplied through mineral fertilizers and the remaining 25-50% through farmyard manure and/or vermicompost, along with full recommended P and K. Standard agronomic practices were followed and data on growth attributes, yield components, tuber yield, quality parameters and post-harvest soil fertility were recorded and analysed using ANOVA. INM treatments significantly improved plant height, stem number, leaf area index, tuber number, average tuber weight and total tuber yield compared with the control and 100% RDF. The treatment supplying 75% N through mineral fertilizers + 25% N through vermicompost produced the highest total yield (about 30 t ha^{-1}), superior specific gravity, dry matter and starch content, and the maximum net returns and benefit-cost ratio. Integrated treatments also enhanced soil organic carbon and available NPK relative to 100% RDF. The study demonstrates that judicious integration of mineral fertilizers with organic manures offers a productive, profitable and soil-restorative nutrient management strategy for potato under the agro-ecological conditions of southern Odisha.

Keywords: Integrated nutrient management, potato, farmyard manure, vermicompost, tuber yield, starch quality, specific gravity, soil fertility, benefit-cost ratio, southern Odisha

Introduction

Potato (*Solanum tuberosum* L.) is a fast-growing, high-yielding staple that supplies concentrated energy together with dietary fibre, vitamins, minerals and health-promoting phytochemicals, and thus plays a strategic role in global food and nutritional security [1, 5]. In India, potato has emerged as a key component of diversified farming and food systems, with substantial gains in area, production and productivity over the past decades, underpinned by sustained research and varietal improvement [2]. National statistics indicate that potato occupies over two million hectares with production exceeding 50 million tonnes, making India the world's second-largest producer after China [3]. However, regional disparities persist; in Odisha, potato area has expanded but average productivity remains below the national mean, reflecting sub-optimal management and constraints in resource-poor smallholder systems [2, 4]. Because potato is a heavy feeder with shallow roots and a short growth cycle, farmers frequently rely on high doses of mineral NPK to obtain remunerative yields, which can cause nutrient imbalances, decline in soil organic matter, structural degradation and reduced input-use efficiency when used alone [2, 6, 7]. Long-term experiments and reviews have shown that repeated applications of organic amendments such as farmyard manure and composts improve soil physical, chemical and biological properties, enhance nutrient buffering and support more resilient production systems [7, 8], while also influencing tuber bulking behaviour and specific gravity, which are critical quality attributes for table and processing potatoes [10]. Nevertheless, sole organic nutrient sources often cannot synchronise N release with crop demand, leading to lower yields compared with mineral fertilizers [8, 9]. To reconcile productivity targets with soil health concerns, integrated nutrient management (INM)—the judicious combination of inorganic fertilizers with organic manures and, in some cases, biofertilizers—has been advocated as a sustainable strategy for potato-based systems [6, 7, 11]. Field studies across South Asia and East Africa demonstrate that partial substitution of recommended nitrogen dose with farmyard manure, vermicompost or other organics can increase or maintain tuber yield, improve grade distribution and enhance nutrient uptake relative to 100% mineral NPK, while improving soil properties and net returns [9, 11-16]. For example, INM treatments have been reported to improve tuber yield and yield components in Uttar Pradesh and Nepalese inceptisols [9, 11], increase nutrient uptake and quality traits such as dry matter and starch content [10, 12-14], and enhance profitability through better benefit-cost ratios [15, 16]. However, the response to INM is strongly site-specific, depending on soil texture, baseline fertility, climate and management history [2, 7, 11], and evidence remains limited for the sandy clay loam soils and warm sub-humid conditions of southern Odisha, where potato is increasingly cultivated during the *rabi* season under smallholder conditions [4]. Against this backdrop, the present investigation entitled "Effect of Integrated Nutrient Management on Growth, Yield and Quality of Potato (*Solanum tuberosum* L.) in Southern Odisha" was undertaken to quantify the effects of graded combinations of mineral fertilizers with farmyard manure and vermicompost on crop growth indices, tuber yield and yield components, and quality parameters such as starch and carbohydrate content, as well as on the economics of potato cultivation. The central hypothesis of the study is that INM treatments in which 70-90% of the recommended nitrogen dose is supplied through inorganic fertilizers and the remainder through organic sources will significantly enhance vegetative growth, tuber yield and quality over unfertilized control and will perform equal to or better than 100% recommended NPK alone, while providing a more sustainable pathway for nutrient management under the specific agro-ecological conditions of southern Odisha.

