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RESEARCH ARTICLE

Impact of Nutrient Management Strategies on Cassava Performance, Nutrient Uptake, and Economic Returns in Agusan del Sur, Philippines

E. G. Atalo*, R. J. C. Rollon and G. D. Jabagat

Highlights

- Site-specific nutrient management (SSNM) delivered highest ROIs (127.68%) despite not producing maximum yields
- Full NPK application maximized cassava productivity (average 47.75 t/ha), significantly outperforming control and nutrient omission treatments
- Potassium omission severely impacted growth parameters, tuber development, and marketable yield
- Both cassava varieties showed similar nutrient uptake patterns despite differences in growth characteristics
- While NPK fertilization improved total yield, it also resulted in higher non-marketable tubers compared to other treatments

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Impact of Nutrient Management Strategies on Cassava Performance, Nutrient Uptake, and Economic Returns in Agusan del Sur, Philippines

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Abstract: This study explores the efficiency of fertilizer management strategies on the yield, nutrient uptake, and economic returns of cassava varieties (Lakan 1 and Golden Yellow) grown in two sites in Agusan del Sur, Philippines. The study employed a split-plot randomized complete block design to assess eleven fertilizer treatments, including site-specific nutrient management (SSNM), full (NPK) application, nutrient omission (N, P, and K omission), adjusted nutrient (N, P, and K adjusted), national fertilizer recommendation (NFR), and farmers' fertilizer practice (FFP) conducted over 12 months. The results revealed that full NPK fertilization consistently produced the highest yields, with Lakan 1 and Golden Yellow reaching 47.61 t/ha and 47.89 t/ha, respectively. However, the SSNM treatment unexpectedly delivered the highest return on investment (ROI), with 128.61% for Lakan 1 and 126.75% for Golden Yellow, outperforming full NPK in economic efficiency. Despite differences in varietal growth characteristics, both varieties showed similar nutrient uptake patterns, indicating a uniform response to the nutrient management strategies applied. Additionally, NPK fertilization enhanced overall tuber yield; it also led to higher non-marketable yields compared to other treatments, particularly in nitrogen and potassium omission plots. SSNM was a cost-effective nutrient management approach, balancing productivity and economic returns and optimizing fertilizer strategies for cassava production, emphasizing the importance of tailored nutrient management for maximizing profitability.

***Keywords*:** Cassava; Nutrient omission; NPK fertilization; Varietal response, Agronomic performance

INTRODUCTION

Cassava (*Manihot esculenta* Crantz) is a small perennial shrub that grows 2–3 meters tall and produces thickened roots primarily composed of starch (Raemakers et al., 1999; Rao et al., 2017). This crop is widely cultivated in tropical and subtropical regions, particularly in Latin America, Africa, and Asia (Montagnac et al., 2009). Cassava is known for its drought tolerance and ability to thrive on low-fertility soils (Muiruri et al., 2021). It is increasingly becoming a critical crop, serving both as a source of direct human consumption and as an input for industrial processes, including animal feed, starch, starch-derived products, and biofuel production. In the Philippines, cassava is planted on more than 705,834 hectares, primarily in Northern Mindanao (PSA, 2016; NAST, 2024). Additional production areas are concentrated in the Cagayan Valley, Bicol Region, and ARMM in Luzon and Visayas. Despite the significant cultivation footprint, there remains considerable potential to boost production by addressing soil-related constraints through improved agricultural practices.

Extensive research has demonstrated that the macronutrients nitrogen (N), phosphorus (P), and potassium (K) are key drivers of crop growth, yield, and nutrient uptake trends (Howeler, 2012; Eke-Okoro & Njoku, 2012). Nitrogen, when applied in combination with other nutrients or organic matter, has been shown to enhance cassava growth and yield (Anwar & Santosa, 2023; Sinta & Dansa, 2023). Phosphorus is vital for root development and yield optimization (Anwar & Santosa, 2023; Katuromunda et al., 2021), while potassium plays a crucial role in improving yield, maintaining plant health, and enhancing nutrient retention (Sinta & Dansa, 2023; Suwarto et al., 2023). Conversely, deficiencies in these essential macronutrients can severely limit cassava productivity, leading to stunted growth, reduced tuber size, and lower yields (Sinta & Dansa, 2023; Suwarto et al., 2023). The balanced application of a complete NPK fertilizer package has been identified as the most effective strategy for maximizing cassava's agronomic performance and economic viability (Lawson et al., 2023). However, specific nutrient requirements and varietal responses often vary across different environments, underscoring the need for context-specific nutrient management strategies (Odedina et al., 2012).

In the Caraga Region, 2,789 hectares are dedicated to cassava cultivation, primarily in Surigao del Sur and Agusan del Sur, with an average yield of 8.8 t/ha (PSA, 2016). Cassava production in Agusan del Sur is shaped by agricultural practices, climate resilience, and market dynamics (Varela et al., 2022). One of the key challenges for the cassava industry in this region is increasing yield. Adaptive practices, such as timely cropping adjustments, can help mitigate climate risks and improve farm income. However, nutrient absorption by the cassava plant is

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also influenced by climatic conditions (Howeler, 2012). Therefore, a localized fertilizer management strategy is critical for optimizing yields in the region and enhancing overall production.

This study aims to comprehensively assess the agronomic performance, yield productivity, and nutrient utilization of two cassava varieties subjected to various fertilizer nutrient treatments in Trento, Agusan del Sur, Philippines. The objectives of the study are to evaluate growth responses, analyze yield attributes, identify nutrient accumulation patterns, assess economic returns. The findings of this research will provide insights into optimal cassava production methods for Trento, Agusan del Sur, which could serve as a model for increasing production, income, and food security in the region.

