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Synergistic Effects of Farmyard Manure and NPK (17-17-17) Fertilizer on Growth and Yield of Irish Potato (*Solanum tuberosum* L.) in Northern Rwanda

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ABSTRACT

This study evaluated the effect of inorganic fertilizers (NPK 17-17-17) and farmyard manure (FYM) at different doses on the agronomic performance of Irish potato in Busogo sector, Northern Rwanda. A field experiment was conducted during season A (January-April 2025) at UR-CAVM model farm using a randomized complete block design with five treatment: T0 (control), T1 (NPK only), T2 (high dose of FYM at 4.05 kg/plot), T3 (low dose of FYM at 2.025 kg/plot), and T4 (combined NPK+FYM). Growth parameters (plant height, leaf numbers, stem diameter) were measured at 50, 65, and 80 DAP. Yield component included tuber weight. Statistical analysis using ANOVA revealed significant differences (p<0.05) among treatments with the T4 producing the highest growth and yield. Combined application of NPK+FYM significantly increased plant height (85.1cm), stem diameter (1.03 cm) and tuber weight (11.5 kg/plot), highlighting synergistic effect of integrating organic-inorganic nutrient sources. The findings support integrated nutrient management as sustainable strategy for optimizing Irish potato production. The study recommends applying FYM at 30 ton/ha and NPK at 300 kg/ha for maximum yield under similar agro-ecological conditions. These results can inform fertilizer guidelines and promote sustainable intensification of potato farming system in Rwanda and other highland regions of sub-Saharan Africa.

1. INTRODUCTION

The Irish potato (*Solanum tuberosum* L.) stands as a foundational crop contributing immensely to global food security. Globally, it ranks third in consumption after rice and wheat, and is the premier root and tuber crop, surpassing cassava, sweet potato, and yams (Nanbol *et al*., 2019). It is a popular and important field crop not only for local consumption but also for generating income through exportation across different countries (Milkias, 2021). With its high nutritional profile including carbohydrates, protein, dietary fiber, vitamins, minerals, and amino acids along with easy digestibility and capacity for bulk quantity production, the potato has become one of the world's most popular vegetables (Beals, 2019). In 2021, a total of 376 million tons of potatoes were produced worldwide, with China and India being the largest producers (Gelaye, 2023). The potato's importance extends beyond nutrition; it plays critical roles in securing food, preventing poverty, and combating hunger, particularly in developing countries (Devaux *et al*., 2021).

The Irish potato is a tuber crop native to South America, specifically in the region between the south of Peru and the North-East of Bolivia (Nally & Kearns, 2020). It was first cultivated in this area between three and seven thousand years ago. The crop's distribution to other parts of the world occurred through the colonial political power of European countries (Ríos & Devaux, 2024). Today, it is cultivated in over 120 countries worldwide (Hellmann *et al*., 2021). In Rwanda, a landlocked country in East Africa's Great Lakes region, the potato was introduced by German missionaries at the close of the 19th century, with its official integration into the agricultural system in 1930 under

Belgian administrators (Shimira *et al*., 2020). Today, the potato is the country's second most important source of calorie intake, only after cassava (Austin *et al*., 2020). The highlands in the southwest and north of the country offer the most favorable climatic conditions for its production, accounting for about 80% of the national potato yield (Muhinyuza *et al*., 2022). The agriculture sector in Rwanda is a top government priority for achieving sustainable development and food security (Perez *et al*., 2023), and the country relies on small, fragmented plots for livelihoods, emphasizing the need for high-yielding crops (Kim *et al*., 2022).

Despite its importance, Rwanda's potato productivity is currently less than its potential (Havugimana *et al*., 2023). This shortfall is attributed to several constraints: the inconsistent use of fertilizers, high cost of chemical fertilizers, poor soil fertility, and a shortage of farmyard manure to cover all fields. The role of fertilizers in enhancing crop yield and quality is well known (Alnaass *et al*., 2021). While farmyard manure is a valuable organic source of N and other nutrients that can decrease the reliance on chemical fertilizers and improve soil fertility, a balanced NPK fertilization is crucial for maximizing both yield and growth (Adekiya *et al*., 2020). This situation highlights the need for an Integrated Nutrient Management (INM) approach. Combining organic (farmyard manure) and inorganic (NPK 17-17-17) fertilizers is theorized to offer a superior strategy (Sande *et al*., 2024), leveraging the rapid nutrient availability of chemical fertilizers with the long-term soil structure and moisture retention benefits provided by organic matter (Geng *et al*., 2019).