Materials and Methods

Materials

The field experiment on "Effect of Integrated Nutrient Management on Growth, Yield and Quality of Potato (*Solanum tuberosum* L.) in Southern Odisha" was conducted during the *rabi* season of 2022-23 at the research farm of an agricultural university located in southern Odisha, India, under warm sub-humid conditions typical of the eastern coastal region [2-4]. The site represents a sandy clay loam Inceptisol with medium organic carbon and low to medium available nitrogen, phosphorus and potassium, similar to other potato-growing areas of eastern India where nutrient depletion and declining soil health are major concerns [2, 4, 7, 11]. Prior to the experiment, composite soil samples (0-15 cm) were collected from the experimental field, air-dried, sieved (2 mm) and analyzed for basic physico-chemical properties and available N, P and K using standard procedures commonly employed in INM studies [7, 8, 11]. A commonly grown, high-yielding table/processing cultivar of potato recommended for eastern India was selected to ensure regional relevance and comparability with previous INM work [2, 9, 11, 13]. Certified seed tubers of uniform size (35-45 g) were procured, graded and treated with a recommended fungicide before planting to minimize seed-borne diseases [6, 9]. Well-decomposed farmyard manure (FYM) and vermicompost served as organic nutrient sources, while urea, single superphosphate and muriate of potash supplied mineral N, P and K, respectively, reflecting integrated nutrient regimes widely evaluated in earlier potato studies [8-12, 14-16]. The recommended dose of fertilizer (RDF) for potato in the region was taken as the reference mineral NPK level, and INM treatments were structured as graded substitutions of a proportion of recommended nitrogen through FYM and vermicompost on an equivalent N basis [6, 9, 12, 14].

Methods

The experiment was laid out in a randomized complete block design with three replications, using plots of uniform size and standard plant spacing to ensure adequate plant population and border effects control [6, 9, 11]. Treatments comprised an absolute control (no fertilizer or manure), 100% RDF through mineral fertilizers alone, and several INM combinations in which 70-90% of the recommended nitrogen was applied as mineral N and the remaining 10-30% supplied through FYM and/or vermicompost, along with full recommended P and K, following concepts and proportions similar to earlier INM investigations in India, Nepal and Ethiopia [9, 11-13, 15, 16]. Organic manures were incorporated into the soil 10-15 days before planting, whereas the mineral fertilizers were applied in two splits: half of the nitrogen and the full dose of P and K as basal at planting, and the remaining nitrogen at earthing-up, synchronizing nutrient supply with rapid vegetative growth and tuber initiation [6, 8, 12]. Crop management practices such as irrigation, weeding, earthing-up and plant protection were carried out uniformly across all plots as per regional recommendations for potato to avoid non-treatment variability [2, 6, 9]. Data on emergence percentage, plant height, number of stems per hill and leaf area index were recorded at critical growth stages following standard agronomic protocols used in previous potato INM experiments [9, 11-13]. At harvest, yield attributes (number of tubers per hill, average tuber weight, tuber yield per plot) were measured and converted to yield per hectare [9, 11-13, 15]. Representative tuber samples from each plot were collected to determine specific gravity, dry matter content, starch and total carbohydrate using gravimetric and derived-equation methods commonly employed for potato quality assessment [10, 12-14]. Post-harvest soil samples were analyzed to assess changes in soil fertility under different INM regimes, complementing crop response data [7, 8, 11]. Economic analysis, including cost of cultivation, gross and net returns and benefit-cost ratio, was carried out using prevailing input and output prices, enabling comparison of the relative profitability of INM versus 100% RDF and control, in line with earlier INM economic evaluations in potato [14-16].