MATERIALS AND METHODS

The study was conducted at the two locations in Trento, Agusan del Sur, Philippines: the DA-Caraga Research Station (Area 1) and an experimental site in Barangay Cuevas (Area 2). The total experimental area of each site was 4,300 m² where soil samples before planting were taken in a Z sampling pattern prescribed by Adajar & Taer (2020) to set up the initial characteristics of the soils, which included the pH, total nitrogen, organic matter, available phosphorus, and exchangeable potassium of the soil.

Two cassava varieties, Lakan 1 (industrial use) and Golden Yellow (food use), were selected to evaluate their responses to varying nutrient levels. The experiment was designed as a split-plot layout, arranged in a randomized complete block design (RCBD) with three replications. The main plot factor was the cassava variety, and the sub-plot factor was the fertilizer treatment. Eleven fertilizer treatments were tested to assess their impact on cassava growth and yield:

T_1 (Control): No fertilizer applied (0-0-0).

T_2 (NPK): Full NPK application (200-100-350 kg N-P_2O_5-K_2O ha^{-1}).

T_3 (PK): Nitrogen omission plot (0-100-350 kg N-P_2O_5-K_2O ha^{-1}).

T_4 (NK): Phosphorus omission plot (200-0-350 kg N-P_2O_5-K_2O ha^{-1}).

T_5 (NP): Potassium omission plot (200-100-0 kg N-P_2O_5-K_2O ha^{-1}).

T_6 (SSNM): Site-Specific Nutrient Management (computer-generated tool).

T_7 (NFR): National Fertilizer Recommendation (56-56-560 kg N-P_2O_5-K_2O ha^{-1}).

T_8 (FFP): Farmers' Fertilizer Practice (rates based on farmer interviews).

T_9 (NPK* Adjusted N): Full NPK with lower nitrogen (100-100-350 kg N-P_2O_5-K_2O ha^{-1}).

T_{10} (NPK** Adjusted P): Full NPK with lower phosphorus (200-50-350 kg N-P_2O_5-K_2O ha^{-1}).

T_{11} (NPK*** Adjusted K): Full NPK with lower potassium (200-100-175 kg N-P_2O_5-K_2O ha^{-1}).

The experimental plots were deep plowed and harrowed repeatedly to a fine tilth then planted with mature cassava cuttings. Each cutting has five nodes, planted upright at a spacing of 1 meter between hills and rows, and each plot measures 6m x 6m to accommodate 36 plants. Fertilizer applications were scheduled in splits: nitrogen was applied at 0, 2.5, and 5 months after planting, while phosphorus was applied as a basal dose, and potassium was applied in three splits: 40% as basal application at planting, 30% at 2.5 months after planting, and the remaining 30% at 5 months after planting, coinciding with the nitrogen application schedule.

Agronomic characters recorded were plant height, stalk diameter, and the number of stalks per plant. Yield components were estimated using tuber length, diameter, marketable yield, non-marketable yield, total yield, and dry matter percentage. The assimilation of nutrients was determined by subjecting the cassava tubers to nitrogen, phosphorus, and potassium tests.

Gathered data were statistically analyzed by Statistical Tool for Agricultural Research (STAR) software, version 2.0.1, with Tukey's Honest Significant Difference (HSD) test at $p < 0.05$ used to compare treatment means. Additionally, correlation analysis was conducted using SPSS Statistics 17.0 to explore relationships between fertilizer treatments, variety, agronomic traits, yields, and yield components.

RESULTS AND DISCUSSION

Soil analysis

Both sites had acidic soils, with pH levels of 4.63 at the Research Station (Area 1) and 4.79 at Barangay Cuevas (Area 2). Organic matter content was higher in Area 1 (2.7%) compared to Area 2 (1.6%). Phosphorus levels varied significantly, with moderately low levels at Area 1 (4 mg/kg) and high levels at Area 2 (12 mg/kg). Potassium levels were sufficient at both sites, with 72 mg/kg and 380 mg/kg in Areas 1 and 2, respectively.

Rainfall, temperature, and relative humidity

Weather conditions during the experimental period (April 2018 to March 2019) are summarized in Figure 1. January 2019 recorded the highest monthly rainfall (945.2 mm), while June 2018 had the lowest (136 mm). Mean maximum temperatures ranged from 29.0°C to 34.1°C, with the warmest period in June-July 2018. Relative humidity remained high throughout, peaking at 87% in January 2019 and reaching its lowest at 77% in August 2018.

Plant height

Table 1 presents the plant height, stalk diameter and stalks of cassava. The result showed that plant height was significantly influenced by both fertilizer treatments and cassava variety at Areas 1 and 2, with fertilizer treatments exerting a stronger effect ($p < 0.01$) than variety ($p < 0.05$). In Area 1, the NPK treatment (T_2) produced the tallest plants (287.67 cm), significantly exceeding all other treatments except NPK* (T_9), NPK** (T_{10}), and NPK*** (T_{11}). A similar pattern was observed in Area 2, where the NPK treatment again resulted in the tallest plants (402.83 cm), while the control treatment produced the shortest (233.33 cm). Across both sites, the Lakan 1 variety consistently grew taller than the Golden Yellow variety. The superior performance of the full NPK treatment at both locations emphasizes the importance of providing complete nutrient supplementation, while the significantly reduced plant heights in the control and omission treatments highlight the detrimental effects of nutrient deficiencies. Particularly, the pronounced impact of potassium omission on plant height emphasizes the critical role of potassium in cassava's vegetative growth, corroborating findings by Howeler (2001).