The Busogo sector, situated in Northern Rwanda near the Virunga National Park, presents a highly specific challenge where intensive cultivation on volcanic soils leads to rapid nutrient depletion and necessitates specialized fertilization strategies to maintain productivity and prevent soil degradation (Anggriawan *et al*., 2023). Furthermore, as potato cultivation represents a major cash crop for farmers in this region, the efficiency and profitability of fertilization directly impact local economic stability (Miklyaev *et al*., 2021). This need for both ecological sustainability and economic viability underscore the urgent requirement for precise, localized data on nutrient application (Maniriho & Nkikabahizi, 2025).

Research has been conducted in Rwanda on the effects of different doses of farmyard manure and inorganic fertilizer (NPK 17-17-17) on the growth and yield of Irish potatoes. However, there is still a gap in fully understanding the synergistic effects of combining these two nutrient sources on the growth and final yield of Irish potatoes, especially under the specific agro-ecological conditions of the Busogo sector. The main objective of this research is to evaluate the synergistic effect of integrating inorganic fertilizers (NPK 17-17-17) and farmyard manure at different doses on the agronomic performance and yield of Irish potato using the Kinigi variety in the Busogo sector, Northern Rwanda. The findings of this study are expected to provide valuable, updated information to farmers on the most effective and sustainable fertilizer management practice and to inform and refine fertilizer guidelines for the sustainable intensification of potato farming systems in Rwanda and other highland regions of sub-Saharan Africa.

2. MATERIALS AND METHODOLOGY

2.1. Experimental Site

The field experiment was conducted during season A (January to April 2025) at the University of Rwanda College of Agriculture, Animal Sciences and Veterinary Medicine (UR-CAVM) model farm, located in the Busogo sector of the Musanze District, Northern Province of Rwanda. This area is situated near the Virunga National Park and is characterized by a high-altitude agro-ecological zone. The region experiences a humid, cool climate that is highly conducive for Irish potato production (Sunday *et al*., 2024). It has mean altitude of approximately 2300 m above sea level, mean temperature of 16.7℃, soil pH of 5.7-5.8, and annual rainfall between 1400 and 1800 mm (Uwiringiyimana *et al*. 2019).

Busogo Sector has 4 seasons: a short dry season from mid-December to mid-February, a heavy rainy season from mid-February to the end of June, a heavy dry season extending from June to August and a short rainy season from August to mid-December. Most of the people in Busogo Sector are involved in agriculture, and the main crops grown are potatoes, maize, beans and vegetables (Nahayo *et al*. 2012). The soils in this sector are predominantly volcanic, characterized by good drainage but often subject to rapid organic matter decomposition and nutrient depletion due to intensive cultivation, thereby underscoring the necessity of integrated nutrient management (Maniriho *et al*., 2022).

2.2. Experimental Design and Layout

The experiment employed a Randomized Complete Block Design (RCBD). This design was chosen to account for potential variability in soil fertility across the experimental field (a common issue in model farms) by grouping similar experimental units into blocks.

- Replications: The experiment was laid out using four (4) replications (blocks).
- Treatments: The study utilized five (5) distinct nutrient treatments, resulting in a total of 20 experimental plots (5 treatments × 4 replications).
- Plot size: Each experimental plot measured 3.0 m × 3.0 m (area of 9.0 m²). A buffer zone of 1.0 m was maintained between blocks and 0.5 m between adjacent plots to minimize interference from neighbouring treatments.

The test crop used was the Kinigi variety of Irish potato (*Solanum tuberosum* L.), which is a high-yielding and locally preferred cultivar in the Northern Province of Rwanda.

2.3. Treatment Combinations and Application Rates

The five treatments were formulated to test the effects of single applications of organic or inorganic fertilizers versus their combination and were applied to the experimental plots as detailed in Table 1. The inorganic fertilizer (NPK 17-17-17) was applied in two splits: half at the time of planting, and the remaining half was applied during the first earthing-up (hilling) stage, approximately four weeks after planting. Meanwhile, FYM was thoroughly mixed into the topsoil of the respective plots one week before planting. The FYM was sourced locally and allowed to decompose adequately before application.