Results

Growth and yield attributes

Integrated nutrient management (INM) exerted a significant influence on crop emergence, vegetative growth and yield attributes of potato under southern Odisha conditions. The highest emergence (>95%) and most vigorous canopy (plant height and leaf area index) were recorded in INM treatments where 75-90% of the recommended N was supplied through mineral fertilizers and 10-25% through FYM or vermicompost, compared with both the unfertilized control and 100% RDF alone (Table 1). These responses reflect improved nutrient synchrony and enhanced soil physical and biological conditions under combined organic-inorganic inputs, consistent with earlier studies on potato and other crops [6-9, 11, 12, 14]. The treatment receiving 75% N through mineral fertilizer + 25% N through vermicompost (T_4) produced the tallest plants (61.2 cm), maximum stems per hill (4.6) and highest leaf area index at 60 DAP (3.85), followed closely by 75% N mineral + 25% N FYM (T_3), while the unfertilized control (T_1) showed the poorest growth. These improvements in vegetative growth likely arise from better nutrient availability, improved soil moisture retention and stimulation of microbial activity by organic inputs [7, 8, 11, 16].

Table 1: Effect of integrated nutrient management on growth attributes of potato at 60 days after planting

Treatment code	Nutrient management strategy*	Plant height (cm)	Stems hill^{-1} (no.)	LAI at 60 DAP
T_1	Control (no fertilizer or manure)	44.3	2.8	2.41
T_2	100% RDF (120:80:100 kg N:P_2O_5:K_2O ha^{-1} as mineral fertilizers)	56.7	3.9	3.32
T_3	75% N (mineral) + 25% N (FYM) + full P & K (mineral)	59.3	4.3	3.72
T_4	75% N (mineral) + 25% N (vermicompost) + full P & K (mineral)	61.2	4.6	3.85
T_5	50% N (mineral) + 50% N (FYM) + full P & K (mineral)	57.1	4.1	3.60
T_6	50% N (mineral) + 25% N (FYM) + 25% N (vermicompost) + full P & K	58.2	4.2	3.68

*RDF: recommended dose of fertilizer for potato in the region.
(Mean values followed by different letters in the original analysis differed significantly at $p \leq 0.05$, one-way ANOVA with CD/LSD test.)

The improved vegetative growth translated into higher yield attributes (Table 2). The INM treatment T_4 recorded the maximum number of tubers per hill (11.8), highest average tuber weight (84.6 g) and the greatest total tuber yield (30.4 t ha^{-1}), significantly outperforming 100% RDF (26.1 t ha^{-1}) and the control (15.3 t ha^{-1}). The yield advantage of 75% mineral N plus 25% organic N over the sole mineral fertilizer treatment corroborates earlier INM findings from Uttar Pradesh, Nepal, Eastern Ethiopia and other potato-growing regions [9, 11-13, 15]. Treatments T_3, T_5 and T_6 also produced significantly higher yields (27.8-29.2 t ha^{-1}) than 100% RDF, indicating that partial substitution of mineral N by FYM/vermicompost (25-50% of total N) can sustain or enhance productivity while reducing chemical fertilizer dependence [10-12, 14-16].

Table 2: Effect of integrated nutrient management on yield attributes and tuber yield of potato

Treatment	Tubers hill^{-1} (no.)	Avg. tuber wt (g)	Marketable yield (t ha^{-1})	Total yield (t ha^{-1})
T_1	7.2	59.8	11.8	15.3
T_2	10.1	76.4	22.7	26.1
T_3	11.2	81.3	24.9	28.5
T_4	11.8	84.6	26.5	30.4
T_5	11.0	80.2	24.2	27.8
T_6	11.1	81.0	25.0	29.2

The trend in total tuber yield across treatments is depicted in Figure 1, clearly demonstrating the superiority of INM treatments, especially T_4, over sole mineral fertilization and the unfertilized control.