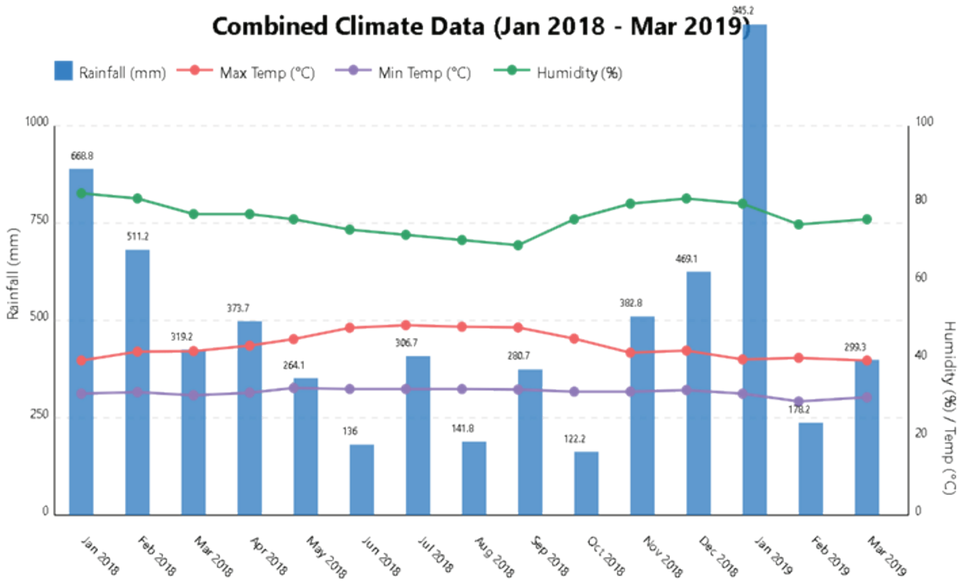

Figure 1: Monthly rainfall (mm), temperature (ºC) and Humidity (%) levels during the experimental period in Trento, Agusan del Sur, Philippines.

Table 1: Effect of fertilizer treatments and cassava variety on plant height, stalk diameter, and number of stalks at two sites in Trento, Agusan del Sur, Philippines

Treatment	Plant height (cm)		Stalk diameter (mm)		Number of stalks	
	Area 1	Area 2	Area 1	Area 2	Area 1	Area 2
Fertilizer						
CTRL	178.8^{f}	233.3^{f}	15.3^{f}	17.8^{h}	2.2^{e}	2.0^{d}
NPK	287.7^{a}	402.8^{a}	28.0^{a}	34.5^{a}	5.3^{a}	3.8^{a}
PK	249.7^{d}	277.3^{def}	21.0^{de}	22.3^{gh}	3.0^{de}	2.3^{cd}
NK	251.5^{d}	282.5^{def}	21.2^{de}	23.2^{efg}	3.2^{de}	2.0^{d}
NP	226.5^{e}	262.5^{ef}	19.8^{e}	19.2^{gh}	3.0^{de}	2.2^{cd}
SSNM	274.8^{abc}	342.7^{bc}	24.5^{bc}	29.2^{bcd}	4.5^{abc}	3.5^{ab}
NFR	266.5^{bcd}	337.0^{bc}	23.3^{cd}	28.0^{bcde}	3.5^{bcd}	2.5^{bcd}
FFP	262.7^{cd}	315.3^{cde}	22.2^{cde}	25.5^{def}	3.3^{cde}	2.5^{bcd}
NPK*	282.7^{ab}	383.2^{ab}	26.2^{ab}	31.8^{ab}	4.7^{ab}	2.7^{bcd}
NPK**	278.8^{abc}	353.5^{abc}	26.3^{ab}	30.8^{abc}	4.5^{abc}	2.8^{abcd}
NPK***	276.8^{abc}	329.7^{bcd}	23.3^{cd}	25.7^{cdef}	4.2^{abcd}	3.2^{abc}
Variety						
Golden Yellow	240.0^{b}	306.0^{b}	17.4^{ns}	18.2^{ns}	3.6^{b}	3.5^{ns}
Lakan1	268.0^{a}	334.0^{a}	30.3^{ns}	31.8^{ns}	4.0^{a}	3.6^{ns}
P=value						
Fertilizer	0.0001**	0.0001**	0.001**	0.0012**	0.0001**	0.0001**
Variety	0.0032*	0.0003*	0.7941^{ns}	0.6049^{ns}	0.0081**	0.2359^{ns}
Fertilizer*Variety	0.5934^{ns}	0.9488^{ns}	0.6421^{ns}	0.9072^{ns}	0.6011^{ns}	0.6711^{ns}

Means with the same letter are not significantly different at 0.05 level
**Highly significant
*Significant
^{ns} Not significant

The intermediate results from the site-specific nutrient management (SSNM, T_6) and national fertilizer recommendation (NFR, T_7) treatments suggest that these approaches provide a balanced nutrient supply for growth. Additionally, the height differences between the Lakan 1 and Golden Yellow varieties suggest important considerations for management practices and yield potential, as reported by Eke-Okoro et al. (2001).

Stalk diameter

Fertilizer treatments significantly influenced stalk diameter at both Area 1 and Area 2 ($p < 0.01$), while varietal differences and the interactions between fertilizer treatments and variety were not statistically significant. In Area 1, the NPK treatment produced the largest stalk diameter (28.00 mm), significantly greater than all other treatments except NPK* and NPK**. Similarly, in Area 2, the NPK treatment again resulted in the largest stalk diameter (34.50 mm), while the control treatment produced the smallest (17.83 mm). Although not statistically significant, the Lakan 1 variety consistently showed larger stalk diameters than the Golden Yellow variety at both sites. The superior performance of the full NPK treatment emphasizes the importance of complete nutrient provision, while the significant reductions in stalk diameter under control and omission treatments highlight the adverse effects of nutrient deficiencies. The severe impact of potassium omission on stalk diameter aligns with its critical role in plant height and stalk strength, as noted by Römheld & Kirkby (2010). The less pronounced reductions by nitrogen and phosphorus omissions further emphasize the need for balanced nutrition in cassava cultivation. The trend of larger stalk diameters in Lakan 1, combined with its earlier height performance, suggests a robust growth habit, which enhance resistance to lodging and support heavier tuber yields (Eke-Okoro et al., 2001).

