Cassava Response to Organomineral Fertilization in Savannah and Forest Zones of the Central African Republic

Abstract

Two experimental seasons (2021-2022 and 2022-2023) were conducted to assess the effects of different fertilizer formulations for cassava growth and yields improvement in the forest and savanna ecosystems of republic of Centrafrique (RCA). A Box and Behnken design was used to determine treatments, with nutrient levels coded at -1 (minimum), 0 (medium) and +1 (maximum). Combinations of N, P, K and organic manure (FY) were generated with MINITAB 18 software. The response surface was generated for the four factors. However, 27 experimental units including the three repeated center points were generated. The central points (where all factors are at their mean level) are included to estimate experimental variability and improve the precision of the estimated effects. Analysis of variance reveals significant ($p = 0.000$) variation between treatments. In the forest ecosystem, maximum yields were obtained with treatments $N_{50}P_0K_{100}FY_{20}$ (47.62 ± 1.33 $t.ha^{-1}$) and $N_{50}P_0K_{50}FY_{40}$ (47.72 ± 1.47 $t.ha^{-1}$), while $N_0P_{37}K_0FY_{20}$ showed the lowest yield (7.14 ± 0.04 $t.ha^{-1}$). In the savannah ecosystem, treatments $N_{100}P_{37}K_{50}FY_{40}$ (41.65 ± 0.10 $t.ha^{-1}$) and $N_{50}P_{37}K_{100}FY_0$ (41.68 ± 2.18 $t.ha^{-1}$) gave the best results. The regression equations for root yields (forest ecosystem and savannah) proved significant ($p = 0.000$), with coefficient of determination (R^2) of 0.91, indicating a strong correlation between the factors studied and yields. This study highlights the impact of adapted fertilization on cassava growth and yields. Treatments contain high potassium level and organic manure, combined with moderate doses of nitrogen and phosphorus, showed the best performance in both ecosystems.

Keywords: Soil fertility, integrated nutrient management, modeling, root and tuber plants, organic amendment.

1. Introduction

Cassava (*Manihot esculenta* Crantz) is a key crop for food and economic security in many tropical regions, including the Central African Republic (CAR). This staple crop accounts for 42% of cultivated land and 55% of agricultural production in CAR (Zingore et al., 2011). Soils in tropical zones are generally characterized by low fertility, high acidity, low water-holding capacity, and phosphorus deficiency (Académie d'Agriculture de France, 2019; Koné et al., 2009; 2010; 2011). Consequently, smallholder farms in sub-Saharan Africa face substantial variability in soil fertility, requiring appropriate nutrient allocation strategies to enhance nutrient use efficiency. Despite efforts to disseminate improved genotypes and manage crop pests and diseases, cassava productivity remains below optimal levels (Rusike et al., 2010; Zinga et al., 2013). In CAR, the average yield of fresh cassava roots is 4.7 $t\ ha^{-1}$, considerably lower than potential yields observed in other parts of the world (FAO Stat, 2015). Previous studies on farmers' perceptions, physico-chemical characteristics, and spatial variability of soil parameters under cassava cultivation in forest and savanna zones of CAR have highlighted nutrient deficiencies and overall low soil fertility (Kolinguenza et al., 2023). Fertilization practices—whether organic or mineral—play a pivotal role in improving cassava yields (El-Sharkawy, 2004). Organic fertilizers such as compost and manure enrich the soil with organic matter and enhance its structure, while mineral fertilizers supply essential nutrients more directly (Howeler, 2002). Earlier studies have demonstrated that applying both organic and mineral fertilizers can significantly improve cassava yields. For instance, compost application has been linked to enhanced plant growth and tuber production