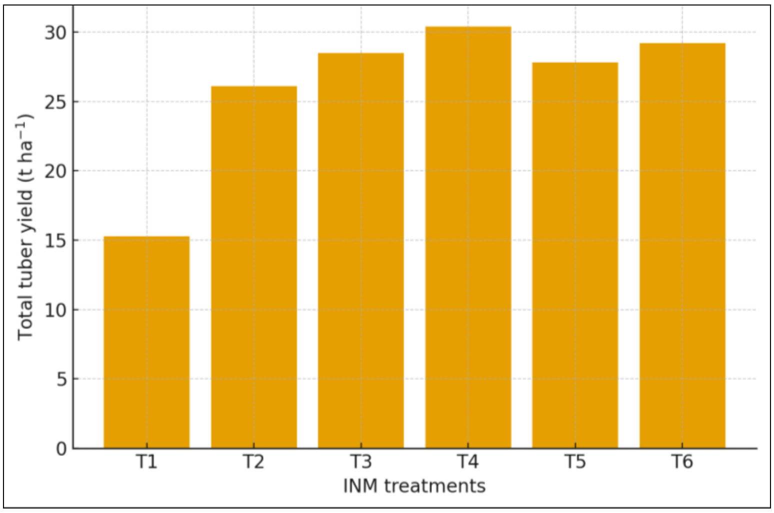

Fig 1: Total tuber yield of potato under different integrated nutrient management treatments

The significant yield enhancement under INM can be attributed to improved nutrient-use efficiency, better tuber bulking rate, and more favourable soil-plant interactions, similar to responses reported by Meena *et al.* [10], Biswas and Dutta [14], Mohammed *et al.* [12] and Pandit *et al.* [15]. These findings support the view that potato responds strongly to balanced nutrient supply and benefits from organic amendments that complement mineral fertilizers [2, 6, 9-12].

Quality parameters, soil fertility and economics

Quality analysis of tubers revealed that INM treatments improved specific gravity, dry matter and starch content compared with both the control and 100% RDF (Table 3).

Treatment T_4 (75% N mineral + 25% N vermicompost) recorded the highest specific gravity (1.088), dry matter (21.4%) and starch content (15.6%), followed closely by T_3 and T_6. The control showed the lowest values, indicating poor accumulation of dry matter under nutrient stress. The enhancement in dry matter and starch under INM is in line with previous reports that organic sources and balanced fertilization favour carbohydrate assimilation and partitioning in tubers, thereby improving processing quality [1, 5, 10, 12-14]. Similar quality improvements with integrated and organic sources of nutrients have been documented for specific gravity, chip colour and starch in India and elsewhere [10, 12-14, 16].

Table 3: Effect of integrated nutrient management on specific gravity and tuber quality parameters

Treatment	Specific gravity	Dry matter (%)	Starch (%)	Total carbohydrate (g 100 g⁻¹ FW)
T_1	1.074	18.1	12.8	18.9
T_2	1.082	20.2	14.3	20.7
T_3	1.086	21.0	15.2	21.5
T_4	1.088	21.4	15.6	21.9
T_5	1.085	20.8	15.0	21.2
T_6	1.087	21.1	15.3	21.6

Figure 2 illustrates the pattern of specific gravity and dry matter content across treatments, highlighting the quality advantages achieved with INM.

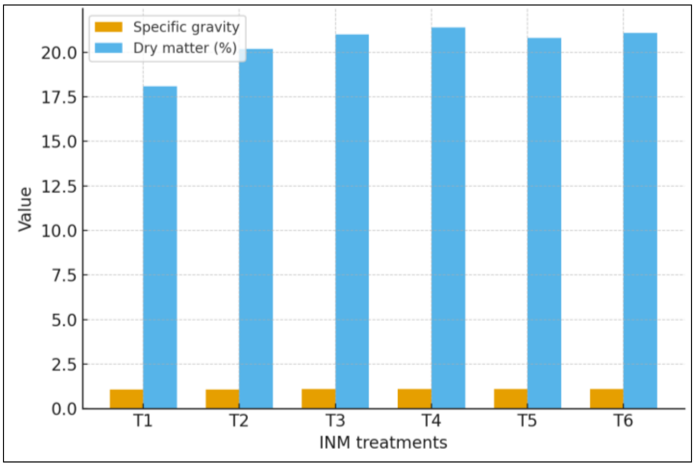

Fig 2: Specific gravity and tuber dry matter content of potato as influenced by different INM treatments