Stalks of cassava

NPK treatment produced the highest stalk number per plant (5.33), significantly more than all other treatments except for NPK*, NPK**, and SSNM in Area 1. Among the nutrient omission treatments, PK and NP treatments had significantly fewer stalks (3.00), followed by NK (3.17). At Area 2, the NPK treatment yielded the highest stalk number (3.83), significantly more than the control, PK, NK, and NP treatments. The NK treatment had the lowest stalk number (2.00), though this was statistically similar to other treatments, including the control.

Regarding varietal differences, Lakan 1 produced significantly more stalks than Golden Yellow (3.94 vs. 3.58) at Area 1. At Area 2, although Lakan 1 had a numerically higher number of stalks compared to Golden Yellow (3.65 vs. 3.50), this difference was not statistically significant, and therefore the two varieties should be considered similar in terms of stalk production at this site.

Nitrogen plays a crucial role in cassava's vegetative growth and branching, consistent with its known effect on vegetative growth in other crops (Marschner, 2011) The effects of potassium and phosphorus omissions further emphasize the complex interplay of nutrients in shaping cassava architecture. The significant varietal difference in stalk number at Area 1, with Lakan 1 producing more stalks than Golden Yellow, suggests a genetic influence on branching behavior. Combined with Lakan 1's taller height and broader stalk diameter, this indicates a more vigorous growth habit. The less pronounced treatment differences at Area 2 compared to Area 1 suggest that site-specific factors, such as soil conditions or microclimate, influence branching traits and responses to fertilization. The significant growth responses (plant height, stalk diameter, and number of stalks) observed under NPK treatment align with findings from other studies. For example, Katuromunda et al. (2021) reported that NPK fertilizer significantly increased stem numbers in cassava varieties NAROCASS 1 and NASE 14, improving both stem height and stem numbers. This consistency supports the conclusion that NPK fertilization enhances cassava's vegetative growth by providing essential nutrients for shoot initiation and development. Similarly, Lawson et al. (2023) demonstrated that NPK 15-15-15 significantly increased tuber and stalk numbers across various cassava varieties, with the TMS 95/0289 variety producing the highest tuber numbers when treated with NPK. This corroborates the current study's results, that NPK fertilization promotes vegetative growth and potentially boosts yield. However, Odedina et al. (2012) noted that some cassava varieties bred for low-nutrient environments did not show significant increases in stalk numbers when treated with NPK, likely due to genetic adaptations that prioritize survival over growth in nutrient-poor soils.

Tuber length

In Area 1, the NPK treatment produced the longest tubers (349.83 cm), significantly surpassing all other treatments. The control treatment resulted in the shortest tubers (218.00 cm), which were significantly smaller than those from all treatments except NP (Table 2). The Golden Yellow variety exhibited significantly longer tubers (290.82 cm) compared to Lakan 1 (276.24 cm). Similarly, in Area 2, the NPK treatment again yielded the longest tubers (330.17 cm), though this was not significantly different from most other treatments except the control (167.50 cm) and NP (219.83 cm). However, in contrast to Area 1, Lakan 1 produced significantly longer tubers (284.91 cm) than Golden Yellow (271.55 cm). Potassium plays a critical role in cassava's tuber development, consistent with previous research emphasizing its importance in promoting root and tuber growth (Sustr et al., 2019). Nitrogen and phosphorus omissions also resulted in significant reductions in tuber length, emphasizing the need for balanced nutrition. The contrasting performance of the two cassava varieties between the sites—Golden Yellow performing better in Area 1 and Lakan 1 in Area 2—suggests that genotype × environment interactions influence tuber length, as supported by previous studies of Budak et al. (1995) and Yang et al. (2021), and Shu et al. (2023).

Nitrogen is essential for promoting vegetative growth and cell elongation, which directly impacts tuber length, while potassium plays a key role in carbohydrate synthesis and translocation, increasing both tuber diameter and overall size (Katuromunda et al., 2021; Lawson et al., 2023). These

Table 2: Effect of fertilizer treatments and cassava variety on tuber length and tuber diameter at two sites in Trento, Agusan del Sur, Philippines

Treatment	Tuber length (cm)		Tuber diameter (mm)	
	Area 1	Area 2	Area 1	Area 2
Fertilizer				
CTRL	218.0[e]	167.5[c]	38.0[e]	42.5[g]
NPK	349.8[a]	330.2[a]	48.7[a]	56.7[a]
PK	260.5[cd]	258.8[ab]	42.7[cd]	48.0[ef]
NK	260.7[cd]	270.2[ab]	42.7[cd]	48.5d[ef]
NP	248.8[de]	277.4[ab]	41.2[de]	46.0[f]
SSNM	296.2[bc]	300.7[ab]	47.0[cd]	51.0[cd]
NFR	288.3[bcd]	289.5[ab]	45.5[bc]	50.3[cde]
FFP	278.8[bcd]	281.0[ab]	45.7[bc]	49.3[cde]
NPK*	315.0[bc]	319.8[a]	48.7[ab]	53.8[ab]
NPK**	294.2[cd]	317.8[ab]	46.8[b]	55.2[a]
NPK***	308.5[b]	305.2[ab]	48.5[cb]	52.0[bc]
Variety				
Golden Yellow	290.8[b]	271.5[a]	46.1[b]	45.2[ns]
Lakan1	276.2[a]	284.9[b]	40.7[a]	46.0[ns]
P=value				
Fertilizer	<0.001**	<0.001**	<0.001**	<0.001**
Variety	0.0232*	0.0252*	0.0294*	0.9691[ns]
Fertilizer*Variety	0.5484[ns]	0.8417[ns]	0.9705[ns]	0.9789[ns]