(Akanbi et al., 2007), while mineral fertilizers, especially NPK, have shown notable yield increases (Fermont et al., 2009). However, the combined effects of organic and mineral fertilizers on cassava productivity in the pedoclimatic zones of forest and savanna in CAR remain underexplored. Understanding how these fertilization practices can be optimized is crucial for maximizing yields while preserving soil fertility (Sanginga and Woomer, 2009). In CAR, soils are often nutrient-depleted due to overexploitation, constraining agricultural productivity (Bationo et al., 2012). The application of organic fertilizers can improve water retention capacity and nutrient availability, while mineral fertilizers provide readily accessible essential elements for plant growth (Vanlauwe et al., 2010). However, excessive fertilization may pose environmental risks such as groundwater pollution (Palm et al., 2001).To optimize fertilizer doses, the use of Response Surface Methodology (RSM) is essential. RSM enables the modeling and analysis of the effects of multiple independent variables on one or more dependent variables, facilitating the optimization of experimental conditions (Montgomery, 2017). Quadratic models, commonly used in RSM, help capture nonlinear effects and interactions among variables (Myers and Montgomery, 2002). The Box–Behnken experimental design is particularly suited for studies requiring optimization with a limited number of experiments. This design identifies optimal conditions while minimizing the number of trials needed (Box and Behnken, 1960). The use of coefficient of determination (R^2) values is critical for evaluating model fit. A high R^2 indicates good model adequacy, which is key to making reliable recommendations (Kutner et al., 2005).This study aims to evaluate the effects of organic and mineral fertilizer doses on yield components of cassava (variety TMS 92/0329) in the forest and savanna pedoclimatic zones of CAR. The results will inform recommendations for integrated soil fertility management tailored to local conditions, with the goal of sustainably improving cassava yields and ensuring food security.

2. Materials and Methods

The experiment was conducted in the pedoclimatic zones of forest and savanna in the Central African Republic (CAR). Specifically, it took place at the experimental farm of the Higher Institute of Rural Development (ISDR) located at 3°52'15"N and 17°59'06"E in the forest zone; in the village of Damara (4°37'71"N and 18°56'27"E); and at the Boélé station of the Regional Multipurpose Research Center (CRPR) in Bouar (4°57'22"N and 18°41'54"E), which are situated in the savanna zone (Figure 1).