Table 1. Description of different treatments and the rate of fertilizers applied

Code	Treatment description	Applied rate (hectare basis)	Plot rate (9.0 m²)
T0	Control (No fertilizer or manure)	0 t/ha FYM + 0 kg/ha NPK	0 kg/plot
T1	NPK (17-17-17) only	0 t/ha FYM + 300 kg/ha NPK	2.7 kg/plot
T2	High Dose Farmyard Manure (FYM)	45 t/ha FYM + 0 kg/ha NPK	4.05 kg/plot
T3	Low Dose Farmyard Manure (FYM)	22.5 t/ha FYM + 0 kg/ha NPK	2.025 kg/plot
T4	Combined NPK and FYM (Synergistic Dose)	22.5 t/ha FYM + 150 kg/ha NPK	2.025 kg/plot FYM + 1.35 kg/plot NPK

2.4. Experimental Maintenance Practices

The experimental maintenance practices were meticulously designed to support the entire growth cycle of the Irish potatoes. This process began with thorough land preparation, where soil tillage and ridging were executed to ensure quick emergence, deep root penetration, and effective drainage. All seeds were planted at a consistent depth of 10 cm. Subsequent crop management included a crucial weeding two weeks after emergence to prevent competition for nutrients, water, and light. Furthermore, the plants were hilled up twice, at four and six weeks after emergence to provide space for tuber formation and to protect them from pests and sunlight. An Integrated Pest Management (IPM) strategy was implemented, featuring weekly sprays of a combined solution of Dithane M45, Lidomil, and Dudu to control early and late blight. The potatoes were harvested at maturity (4 month after planting), which was determined by the complete drying of the vegetative parts, indicating the end of dry matter accumulation at approximately four months. At this stage, the tubers were carefully harvested, and key yield parameters were recorded. This data, alongside observations collected during the growth period, was then prepared for comprehensive analysis and interpretation in the final research report.

2.5. Data Collection

Growth parameters including plant height, number of leaves, and stem diameter. While yield parameters fresh tuber weight per sample and per plot were observed at harvesting time (4 months after planting). For growth parameters, 5 plants in each treatment were sampled randomly, and measurement was conducted at three growth stages 50, 65, and 80 day after planting (DAP) as the following:

1. Plant height (cm) was measured using the a tape meter from the ground surface to the highest point of plants.
2. Number of leaves was observed by counting true leaves of 5 sampled plants.
3. Stem diameter was measured using Vernier caliper.
4. Weight of tuber was measured for 5 sampled plants. The weighing balance was used to measure the weight of tubers. Then mean weight was calculated to get weight of tubers per plant.
5. Potato yield per plot was measured by weighing tubers per plot. In this case, all tubers in a plot were weighed using a beam balance.

2.5.1. Statistical Analysis

Data were recorded and initially managed in Microsoft Excel. To determine the impact of the treatments, the data were analyzed using a one-way analysis of variance (ANOVA) in JMP PRO 17, with statistical significance defined at $p < 0.05$. Following a significant F-test, post-hoc comparisons of treatment means were performed using Tukey's Honest Significant Difference (HSD) test to control for Type I error across multiple comparisons.

3. RESULTS

3.1. Plant Height

Table 2 represents analysis of plant height data that reveals significant differences among fertilizer treatments across all measured growth stages. The combined application of FYM and inorganic NPK fertilizer (T4) consistently resulted in the tallest plants, demonstrating a significant advantage over all other treatments at 50 and 65 DAP, and achieving the highest final height of 85.13 cm at 80 DAP. The only inorganic fertilizer (T1) and high-dose FYM (T2) treatments were statistically equivalent to each other at all stages, forming a second-tier group that outperformed the lower-dose treatments but was generally surpassed by the combined T4 treatment. The low-dose farmyard manure (T3) provided a moderate but significant growth improvement over the unfertilized control (T0), which consistently yielded the shortest plants. By the final measurement at 80 days, the statistical distinction between the top treatment (T4) and the intermediate treatments (T1, T2) narrowed, indicating that while T4 promoted more rapid early growth, T1 and T2 approached a similar, although lower, final growth potential. These results underscore the superior efficacy of integrated nutrient management, where the synergistic effect of combining organic and inorganic sources provides a more readily available and sustained nutrient supply for optimal plant growth.