Means with the same letter are not significantly different at 0.05 level
**Highly significant
* Significant
[ns] Not significant

physiological mechanisms, including improved nutrient uptake and transport, are critical for tuber development. Adequate nitrogen supports nucleic acid and protein synthesis necessary for cell growth and division, leading to tuber elongation (Suwarto et al., 2023). Potassium enhances the plant's ability to regulate water and nutrient movement, maintain turgor pressure, and efficiently accumulate carbohydrates in the tubers, resulting in thicker, more robust tubers with higher marketable yields and fewer defects (Ojeniyi et al., 2012; Macalou et al., 2018). In contrast, nutrient deficiencies hinder the plants to develop well-formed tubers, resulting in shorter, smaller, and irregularly shaped tubers that are less marketable. The absence of balanced fertilization impairs nutrient uptake and distribution, leading to suboptimal tuber growth and increased non-marketable yield (Anwar & Santosa, 2023).

Tuber diameter

The NPK and NPK* treatments resulted in the largest tuber diameters (both 48.67 mm) in Area 1, significantly exceeding all other treatments except NPK** and NPK***. In Area 2, the NPK treatment again produced the largest tuber diameters (56.67 mm), significantly larger than all treatments except NPK* and NPK** as detailed in Table 2. Regarding varietal differences, Golden Yellow produced significantly larger tuber diameters than Lakan 1 in Area 1 (46.06 mm vs. 40.70 mm, $p < 0.001$), while no significant difference was observed between the two varieties in Area 2 (45.22 mm vs. 46.01 mm, $p > 0.05$). The significant increase in tuber diameter with NPK (17:17:17) application aligns with findings from previous studies, where balanced NPK fertilization led to larger tuber diameters (Katuromunda et al., 2021). Similarly, Lawson et al. (2023) reported that NPK (15:15:15) fertilization resulted in thicker, more robust tubers, highlighting the importance of balanced nutrition for achieving desirable tuber characteristics. Macalou et al. (2018) also observed improvements in tuber size with increased NPK application, particularly in nutrient-poor soils, emphasizing the critical role of potassium in tuber development. However, Odedina et al. (2012) noted that the increase in tuber diameter with NPK application was less pronounced in some cases, suggesting that responses to fertilization vary depending on local conditions and cassava varieties.

Marketable tubers

Marketable tuber yield was significantly influenced by fertilizer treatments at both the sites ($p < 0.01$). At the Area 1, the NPK treatment produced the highest marketable yield (46.17 t/ha), significantly outperforming all other treatments except NPK* (40.38 t/ha). The nutrient omission treatments, particularly NP, led to the most severe reduction in yield (23.38 t/ha), followed by NK and PK at 25.88 t/ha and 25.00 t/ha, respectively (Table

3). Similar trends were observed at the Area 2, where NPK again resulted in the highest marketable yield (49.33 t/ha), significantly higher than all treatments except NPK* and NPK**. However, the nitrogen omission treatment (PK) caused the most severe reduction in yield at this site, though the differences between omission treatments were less pronounced than at the Area 1. Additionally, Golden Yellow produced significantly higher marketable yields than Lakan 1 at the Area 1 (32.30 t/ha vs. 29.90 t/ha), while no significant difference was observed between varieties at the Area 2. The severe reductions in yield observed in the control and potassium omission on marketable yield at the Area 1 supports previous research indicating potassium's essential role in assimilate translocation and tuber bulking in root crops (Sustr et al., 2019).

Non-marketable tubers

In Area 1, the NPK* treatment produced the highest non-marketable yield (12.67 t/ha), though this was not significantly different from most other fertilized treatments, including the full NPK treatment (11.77 t/ha). The control treatment resulted in the lowest non-marketable yield (5.02 t/ha), significantly lower than most fertilized treatments except for PK (Table 3). In Area 2, the full NPK treatment produced the highest non-marketable yield (10.90 t/ha), though it was not significantly different from several other fertilized treatments. As in Area 1, the control yielded the lowest amount (3.12 t/ha). Varietal differences were also site-dependent. In Area 1, Lakan 1 produced significantly higher non-marketable yields than Golden Yellow (10.93 t/ha vs. 8.48 t/ha), while in Area 2, Golden Yellow had higher yields (8.63 t/ha vs. 6.65 t/ha for Lakan 1). The generally higher non-marketable yields in fertilized treatments suggest that improved nutrition enhances overall tuber production, even though some tubers do not meet market standards (Raj et al., 2020). The variability in responses to nutrient omissions across sites suggests that the impact of specific nutrient deficiencies on tuber quality depend on local soil conditions and other environmental factors (Chapman et al., 1992; Wekesa et al., 2014). Furthermore, the contrasting varietal performance between the sites highlights the influence of genotype-environment interactions in cassava production (Budak et al., 1995; Yang et al., 2021; Shu et al., 2023).