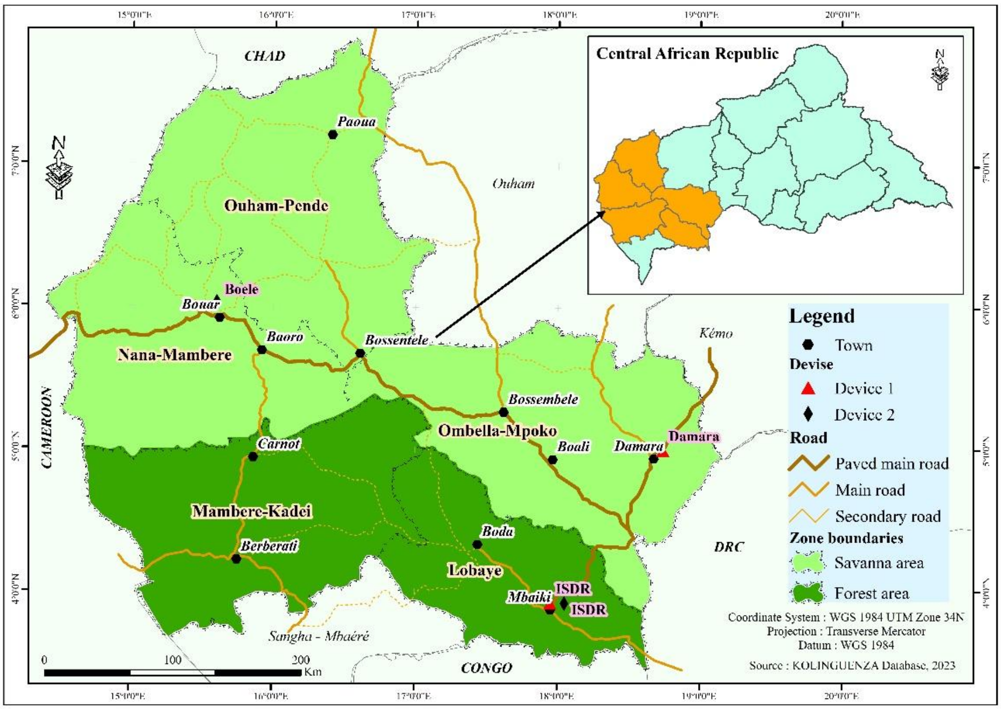

Figure 1: Map of the study area

2.1.2 Plant Material

The plant material used was the cassava variety TMS 92/0329, locally known as "Togo." Stem cuttings were selected from a single, highly homogeneous plot at the CRPR of Boukoko/ICRA. This variety has high production potential, producing large fusiform roots with an average length of up to 100 cm and a diameter ranging from 20 to 35 cm. Its average yield is approximately 30 tons per hectare. TMS 92/0329 is resistant to cassava mosaic disease and tolerant to drought, making it one of the most resilient varieties to climate variability. It also has a low cyanogenic acid content. Its growth cycle lasts 12 months. For the trials, the cuttings were provided by the Central African Institute of Agricultural Research (ICRA).

2.2.2 Fertilizer Sources Used

Simple mineral fertilizers were applied, including:

- Urea ($CO(NH_2)_2$) containing 46% nitrogen (N) ;
- Triple superphosphate (TSP) ($Ca(H_2PO_4)_2 \cdot H_2O$) containing 46% P_2O_5 ;
- Potassium chloride (KCl) containing 60% K_2O.

Table 1 : different fertilizer doses applied.

Fertilizer type	Doses (kg.ha^{-1})	Fertilizer quantity per plant (kg)	Fertilizerquantities (kg·ha^{-1})
N1 - Urea at 46%	40	8,69	86,9
N2 - Urea at 46%	80	17,39	173,91
N3 - Urea at 46%	120	26,08	260,81
N4 - Urea at 46%	160	34,78	347,82
P1 – Triple superphosphate at 46%	20	4,34	43,47
P2 - Triple superphosphate at 46%	40	8,69	86,95
P3 - Triple superphosphate at 46%	60	13,04	130,42
P4 – Triple superphosphate at 46%	80	17,39	173,90
K1 - Potassium chloride at 60%	60	10,00	100
K2 - Potassium chloride at 60%	120	20,00	200
K3 - Potassium chloride at 60%	180	30,00	300
K4 - Potassium chloride at 60%	240	40,00	400

2.2.2 Organic Fertilizer Used

The organic fertilizer applied was cattle manure sourced from the State Company for Abattoir Management (SEGA) in Bangui, Mbaïki, and Bouar. Once collected, the manure underwent sun-drying for seven days, with daily watering to promote the evaporation of excess ammonia present in the cattle urine.

2.2.3 Chemical Analyses of Soil Before Trial Establishment

A total of thirty-two composite soil samples were collected at a depth of 0–50 cm, along with sixteen samples of cattle manure. Chemical analyses were conducted at the Support Laboratory for Soil Health Improvement and Environmental Protection (L2A2S2E) of the National Institute of Agricultural Research of Benin (INRAB). The soil analyses included:

- pH in water (pH_{h2o}) and in KCl (pH_kC_l): measured using a potentiometric method with a soil-to-distilled-water and soil-to-KCl ratio of 1:2.5.
- Organic carbon: determined via the Walkley & Black method, which oxidizes soil organic matter with 1 N potassium dichromate ($K_2Cr_2O_7$) in acidic medium at a soil-to-reagent ratio of 0.25:10 (AFNOR, 2017).
- Exchangeable potassium and calcium: extracted using the Metson method with 1 N ammonium acetate at pH 7. Potassium content was measured using a flame photometer, and calcium using atomic absorption spectrophotometry (AAS).
- Available phosphorus: determined by the Bray I method. The filtrate was color-reacted with ammonium molybdate in the presence of ascorbic acid, and the color intensity was measured colorimetrically at 660 nm. The extractant solution consisted of NH_4F and HCl.
- Total nitrogen: determined using the Kjeldahl method, involving acid digestion with sulfuric acid and a selenium catalyst, followed by micro-distillation.