Table 2. Effects of FYM and inorganic fertilizer NPK treatments on plant height (cm) at different growth stages

	Mean at 50th day	Mean at 65th day	Mean at 80th day
T0: Control (no fertilizer)	31.47 ^{C}	50.67 ^{C}	64.27 ^{B}
T1: Inorganic fertilizer (NPK17-17-17)	43.53 ^{B}	63.27 ^{B}	74.47 ^{AB}
T2: High doses of farmyard manure	43.33 ^{B}	64.33 ^{B}	74.53 ^{AB}
T3: Low doses of farmyard manure	36.07 ^{BC}	58.27 ^{BC}	67.13 ^{B}
T4: Combination of FMY and NPK (17-17-17)	56.73 ^{A}	78.07 ^{A}	85.13 ^{A}

Note: Means within a column followed by the same letter are not significantly different at $p < 0.05$ according to Fisher's LSD test.

Table 3. Effects of different doses of farmyard manure and inorganic fertilizer (NPK17-17-17) on stem diameter

Treatment	Mean at 50th day	Mean at 65th day	Mean at 80th day
T0: No control	0.260 ^{C}	0.413 ^{C}	0.613 ^{D}
T1: Inorganic fertilizer (NPK17-17-17)	0.540 ^{A}	0.720 ^{AB}	0.867 ^{B}
T2: High doses of farmyard manure	0.500 ^{AB}	0.693 ^{AB}	0.833 ^{BC}
T3: Low doses of farmyard manure	0.293 ^{BC}	0.546 ^{BC}	0.713 ^{CD}
T4: Combination of FMY and NPK (17-17-17)	0.66 ^{A}	0.89 ^{A}	1.03 ^{A}

Note: Means within a column followed by the same letter are not significantly different at $p < 0.05$ according to Fisher's LSD test.

Table 3 shows mean data collected for stem diameter of potato plants. The results showed that there is significance difference among T0, T1, T2, T3 and T4 fertilizers applied on stem diameter of Irish potatoes at 50, 65 and 80 DAP. A plant with the biggest of stem diameter observed in T4 with mean 0.66 cm, 0.893 cm, and 1.00 respectively at 50, 65 and 80 DAP. The smallest were observed in T0 (control) with mean 0.26 cm, 0.41 cm, and 0.61 cm at 50, 65 and 80 DAP, respectively.

Table 4 provides mean data collected on number of leaves. The results show that among different treatment of fertilizers application T0, T1, T2, T3, and T4 resulted in significant difference on number of leaves of Irish potatoes observed at 50, 65, and 80 DAP. A plant with maximum number of leaves observed in T0 with mean 7.73 at 50 DAP. At 65 and 80 DAP, treatment T4 lead by 14.4 and 21.27 leaves, respectively. Low numbers of leaves were observed in T3 and T4 with mean 5.3 at 50 DAP, and treatment T3 with mean 8.73 and 13 at 65 and 80 DAP, respectively.

Table 4. Effects of different doses of farmyard manure and inorganic fertilizer (NPK17-17-17) on number of leaves of potato

Treatment	Mean at 50th day	Mean at 65th day	Mean at 80th day
T0: No control	7.73 A	12.67 A	16.47 B
T1: Inorganic fertilizer (NPK17-17-17)	7.33 A	13.13 A	16.60 B
T2: High doses of farmyard manure	7.47 A	12.87 A	17.33 B
T3: Low doses of farmyard manure	5.33 A	8.73 B	13.07 C
T4: Combination of FMY and NPK (17-17-17)	5.33 A	14.40 A	21.27 A

Note: Means within a column followed by the same letter are not significantly different at $p < 0.05$ according to Fisher's LSD test.

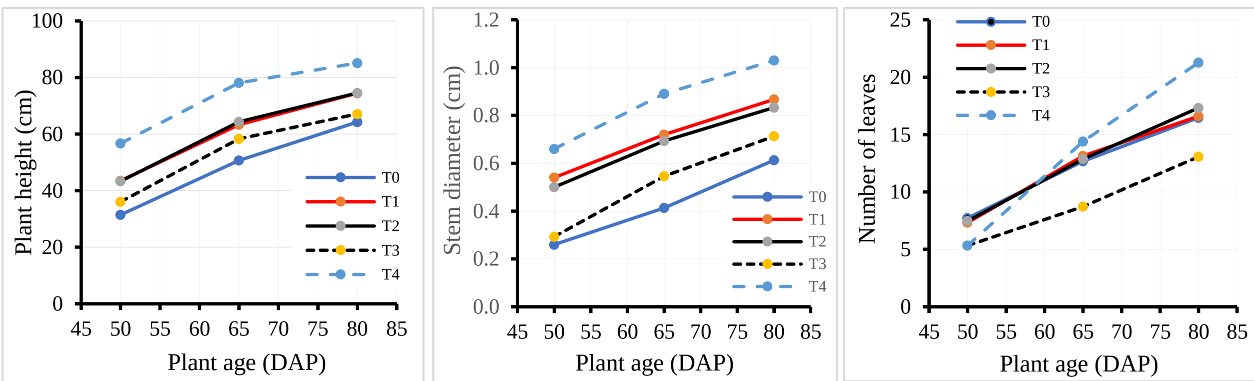

Figure 1. Agronomic development of potato plant as affected by different fertilizer treatments: (a) height height, (b) stem diameter, and (c) number of leaves