Optimized nutrient management can significantly increase marketable tuber yields but also lead to higher non-marketable yields, as observed in several studies. Raj et al. (2020) demonstrated that integrated nutrient management, combining synthetic fertilizers and organic manures, improved marketable tuber yield in potatoes, though it had mixed effects on non-marketable yields. Similarly, Sharma & Arora (1987) found that increasing nitrogen, phosphorus, and potassium levels affected tuber size and quality, influencing the proportion of different grades of tubers. Wang et al. (2008) noted that proper fertilization generally enhances crop yield and nutritional quality, but

Table 3: Effect of fertilizer treatments and cassava variety on marketable tuber, non-marketable tuber and dry matter content at two sites in Trento, Agusan del Sur, Philippines

Treatment	Marketable tuber		Non-marketable		Dry matter (%)	
	Area 1	Area 2	Area 1	Area 2	Area 1	Area 2
Fertilizer						
CTRL	12.9^{g}	15.3^{d}	5.02^{c}	3.1^{d}	26.4^{e}	26.3^{h}
NPK	46.2^{a}	49.3^{a}	11.8^{ab}	10.9^{a}	35.6^{ab}	34.6^{a}
PK	25.0^{f}	26.3^{cd}	5.9^{bc}	5.1^{cd}	28.2^{de}	27.3^{fgh}
NK	25.9^{ef}	27.3^{c}	9.3^{abc}	6.7^{bcd}	28.6^{de}	28.4^{fgh}
NP	23.4^{f}	27.5^{c}	8.1^{abc}	8.1^{abc}	27.0^{e}	26.7^{gh}
SSNM	34.5^{bcd}	34.0^{bc}	10.0^{abc}	7.1^{abc}	32.5^{bc}	30.8^{cde}
NFR	32.3^{cde}	33.9^{bc}	8.9^{abc}	6.4^{bcd}	30.8^{cd}	29.2^{def}
FFP	30.4^{def}	31.2^{bc}	11.1^{abc}	9.7^{ab}	30.4^{cd}	28.8^{efg}
NPK*	40.4^{ab}	40.1^{ab}	12.7^{a}	9.5^{ab}	35.8^{a}	33.5^{ab}
NPK**	37.7^{bc}	40.4^{ab}	12.0^{ab}	8.2^{abc}	34.4^{ab}	32.3^{bc}
NPK***	33.6^{bcd}	36.8^{bc}	11.9^{ab}	8.7^{abc}	32.7^{abc}	31.2^{cd}
Variety						
Golden Yellow	32.3^{b}	30.2^{ns}	8.5^{b}	8.63^{a}	31.5^{ns}	29.3^{ns}
Lakan1	29.9^{a}	31.3^{ns}	11.0^{a}	6.65^{b}	32.4^{ns}	31.0^{ns}
P=value						
Fertilizer	<0.001**	<0.001**	0.0029**	<0.001**	<0.001**	<0.001**
Variety	0.0095**	0.128^{ns}	0.027*	0.0075**	0.8235^{ns}	0.4011^{ns}
Fertilizer*Variety	0.1427^{ns}	0.982^{ns}	0.867^{6ns}	0.984^{ns}	0.905^{ns}	0.9729^{ns}

Means with the same letter are not significantly different at 0.05 level
**Highly significant
*Significant
^{ns} Not significant

excessive nutrient application of nitrogen can negatively impact crop quality and increase the proportion of non-marketable produce. These findings align with the current study that optimized nutrient management is essential for boosting marketable yield but also result in a higher overall tuber production, including non-marketable tubers, due to improved plant vigor and resource allocation. Adequate fertilization enhances plant vigor, particularly with balanced NPK (nitrogen, phosphorus, and potassium), and improves overall plant health and vigor (Yadav et al., 2022). This increased vitality promotes tuber formation, though it can also lead to a higher proportion of tubers that fail to meet market standards due to overgrowth or uneven development. Resource allocation is significantly influenced by improved nutrient availability. This allows the plant to allocate resources to tuber development (Fujita et al., 2020). The increase in the size and number of marketable tubers is a positive outcome but can also result in a rise in non-marketable tubers, as the plant produces more tubers, some of which are smaller or misshapen. Growth regulation is another factor, with nutrients such as potassium playing a key role in carbohydrate synthesis, and translocation is essential for tuber bulking (Sustr et al., 2019). With adequate potassium that promotes healthy tuber, imbalances or excessive amounts can cause variations in tuber size and quality, contributing to the production of both marketable and non-marketable tubers.

Dry matter content of tubers

The NPK* treatment resulted in the highest dry matter content (35.83%) at Area 1, though it was not significantly different from the full NPK treatment (35.61%) or the NPK** treatment (34.46%) (Table 3). Similarly, at Area 2, the full NPK treatment produced the highest dry matter content (34.68%), significantly higher than all treatments except NPK* (33.59%). These findings align with previous research, such as Silva et al. (2020), which demonstrated that varieties with higher nitrogen and potassium uptake achieve greater dry matter accumulation and productivity. Gaj et al. (2018) found that combining NPK with manure and stubble crops significantly improved nutrient accumulation in potato tubers, correlating with higher yields and starch content. Bansal & Trehan (2011) emphasize potassium's influence on yield and quality parameters in potato crops, particularly dry matter content and tuber size. Imas & Bansal (2002) further support potassium's role in improving tuber quality, including dry matter percentage and disease resistance. Similarly, Jenkins & Mahmood (2003) observed that potassium deficiency in potatoes significantly reduced dry matter partitioning to tubers, mirroring the reductions observed in cassava. Potassium plays a critical role in activating enzymes involved in carbohydrate metabolism, which converts sugars and starches into storage forms within tubers (Cui & Tcherkez, 2021). Without sufficient potassium, these enzymatic processes are hindered, reducing carbohydrate synthesis and consequently lowering dry matter content. Additionally, potassium regulates stomatal function, optimizing photosynthesis by controlling gas exchange (Tränkner et al., 2018). Efficient photosynthesis increases sugar production, which is then translocated to storage organs like cassava tubers. Potassium deficiency reduces photosynthetic efficiency, limiting the carbohydrates available for storage and ultimately decreasing dry matter accumulation in tubers.