With regard to trial implementation, two experimental seasons were conducted (2021–2022 and 2022–2023). The Box–Behnken design was employed to determine the different treatment combinations. Each factor was set at its coded central level (0) as well as at minimum (-1) and maximum (+1) coded levels. The various combinations of the four nutrient levels in each treatment were generated using Response Surface Methodology (RSM) in MINITAB 18 software, based on nutrient ranges recommended by IAEA (2015), Ballo et al.,2016, and Kosh-Komba et al.,2019, currently applied in the Central African Republic: Nitrogen (50–100 kg·ha^{-1}), Phosphorus (37.5–75 kg·ha^{-1}), and Potassium (50–100 kg·ha^{-1}). Table 1 presents the factor levels generated by MINITAB from the corresponding nutrient and organic fertilizer doses.

Table 2: Factor levels generated by Minitab software

Factor	Level 1	Level 2	Level 3
N (kg.ha^{-1})	0	50	100
P (kg.ha^{-1})	0	37,5	75
K (kg.ha^{-1})	0	50	100
FY (t.ha^{-1})	0	20	40

2.2.4.Plot Layout and Agronomic Management

The elementary plot size was 4 m × 5 m, corresponding to a surface area of 20 m². Measurements were conducted on net plot areas, excluding border plants and rows. The experiments were established on May 7th, 2021 and 2022 in the forest zone, and on August 19th, 2021 and 2022 in the savanna zone, in accordance with the respective agricultural calendars.The cassava cuttings used were taken from the lower third of 12-month-old stems, with a standard length of 20 cm Bakayoko *et al.,* 2009). Cuttings were planted at an oblique angle of 45°, with two-thirds of their length buried in the soil. Spacing between plants was 1 m × 1 m, resulting in a planting density of 10,000 plants per hectare.Three weedings were conducted: the first at 12 weeks, the second at 20 weeks, and the third at 30 weeks after planting.Fertilizer application followed a ring spreading method around the base of the plants, within a diameter of 5 to 15 cm. Triple superphosphate (TSP) was applied as a basal fertilizer on the day of planting, urea was applied one week after planting, and potassium chloride was applied two weeks after planting.

2.2.5 Experimental Design Description Using the Box–Behnken Design

The Box–Behnken design, a type of Response Surface Methodology (RSM) design, was used to explore the interactions among four factors while minimizing the number of experimental runs required.

Each factor was assessed at three levels: low (–1), medium (0), and high (+1). For treatment combinations in this study, Minitab 18 software generated 27 experimental units across the four factors, including three replicates of the central point.The central points where all factors are at their median levels were included to estimate experimental variability and enhance the accuracy of effect estimations. The Box–Behnken design also avoids scenarios where extreme combinations dominate (i.e., where several factors are simultaneously at their highest levels), which often occurs in central composite designs. This reinforces the representativeness and balance of the central points within the experimental space.

2.2.5 Methods for Yield Data Collection

Observations focused on both vegetative parameters including plant heights at 3, 6, and 9 months and productive parameters, such as:

- Number of tuberous roots per plant
- Average lengths and circumferences of roots
- Yields of leaves, stems, and roots

These yield components were weighed per net plot at 12 months after planting.
The yield of fresh roots (FRY) was estimated using the formula proposed by Kamau et al.,2010

$$\text{FRY (t/ha)} = \text{Root weight (kg/m}^2\text{)} \times 10{,}000 / 1{,}000$$