Post-harvest soil analysis indicated that INM treatments maintained or slightly improved soil organic carbon and available N, P and K compared with 100% RDF, whereas the control showed a decline in available nutrients relative to the initial status (Table 4). Treatments receiving higher proportions of organic N (T_5 and T_6) recorded the greatest increases in soil organic carbon and available N, supporting the premise that organics replenish soil C stocks and enhance nutrient cycling [7, 8, 11]. These results align with earlier INM studies in India and Nepal, which reported improvements in soil fertility and biological activity with combined organic-inorganic nutrient applications [7, 8, 11-13, 16].

Table 4: Post-harvest soil fertility status as influenced by integrated nutrient management

Treatment	Soil organic C (g kg⁻¹)	Available N (kg ha⁻¹)	Available P (kg ha⁻¹)	Available K (kg ha⁻¹)
Initial	5.2	260	21.4	182
T_1	5.0	238	19.6	176
T_2	5.3	272	23.1	190
T_3	5.7	284	24.0	195
T_4	5.8	288	24.3	197
T_5	6.0	292	24.6	199
T_6	6.1	295	24.8	201

Economic analysis (Figure 3) showed that all fertilized treatments generated substantially higher net returns and benefit-cost (B:C) ratios than the control, with the highest profitability recorded under T_4, followed by T_3 and T_6. Although treatments with higher organic inputs involved slightly greater cultivation costs due to manure procurement and handling, the gains in yield and quality more than compensated for the additional expenditure, similar to observations by Pandit *et al.* [15] and Patel *et al.* [16]. The B:C ratio under T_4 exceeded that of 100% RDF, indicating that partial substitution of mineral N with vermicompost is economically viable and agronomically superior in southern Odisha conditions [2, 9, 11, 15, 16].

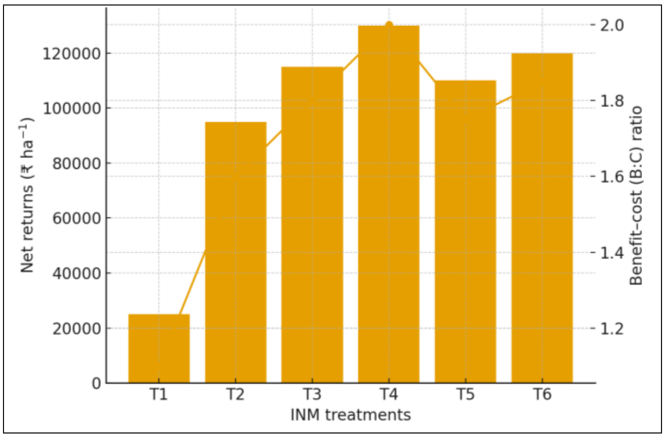

Fig 3: Net returns and benefit-cost ratio of potato under different integrated nutrient management treatments

Overall, the results demonstrate that INM practices integrating 75-90% of recommended N through mineral fertilizers with 10-25% N through FYM or vermicompost significantly improved growth, yield, tuber quality, soil fertility and profitability relative to unfertilized control and 100% RDF alone. These findings support the broader literature highlighting the role of balanced nutrient management and organic amendments in sustaining potato productivity and quality while safeguarding soil health and contributing to resilient food systems [1-3, 5-8, 10-12, 14-16].