Nutrient uptakes of nitrogen, phosphorus, and potassium

At Area 1, the full NPK treatment resulted in the highest nitrogen uptake (0.827%), significantly outperforming all other treatments except for the adjusted NPK treatments (NPK** and NPK***) (Table 4). Similarly, at Area 2, the NPK** treatment showed the highest nitrogen uptake (0.794%). In contrast, the control treatment consistently exhibited the lowest nitrogen uptake at both sites (0.433% and 0.345%, respectively). For phosphorus, the full NPK treatment yielded the highest uptake (2.77%) at Area 1, while at Area 2, the NFR treatment showed the highest uptake (2.18%), closely followed by the NPK treatment (2.03%). Regarding potassium, the full NPK treatment resulted in the highest uptake (2.31%) at Area 1, whereas at Area 2, the NPK*** and NPK** treatments showed the highest uptake (both 2.18%).

The superior nutrient uptake in the full NPK and adjusted NPK treatments correlates with improved growth and yield parameters. The NPK treatment consistently led to the tallest plants, largest stalk diameters, longest tubers, and highest marketable yields at both sites. Additionally, the NPK and NPK* treatments produced the largest tuber diameters and the highest dry matter content across both locations. The consistent superior performance of the full NPK and adjusted NPK treatments across various parameters stresses the importance of balanced nutrition in cassava cultivation (Macalou et al., 2018; Lawson et al., 2023). The synergistic effects of nitrogen, phosphorus, and potassium enhance the uptake and utilization of each nutrient (Silva et al., 2020; Katuromunda et al., 2021; Lawson et al., 2023). The lack of significant differences in nutrient uptake between cassava varieties suggests that both Lakan 1 and Golden Yellow respond similarly to nutrient management practices. However, the variation in results between the two sites highlights the need to consider local soil conditions and environmental factors when developing nutrient management strategies. Byju et al. (2012) reported that balanced NPK fertilizer application enhanced nutrient uptake efficiency in tropical soils, showing a direct correlation between NPK application rates and increased cassava yields. This result is consistent with the present study, where NPK-treated plots demonstrated higher nutrient uptake and improved yield components. Similarly, Adiele et al. (2020) found that applying NPK at various rates significantly increased dry matter yield and nutrient uptake in cassava, supporting the conclusion that NPK fertilization enhances both nutrient use efficiency and crop yield. However, discrepancies arise when comparing nutrient allocation under different environmental conditions. Hartemink & Johnston (1998) observed that NPK fertilization increased root biomass in taro, and nutrient uptake was similar between fertilized and unfertilized plots at harvest. The finding contrasts with the current study, where NPK consistently improved

Table 4: Means of nitrogen, phosphorus, and potassium uptake in cassava tubers as affected by different fertilizer levels and variety at the two sites in Trento, Agusan del Sur

Treatment	Nitrogen uptake (%)		Phosphorous uptake (%)		Potassium uptake (%)	
	Area 1	Area 2	Area 1	Area 2	Area 1	Area 2
Fertilizer						
CTRL	0.43^{a}	0.3^{b}	0.6^{b}	1.1^{ab}	1.6^{d}	0.8^{b}
NPK	0.82^{a}	0.4^{ab}	2.7^{a}	2.0^{a}	2.3^{a}	0.8^{b}
PK	0.5^{b}	0.5^{ab}	1.0^{ab}	0.7^{b}	1.7^{bcd}	0.9^{b}
NK	0.5^{b}	0.5^{a}	1.0^{ab}	1.3^{ab}	1.6^{bcd}	0.9^{b}
NP	0.4^{b}	0.3^{b}	0.8^{b}	0.8^{b}	1.4^{d}	1.3^{ab}
SSNM	0.5^{b}	0.3^{b}	0.9^{b}	0.8^{b}	1.9^{bcd}	1.3^{ab}
NFR	0.4^{b}	0.6^{a}	1.2^{ab}	2.1^{a}	1.8^{bcd}	1.7^{a}
FFP	0.5^{b}	0.4^{b}	1.2^{ab}	0.8^{b}	1.8^{bcd}	1.8^{a}
NPK*	0.5^{b}	0.6^{a}	1.4^{ab}	0.8^{b}	2.1^{bc}	1.8^{a}
NPK**	0.6^{ab}	0.7^{a}	1.1^{ab}	1.6^{ab}	2.0^{bc}	2.1^{a}
NPK***	0.6^{ab}	0.5^{ab}	1.2^{ab}	0.8^{b}	1.9^{bcd}	2.1^{a}
Variety						
Golden Yellow	0.5^{NS}	0.5^{NS}	1.2^{NS}	0.6^{NS}	1.5^{NS}	0.9^{NS}
Lakan1	0.6^{NS}	0.5^{NS}	1.3^{NS}	0.8^{NS}	1.8^{NS}	1.0^{NS}
P=value						
Fertilizer	0.001**	0.005*	0.035*	0.007*	0.0003**	0.004**
Variety	0.4913^{NS}	0.094^{NS}	0.2173^{NS}	0.284^{NS}	0.0718^{NS}	0.214^{NS}
Fertilizer*Variety	0.6652^{NS}	0.354^{NS}	0.6303^{NS}	0.645^{NS}	0.9479^{NS}	0.398^{NS}

Means with the same letter are not significantly different at 0.05 level
**Highly significant
*Significant
^{NS} Not significant

nutrient uptake throughout the growth cycle. Additionally, Law-Ogbomo & Remison (2009) found that optimal NPK levels varied across crops and soil types, suggesting that the effectiveness of NPK fertilization depend on local conditions, including soil fertility and crop-specific nutrient requirements. Future research should explore the interactions of environmental factors and cassava variety on nutrient uptake efficiency.