2.2.6 Data Processing and Statistical Analysis

Statistical analyses were performed using SAS (Statistical Analysis System) version 9.2. The analyses primarily consisted of one-, two-, and three-way analyses of variance (ANOVA).Three-factor ANOVA (season, zone, and treatment) was applied to data related to cassava root, stem, and leaf yields, as well as root circumference and length.Two-factor ANOVA (season and zone) was applied to the organic fertilizer analysis data. One-way ANOVA (zone) was used to analyze soil characteristics prior to trial establishment. To satisfy the normality assumption required for ANOVA, root count data were transformed using $\log_{10}(n)$ (Dagnelie, 1998). The Student–Newman–Keuls test was used for mean separation at a significance level of $p < 0.05$.Optimal nutrient rates for each element were determined based on response surface analyses conducted using MINITAB 18 software.

3. Results

3.1. Soil Characteristics Before Trial Establishment

The results of the chemical characteristics of the various soils are presented in Table 2. Analysis of the table indicates that there were no significant differences ($p > 0.05$) between the two zones regarding clay, silt, and sand content, exchangeable base levels, and pH(KCl). Similarly, the sum of exchangeable cations and the cation exchange capacity (CEC) did not vary between sampling zones. However, the sand content in forest zones was significantly higher ($p < 0.01$ to $p < 0.001$) than in the savanna zone.Overall, savanna soils were found to be significantly richer ($p < 0.01$ to $p < 0.001$) in organic carbon, total nitrogen, and exchangeable potassium compared to forest soils. Additionally, the base saturation rate was highly significantly greater ($p < 0.001$) in the savanna zone than in the forest zone.Regarding pH measured in water, savanna soils were significantly more acidic ($p < 0.001$) than those of the forest. Conversely, forest soils were significantly richer ($p < 0.001$) in exchangeable sodium (Table 2) .

Table 3: Physico-chemical characteristics of soils (means ± standard errors) at the sites before trial establishment

Zones	Clay (%)	Silt (%)	Sand (%)	Organic C (%)	N (%)	OM (%)	pH(H_2O)	pH(KCl)	Exchangeable bases (cmol/kg)				Sum of cations (cmol/kg)	CEC (cmol/kg)	%BS = S/T × 100	Available P (mg/kg)
									Ca^{2+}	Mg^{2+}	K^{+}	Na^{+}				
Bouar (Boe)	25,17± 4,41	28,89± 4,81	46,55± 3,61	0,57± 0,13b	0,05± 0,00c	0,91± 0,26b	5,27± 0,12**a**	4,86± 0,14	1,71± 0,63	0,69± 0,21	0,06± 0,02b	0,13± 0,02b	2,24± 0,82	14,63± 7,68	44,43± 4,01b	1,79± 0,41
Damara	19,70± 0,99	31,37± 1,37	48,93± 2,02	12,33± 0,20**a**	0,80± 0**a**	2,12± 0,03**a**	5,42± 0,10**a**	4,60± 0,05	2,75± 0,58	0,75± 0,08	4,84± 0,21**a**	0,04± 0,0b	2,92± 0,43	3,46± 0,47	84,47± 3,81**a**	0,25± 0,01
SAVANNA	22,43± 2,33	30,13± 2,36	47,74± 1,96B	6,45± 2,23**A**	0,43± 0,14**A**	1,52± 0,26	5,35± 0,08**A**	4,73± 0,08	2,23± 0,44	0,72± 0,11	2,45± 0,91**A**	0,09± 0,02B	2,58± 0,45	9,05± 4,14	64,45± 7,99**A**	1,02± 0,35
Mbaikil SDR1	22,55± 4,51	19,86± 6,57	57,59± 2,85	0,85± 0,13b	0,08± 0,01b	1,47± 0,23ab	4,48± 0,15	4,47± 0,17	1,05± 0,25	0,40± 0,11	0,13± 0,04b	0,32± 0,05**a**	1,91± 0,40	10,27± 2,67	43,11± 8,98b	3,53± 2,49
Mbaikil SDR2	18,22± 3,62	25,69± 4,26	56,06± 4,22	0,79± 0,11b	0,09± 0,01b	1,36± 0,18ab	4,66± 0,20b	4,57± 0,05	1,40± 0,36	0,53± 0,14	0,17± 0,05b	0,28± 0,05**a**	2,38± 0,56	9,03± 0,95	39,96± 9,41b	1,16± 0,08
FOREST	20,38± 2,79	22,77± 3,79	56,82± 2,37**A**	0,82± 0,08B	0,08± 0,01B	1,42± 0,14	4,57± 0,12B	4,52± 0,08	1,23± 0,21	0,46± 0,09	0,15± 0,03B	0,30± 0,03**A**	2,14± 0,33	9,65± 1,33	41,54± 6,05B	2,34± 1,24
F-value	0,65	1,11	2,28	1742,27	2971,37	5,90	9,81	2,23	2,20	0,92	499,08	11 ,71	0,44	1,40	13,07	1,24
Prob	0,60	0,39	0,14	<0,001	<0,001	0,01	0,003	0,15	0,16	0,47	<0,001	0,002	0,73	0,31	<0,001	0,35