Figure 1 shows the effect of different fertilizer treatments on the plant development observed at three periods, namely 50, 65, and 80 DAP. The values in the figures are same as in the previous tables. The figure, however facilitates to quickly observe potato plant development.

Table 5. Effects of different doses of FYM and NPK on the sample tuber weight of potato

Treatment	Tuber weight (kg/plant)	Tuber weight (kg/plot)
T0: Control	0.65 B	6.83 C
T1: Inorganic fertilizer (NPK17-17-17)	1.00 AB	9.16A BC
T2: High doses of farmyard manure	0.75 AB	10.66 AB
T3: Low doses of farmyard manure	0.78 AB	8.0 BC
T4: Combination of FMY and NPK (17-17-17)	1.23 A	11.5 A

3.2. Plant Yield Parameters

Table 5 represents the mean data collected on the weight of tubers of plant samples. The weight was measured immediately after harvest. The results on the sample weight showed significant difference between control and treatment T4. However there was no significant difference among treatments T1, T2, T3, and T4 as well as among T0, T1, T2, and T3. The maximum weight of the sample was recorded from T4, with a mean of 1.23 kg/plant, followed by T1 with a mean of 1 kg/plant, and then the lowest from T0 (control), with a mean of 0.65 kg/plant. Table 5 also represents the mean data collected on the weight of tubers per plot; their weight was measured immediately. The results on the weight of tubers per plot showed no significant difference among T0, T1, T2, T3, and T4. The maximum weight of tubers per plot was recorded from T4, with a Mean of 11.5 kg, followed by T2, with a Mean of 10.6 kg, and then the lowest from T0, with a Mean of 6.8 kg.

4. DISCUSSIONS

The findings of this study clearly demonstrate that integrated nutrient management, combining farmyard manure (FYM) and inorganic fertilizer (NPK 17-17-17), had a significantly positive impact on the growth and yield of Irish potato (Alemayehu *et al*., 2020). Treatment T4, which applied combined FYM and NPK, consistently outperformed all other treatments across key agronomic parameters, highlighting a crucial synergy between the organic and inorganic nutrient sources (Ierna & Distefano, 2024).

- Enhanced plant growth: The superior performance of T4 in plant height (85.13 cm at 80 DAP) and stem diameter (1.03 cm at 80 DAP) compared to sole applications suggests that the combined approach optimizes nutrient availability and uptake kinetics. As presented in Figure 1, similar trends are observed for each growth parameter, indicating that each treatment resulted in similar growth rate, but different in starting point. In Figure 1(c), however, treatment T4 (combined FYM+NPK) shows the highest slope compared to other treatments. This implies that treatment T4 resulted in the highest rate of leaf formation.
- Inorganic fertilizer (NPK): The readily available nutrients, especially the balanced N, P, and K from NPK (Treatment T1), provided the immediate nutritional boost necessary for rapid early vegetative growth, which is critical for shoot elongation and stem thickening (Ren *et al*., 2025).
- Farmyard manure (FYM): The organic matter in FYM, even when applied alone at a high dose (Treatment T2), significantly improves soil structure and moisture retention and provides a slower, sustained release of both macro- and micronutrients. This improvement in the soil environment supports better root health and water use efficiency, which translates into stronger, thicker stems and overall better plant development (Gurmu, 2019).
- Synergistic effect (T4): The combination of T4 achieved the best of both worlds. The NPK provided the quick initial energy, while the FYM enhanced the long-term nutrient supply and the physical quality of the soil. This synergistic interaction allowed for maximal plant growth, resulting in the tallest and thickest plants across all measured stages (Sahoo, 2022).
- Maximized tuber yield: Direct and indirect benefits

The combined treatment (T4) resulted in the highest tuber yield, both in terms of mean weight per sample (1.23 kg) and total yield per plot (11.5 kg), demonstrating clear benefits from integrated nutrient management. The rapid nutrient delivery from NPK in T4 facilitated the necessary tuber initiation and bulking during the critical growth phases. Tania *et al*. (2024) reported that FYM simultaneously improve the soil's capacity to retain water and buffer nutrients, mitigate the potential for nutrient leaching and ensure a steady supply during tuber development. These combined factors provided the optimal conditions for maximum photosynthetic activity and efficient partitioning of assimilates toward the tubers. This outcome aligns with Bolo *et al*. (2024), highlighting that integrating FYM with inorganic fertilizers significantly enhances potato tuber yield by improving soil fertility and microbial activity.