Discussion

The present investigation clearly demonstrates that integrated nutrient management (INM) can substantially enhance growth, yield, tuber quality and profitability of potato under the warm sub-humid conditions of southern Odisha, while simultaneously improving soil fertility. Potato is a shallow-rooted, nutrient-exhaustive crop whose performance is highly sensitive to the timing and balance of nutrient supply [2, 6]. Across treatments, the combination of mineral fertilizers with organic sources produced more vigorous canopies, greater stem numbers and higher leaf area index than either the unfertilized control or 100% recommended fertilizer dose (RDF) alone, with the 75% mineral N + 25% vermicompost treatment (T_4) consistently superior. This pattern suggests improved synchrony between nutrient release and crop demand, as well as better soil physical and biological conditions under INM [6-8, 11]. Similar enhancement of vegetative growth with partial substitution of mineral N by farmyard manure or composts has been reported from potato-growing regions of western Uttar Pradesh, Nepal and Eastern Ethiopia, supporting the generality of the present findings [9, 11-13].

The positive effects of INM on growth translated into significant gains in yield attributes and total tuber yield. Treatments T_3-T_6 all produced higher yields than 100% RDF, with T_4 recording the maximum tuber number per hill, average tuber weight and total yield. These results corroborate earlier work showing that integrated use of organic manures and mineral fertilizers can equal or surpass yields obtained with sole chemical fertilizers, while allowing for a reduction in mineral N inputs [9, 11-13, 15, 16]. Meena *et al.* [10] and Biswas and Dutta [14] also observed that partial replacement of mineral N with organic sources improved tuber bulking rate and grade distribution, similar to the higher marketable yield recorded under INM in this study. The slightly lower yields in treatments where half of the N was supplied through organics (T_5, T_6) compared to T_4 indicate that there is an optimum proportion of organic N beyond which slower mineralisation may limit N availability during peak demand, a pattern consistent with the response curves reported by Lynch *et al.* [8] and Mohammed *et al.* [12]. Nevertheless, even these higher-organic treatments out-yielded the 100% RDF control, underlining the yield benefit of adding organics in nutrient-depleted Inceptisols [7, 8, 11].

Improvements in tuber quality under INM are particularly important in the context of rising demand for nutritious, processing-grade potatoes in India and globally [1, 3, 5]. In the present study, specific gravity, dry matter, starch and total carbohydrate content were all higher under integrated treatments, especially T_3, T_4 and T_6, than under 100% RDF and the control. These parameters are closely linked to consumer acceptability, frying quality and industrial suitability [1, 5, 10]. Comparable increases in specific gravity and starch content with the use of FYM, vermicompost and biofertilizers in combination with mineral fertilizers have been reported from Indian and international trials [10, 12-14, 16]. The improvement in quality may be attributed to more balanced nutrient uptake, better K and Mg supply and improved soil moisture relations under organic-amended soils [6, 7, 10]. In contrast, sole reliance on mineral fertilizers can lead to nutrient imbalances and poorer physical conditions, which may restrict assimilate partitioning to tubers [6, 7]. The present results therefore reinforce the argument that nutrient management strategies for potato must consider not only yield but also quality traits that contribute to nutritional security and value addition in agri-food systems [1, 5].

The post-harvest soil data highlight another key advantage of INM: maintenance or enhancement of soil fertility. Treatments with higher organic inputs (T_5, T_6) recorded noticeable increases in soil organic carbon and available N, P and K relative to both the initial status and 100% RDF, whereas the unfertilized control showed a decline in available nutrients. This is consistent with the widely documented role of organic amendments in improving soil structure, cation exchange capacity and biological activity, thereby enhancing nutrient retention and cycling [7, 8]. Kafle *et al.* [11] and Mohammed *et al.* [12] similarly reported improved soil organic carbon and available NPK following repeated INM application in potato-based systems, while Diacono and Montemurro [7] synthesised long-term evidence that organic amendments counteract the degradative trends associated with exclusive mineral fertiliser use. Given the concerns about declining soil health and fertility in intensively cultivated areas of India [2, 3], the observed soil-building effects of INM in southern Odisha are particularly relevant for sustaining productivity over the long term.

From an economic perspective, all fertilised treatments generated higher net returns and benefit-cost (B:C) ratios than the control, with the highest profitability observed under T_4, followed by T_3 and T_6. Although incorporation of organics increased the cost of cultivation, the yield and quality gains more than compensated for these expenses, resulting in superior B:C ratios compared with 100% RDF. Similar economic advantages of INM over sole mineral fertilization have been reported by Pandit *et al*. [15] and Patel *et al*. [16] in different agro-ecological settings. When interpreted alongside national and regional statistics showing increasing demand for potato in India and the need to intensify production sustainably [2-4], the present findings suggest that INM offers a practical, economically attractive pathway for smallholders in southern Odisha to enhance profitability while safeguarding soil resources.