Note: Means followed by the same alphabetical letter, in the same format and for the same factor, are not significantly different (P > 0.05) according to the Student–Newman–Keuls test.

3.2. Chemical Characteristics of the Organic Fertilizers Used

The results of the two-factor analysis of variance conducted on the chemical characteristics of cattle manure are presented in Table 3. The table shows that there is no significant difference ($p > 0.05$) either between the seasons during which samples were collected or between the collection zones in terms of carbon content, total nitrogen, sum of exchangeable bases (SEB), available phosphorus, calcium, magnesium, potassium, sodium, copper, and zinc. Similarly, the total cation content does not vary significantly ($p > 0.05$). However, pH varied significantly ($p < 0.05$) from one season to another (Table 3). The results of the Student-Newman-Keuls test (Table 4) also showed no significant difference ($p > 0.05$) between seasons or zones in terms of carbon content, total nitrogen, SEB, available phosphorus, calcium, magnesium, potassium, sodium, copper, and zinc. However, the pH values of the manure from the 2022–2023 season were significantly higher ($p < 0.05$) than those from the 2021–2022 season. Overall, pH values are close to neutral, regardless of the cultivation zone or season (Table 4).

Table 4: Results of two-factor analysis of variance on cattle manure

		Fisher's F-value												
Sources of Variation	Degrees of Freedom	pH	C (%)	N (%)	C/N	SBE	Pass (mg/kg)	Ca éch (méq/100g)	Mg (méq/100g)	K éch (méq/100g)	Na éch (méq/100g)	Sum of Exchangeable Cations (meq/100g)	Cu	Zn
Seasons	1	6,41*	0,09ns	0,00ns	1,98ns	0,76ns	0,97ns	0,57ns	0,67ns	1,84ns	0,36ns	1,28ns	0,69ns	2,28ns
Zones	1	0,48ns	0,51ns	0,22ns	1,59ns	0,90ns	0,01ns	0,23ns	2,17ns	1,62ns	0,36ns	1,11ns	1,01ns	1,04ns
Seasons × Zones	1	0,26ns	1,15ns	0,07ns	3,85ns	0,83ns	0,08	1,35ns	0,97ns	1,84ns	0,09ns	1,03ns	0,94ns	1,56ns

ns : p >0,05 ; * : p < 0,05 ;

Table 5: Chemical Characteristics of the Manure (Mean ± Standard Errors) Used as Organic Fertilizers at the Sites