Return on investment

Fertilized treatments consistently outperformed the control in yield, net income, and ROI. The NPK treatment produced the highest yields and gross incomes for both Lakan 1 and Golden Yellow (Table 5 and Table 6, respectively). Golden Yellow generally showed superior performance in yield and economic returns. For instance, the control treatment for Golden Yellow yielded 15.83 t ha^{-1}, compared to 12.33 t ha^{-1} for Lakan 1, suggesting Golden Yellow have a higher inherent yield potential or better adaptability to local conditions. This higher yield translated into greater net income and ROI for Golden Yellow across most treatments.

Interestingly, the SSNM treatment provided the highest ROI for both Lakan 1 (128.61%) and Golden Yellow (126.75%) despite not producing the highest yields. This indicates that SSNM offers more efficient use of inputs relative to outputs, likely due to its tailored approach to nutrient application. The high ROI from SSNM suggests it could be a more economically optimal strategy for cassava farmers, balancing input costs with yield gains. Although the NPK treatment resulted in the highest yields and gross incomes, it did not achieve the highest ROI due to its higher input costs. The consistently higher ROI of Golden Yellow across most treatments suggests to be the more economically viable variety for farmers in this region. The stark contrast between the performance of the control and fertilized treatments for Lakan 1, where the control ROI was just 0.54%, highlights the economic necessity of fertilizer use in cassava production. Even the least effective fertilizer treatments significantly outperformed the control, indicating that some level of fertilization is crucial for profitable cassava farming. Both varieties respond positively to fertilization. However, Golden Yellow offers superior economic returns under most conditions. The SSNM approach shows promise as an economically efficient fertilization strategy for both varieties.

CONCLUSIONS

In conclusion, the study demonstrates the critical role of balanced nutrient management in optimizing cassava production. Both Lakan 1 and Golden Yellow varieties showed significant improvements in yield, net income, and return on investment (ROI) with the application of fertilizers, particularly under the NPK (T_2) and SSNM treatments (T_6). The NPK treatment produced the highest yields, gross, and net income for both varieties. However,

Table 5: Cost and return analysis of cassava production using the Lakan 1 variety

Parameters	CTRL	NPK	PK	NK	NP	SSNM	NFR	FFP	NPK*	NPK**	NPK***
Variety: Lakan1											
Yield (t ha $^{-1}$)	12.33	47.61	26.56	24.11	22.56	34.39	32.56	29.00	38.78	38.17	32.39
Production Cost (PhP)	36,801.00	70,890.00	60,954.60	59,340.00	58,286.40	45,129.76	45,937.00	45,266.70	57,913.10	65,166.58	64,686.88
Gross Income (PhP)	36,999.00	142,830.00	79,680.00	72,330.00	67,680.00	103,170.00	97,680.00	87,000.00	116,340.00	114,510.00	97,170.00
Net Income (PhP)	198.00	71,940.00	18,725.40	12,990.00	9,393.60	58,040.24	51,743.00	41,733.30	58,426.90	49,343.42	32,483.12
ROI (%)	0.54%	101.48%	30.72%	21.89%	16.12%	128.61%	112.64%	92.19%	100.89%	75.72%	50.22%

Table 6: Cost and return analysis of cassava production using the Golden Yellow variety

Parameters	CTRL	NPK	PK	NK	NP	SSNM	NFR	FFP	NPK*	NPK**	NPK***
Variety: Golden Yellow											
Yield (t ha $^{-1}$)	15.83	47.89	24.72	29.11	28.33	34.11	33.67	32.61	41.72	39.94	37.94
Production Cost (PhP)	36,801.00	70,890.00	60,954.60	59,340.00	58,286.40	45,129.76	45,937.00	45,266.70	57,913.10	65,166.58	64,686.88
Gross Income (PhP)	47,499.00	143,670.00	74,160.00	87,330.00	84,990.00	102,330.00	101,010.00	97,830.00	125,160.00	119,820.00	113,820.00
Net Income (PhP)	10,698.00	72,780.00	13,205.40	27,990.00	26,703.60	57,200.24	55,073.00	52,563.30	67,246.90	54,653.42	49,133.12
ROI (%)	29.07%	102.67%	21.66%	47.17%	45.81%	126.75%	119.89%	116.12%	116.12%	83.87%	75.96%

SSNM emerged as the most efficient strategy, delivering the highest ROI due to its tailored nutrient application approach.

Golden Yellow consistently outperformed Lakan 1 in terms of yield and economic returns, suggesting a more profitable variety under the given conditions. However, the choice of variety depends on other factors, such as market demand and resistance to pests and diseases. The stark contrast in performance between fertilized and control treatments emphasizes the economic necessity of fertilizer application in cassava farming, with even the least effective fertilization outperforming the control. These findings provide valuable insights for farmers seeking to optimize cassava production and profitability. Future research should explore these interactions over multiple seasons and locations to confirm the broader applicability of the results across varying environmental conditions.

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DECLRATION OF CONFLICT OF INTEREST

The authors declare no conflicts of interest associated with this research paper

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AUTHOR CONTRIBUTION

Conceptualization, Design of the study: **E.G.A.;** Data collection and Manuscript drafting: **R.J.C.R.;** Data analysis and interpretation: **G.D.J.;** All authors read and approved the final version of the manuscript.

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