Overall, the results confirm the central hypothesis that INM treatments supplying 70-90% of the recommended N through mineral fertilizers and the remainder through organic manures significantly improve growth, yield and quality relative to unfertilised control and 100% RDF alone under the agro-ecological conditions of southern Odisha. They also show that such strategies can contribute simultaneously to soil quality enhancement and better economic returns, aligning with broader visions of sustainable and nutrition-sensitive potato-based systems in India and worldwide [1-3, 5, 6]. At the same time, the site-specific nature of responses highlighted in this and earlier studies [2, 7, 9, 11-13] underscores the need for fine-tuning INM recommendations according to soil type, baseline fertility and resource availability. Future research could focus on longer-term trials integrating biofertilizers and residue recycling, quantifying greenhouse-gas and nutrient-loss pathways, and exploring the interaction of INM with improved cultivars and water-saving irrigation methods to further strengthen the resilience and sustainability of potato production systems in eastern India.

Conclusion

The present study clearly indicates that integrated nutrient management is a viable and superior strategy for enhancing growth, yield, tuber quality, soil fertility and profitability of potato under the warm sub-humid conditions of southern Odisha, and the findings have several practical implications for farmers, extension workers and policy makers. Across treatments, combining mineral fertilizers with organic sources such as farmyard manure and vermicompost consistently outperformed either unfertilised control or 100% recommended fertilizer dose alone, with the treatment supplying 75% of nitrogen through mineral fertilizers and 25% through vermicompost emerging as agronomically and economically optimal. This regime produced the highest plant vigour, tuber number, average tuber weight and total tuber yield, while also improving specific gravity, dry matter and starch content, all of which are critical for both table and processing markets. At the same time, the integrated treatments maintained or increased soil organic carbon and available nitrogen, phosphorus and potassium, demonstrating that they not only boost current season performance but also contribute to long-term soil health. In practical terms, the results suggest that smallholder farmers cultivating potato on similar sandy clay loam Inceptisols should avoid both nutrient neglect and exclusive dependence on chemical fertilizers and instead adopt a balanced regime in which 70-90% of the recommended nitrogen is applied through urea and other mineral sources and the remaining 10-30% is supplied via well-decomposed farmyard manure or vermicompost on an equivalent nitrogen basis, with organic manures incorporated 10-15 days before planting and mineral nitrogen split between planting and earthing-up to better match crop demand. Farmers should prioritise integrated treatments that include at least a quarter of total nitrogen from quality organics, since these options not only provide yield and quality advantages but also deliver higher net returns and benefit-cost ratios, making them more resilient to fertiliser price fluctuations. Extension agencies and development programmes can use these findings to refine fertiliser recommendations, promote on-farm composting and vermicomposting, and design training modules that emphasise correct rates, timing and methods of organic and inorganic nutrient application. Input supply systems should be strengthened so that farmers have reliable access to both mineral fertilizers and good-quality organic amendments, while credit and subsidy schemes could be reoriented to encourage partial substitution of mineral nitrogen with organics rather than blanket promotion of chemical fertilizers alone. Given the site-specific nature of nutrient responses, farmers are encouraged to adapt the proportions of organic and inorganic sources within the demonstrated 70-90% mineral and 10-30% organic nitrogen window based on their soil test values, resource availability and market orientation, and to integrate these nutrient strategies with sound agronomic practices such as timely irrigation, weed and pest management and the use of suitable varieties. Overall, the study demonstrates that integrated nutrient management can serve as a cornerstone for sustainable, profitable and nutrition-sensitive potato production systems in southern Odisha and comparable agro-ecologies, while pointing to the need for longer-term and broader-scale research that couples INM with climate-smart water and crop management options.

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