Seasons	Zones	pH	C (%)	N (%)	C/N	SBE	Pass (mg/kg)	Ca éch (méq/100g)	Mg (méq/100g)	K éch (méq/100g)	Na éch (méq/100g)	Sum of Cations (meq/100g)	Cu	Zn
2021-2022	SEGAN BAN	7,29± 0,01	17,86± 0,25	0,82± 0,01	21,92± 0,46	3,10± 0,00	0,43± 0,01	0,38± 0,01	0,32± 0,01	0,81± 0,00	0,13± 0,0	3,15± 0,01	7,75± 0,01	237,33± 1,67
	SEGAN MBA	7,27± 0,01	18,27± 0,30	0,81± 0,01	22,69± 0,56	3,10± 0,00	0,42± 0,01	0,39± 0,01	0,31± 0,01	0,81± 0,01	0,12± 0,01	3,14± 0,01	7,73± 0,01	240,11± 2,00
	Mean	7,28± 0,01**A**	18,06± 0,20	0,81± 0,01	22,31± 0,37	3,10± 0,00	0,42± 0,01	0,39± 0,01	0,31± 0,01	0,81± 0,00	0,13± 0,00	3,14± 0,00	7,73± 0,01	238,72± 1,32
2022-2023	SEGAN BAN	7,09± 0,17	18,76± 0,47	0,84± 0,03	22,53± 0,21	3,11± 0,01	0,49± 0,08	0,39± 0,01	0,32± 0,02	0,81± 0,00	0,12± 0,00	3,13± 0,01	7,81± 0,08	234,17± 6,09
	SEGAN MBA	6,98± 0,07	16,68± 2,24	0,79± 0,13	18,99± 2,06	2,78± 0,36	0,52± 0,15	0,35± 0,05	0,27± 0,04	0,70± 0,08	0,12± 0,02	2,77± 0,34	6,93± 0,89	206,72± 23,28
	Mean	7,04± 0,09B	17,72± 1,12	0,82± 0,06	20,76± 1,22	2,94± 0,18	0,51± 0,08	0,37± 0,02	0,29± 0,02	0,75± 0,04	0,12± 0,01	2,95± 0,17	7,37± 0,44	220,44± 12,38

Note: Means followed by the same alphabetical letter, with the same formatting and for the same factor, are not significantly different (p > 0.05) according to the Student–Newman–Keuls test

3.3. Treatment Performance on Cassava Productivity in Forest Zones

3.3.1. Evolution of Height Parameters According to the Different Fertilizer Formulas Applied

Table 5 presents the progression of height growth parameters of cassava plants at different measurement periods, according to the various nutrient combinations involving nitrogen (N), phosphorus (P), potassium (K), and organic fertilizer (FY) applied. The results of the analysis of variance indicate significant differences in plant height between the different measurement periods (p = 0.000). Moreover, the various treatment combinations also had a significant impact on plant height at each measurement period (p = 0.000).From the table results, we observe that in the first measurement period, the treatments N50P75K0FY20, N50P75K50FY0, and N50P75K50FY40 showed the greatest heights with values of 0.48 ± 0.01 m and 0.47 ± 0.01 m respectively. In contrast, the N0P37K0FY20 treatment had the lowest height (0.12 ± 0.01 m).In the second measurement period, the treatments N0P37K0FY20 and N50P37K100FY0 showed heights of 1.70 ± 0.07 m and 1.72 ± 0.16 m respectively. Treatments without organic fertilizer application, such as N50P0K50FY40, showed more modest growth (0.45 ± 0.12 m).

During the third measurement period, the treatments N50P75K0FY20, N50P75K50FY0, and N50P75K50FY40 continued to display the highest plant heights, with values of 3.74 ± 0.03 m, 3.66 ± 0.15 m, and 3.52 ± 0.28 m respectively. The treatments N0P0K50FY20 and N50P0K50FY0 showed lower growth (1.63 ± 0.02 m and 1.54 ± 0.31 m respectively).