1. Comparison with sole applications: The performance of the sole-application treatments underscores the limitations of relying on a single nutrient source.
2. High FYM alone (T2): This treatment performed commendably and was second to T4 in total yield per plot. This confirms the vital role of organic matter in sustaining high yields through improved soil health. However, the lower yields compared to T4 indicate that relying solely on organic sources may not be sufficient to meet the high, immediate nutrient demands of the Irish potato crop during critical stages.
3. NPK alone (T1): While superior to the control, T1 was generally inferior to T4 and T2 in terms of overall yield and growth. This is because inorganic fertilizers, while providing readily available nutrients, lack the long-term soil health benefits and moisture retention properties conferred by organic amendments, which are crucial for maintaining productivity (Aytenew & Bore, 2020).
4. Control (T0) and low FYM (T3): The lowest yields were recorded in the control (T0) and low FYM (T3)

treatments. This reinforces the known fact that Irish potato is a nutrient-exhaustive crop, and insufficient nutrient input, either through complete absence (T0) or suboptimal organic levels (T3), severely limits growth, tuber initiation, and overall productivity.

5. CONCLUSION

This study investigated the effects of different doses of farmyard manure (FYM) and inorganic fertilizer (NPK 17-17-17) on the growth and yield of Irish potatoes (*Solanum tuberosum* L.) in the Busogo sector, Northern Rwanda. The results demonstrated the scientific contribution that Integrated Nutrient Management (INM), specifically the combined application of farmyard manure and NPK (Treatment T4), is superior to sole applications of either input for optimizing Irish potato production. The maximum growth and yield were obtained from T4, which delivered the highest measurements for plant height (85.1 cm), stem diameter (1.03 cm), and tuber weight per plot (11.5 kg). This superior performance is a result of the synergistic effect of the two sources, which enhanced immediate nutrient availability, improved soil structure, and sustained nutrient supply.

RECOMMENDATIONS

Based on the findings of this research, recommendations are proposed for both scientific and practical applications. As practical recommendations, farmers are encouraged to use a combination of farmyard manure (30 t/ha) and NPK 17-17-17 fertilizer (300 kg/ha), as this treatment (T4) consistently resulted in the highest growth and yield performance of Irish potato (Kinigi variety). Where possible, farmers should collect and properly decompose farmyard manure before field application. Well-decomposed manure improves soil moisture retention, structure, and biological activity, all of which support sustainable crop productivity. Applying both manure and inorganic fertilizer reduces dependency on costly chemical inputs, increases soil fertility over time, and minimizes nutrient losses through leaching. In addition, agricultural extension officers in Busogo and similar highland regions should promote the practice of integrated nutrient management among smallholder potato growers through training and demonstration plots. Policy support: The Rwanda Agriculture and Animal Resources Development Board (RAB) should design policies promoting integrated fertilizer use by improving farmers' access to both mineral fertilizers and organic amendments through subsidies or community-based compost programs.

Future studies should investigate the long-term effects of integrating organic and inorganic fertilizers on soil fertility dynamics, nutrient use efficiency, and potato yield stability across multiple seasons and soil types. Additional experiments are recommended to analyze nutrient uptake kinetics and the soil plant nutrient balance under combined fertilizer application, to better understand the mechanisms behind nutrient synergy. In addition, it is also important for research institutions to replicate this experiment under different agro-ecological zones of Rwanda to develop region-specific fertilizer management guidelines.

AUTHOR CONTRIBUTION STATEMENT

Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
NA	✓	✓			✓	✓		✓	✓	✓				
IJ	✓	✓		✓		✓	✓			✓	✓	✓	✓	

C: Conceptualization	Fo: Formal Analysis	O: Writing - Original Draft	Fu: Funding Acquisition
M: Methodology	I: Investigation	E: Writing - Review & Editing	P: Project Administration
So: Software	D: Data Curation	Vi: Visualization	
Va: Validation	R: Resources	Su: Supervision	

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