Table 6: Evolution of Cassava Plant Height Growth Parameters According to the Different Fertilizer Formulas Applied in the Forest Zone

Treatments	Measurement Frequency 1	Measurement Frequency 2	Measurement Frequency 3
N0P0K50FY20	0,31±0,07 abcdef	0,63±0,07 cde	1,63±0,02 fghi
N0P37K0FY20	0,12±0,01 f	1,70±0,07 ab	2,51±0,03 de
N0P37K100FY20	0,21±0,09 cdef	1,51±0,23 ab	2,47±0,28 de
N0P37K50FY0	0,21±0,01 cdef	1,23±0,73 abcde	2,38±0,32 defg
N0P37K50FY40	0,25±0,02 cdef	1,55±0,18 ab	2,42±0,36 def
N0P75K50FY20	0,38±0,05 abcd	1,49±0,04 ab	3,52±0,35 ab
N100P0K50FY20	0,17±0,06 ef	0,62±0,17 cde	1,56±0,07 ghi
N100P37K0FY20	0,31±0,08 abcdef	1,45±0,31 abcd	2,65±0,01 cd
N100P37K100FY20	0,18±0,05 def	1,54±0,25 ab	2,43±0,37 def
N100P37K50FY0	0,14±0,01 ef	1,22±0,11 abcde	2,17±0,10 defgh
N100P37K50FY40	0,22±0,02 cdef	1,50±0,35 ab	2,60±0,13 d
N100P75K50FY20	0,47±0,03 ab	1,53±0,14 ab	3,66±0,20 a
N50K75K0FY20	0,48±0,01 a	1,54±0,42 ab	3,74±0,03 a
N50P0K0FY20	0,20±0,09 cdef	0,91±0,10 bcde	1,64±0,18 fghi
N50P0K100FY20	0,19±0,03 def	0,62±0,19 de	1,72±0,06 efghi
N50P0K50FY0	0,19±0,12 def	0,61±0,32 de	1,54±0,31 hi
N50P0K50FY40	0,16±0,04 def	0,45±0,12 e	1,32±0,09 i
N50P37K0FY0	0,25±0,03 cdef	1,58±0,35 ab	2,49±0,33 de
N50P37K0FY40	0,16±0,07 ef	1,62±0,17 ab	2,69±0,11 cd
N50P37K100FY0	0,22±0,07 cdef	1,72±0,16 ab	2,69±0,04 bcd
N50P37K100FY40	0,23±0,05 cdef	1,51±0,19 ab	2,51±0,17 de
N50P37K50FY20	0,30±0,05 bcde	1,67±0,18 a	2,62±0,07 d
N50P75K100FY20	0,41±0,02 abc	1,48±0,39 abc	3,46±0,43 abc
N50P75K50FY0	0,48±0,01 a	1,50±0,50 ab	3,66±0,15 a

N50P75K50FY40	0,47±0,01 ab	1,61±0,32 ab	3,52±0,28 a

Note: Means followed by the same alphabetical letter with the same format and for the same factor are not significantly different ($p > 0.05$) according to the Student-Newman-Keuls test

3.3.2. Cassava Root, Stem, and Leaf Yields According to the Different Fertilizer Formulas Applied

Table 6 presents the results of cassava root, stem, and leaf yields under various treatment combinations. The results of the analysis of variance performed on the yield parameters showed significant differences for root yields only (p = 0.000). The treatments N50P0K100FY20 and N50P0K50FY40 led to high root yields, with 47.62 ± 1.33 $t.ha^{-1}$ and 47.72 ± 1.47 $t.ha^{-1}$ respectively. Conversely, the treatments N0P37K0FY20 and N50P37K0FY0 produced the lowest root yields, with 7.14 ± 0.04 $t.ha^{-1}$ and 7.28 ± 1.10 $t.ha^{-1}$.Regarding stem yields, most treatments showed relatively similar values, generally between 2 and 3 $t.ha^{-1}$. However, the treatment N0P37K0FY20 stood out with a yield of 3.55 ± 1.14 $t.ha^{-1}$.

For leaf yields, the treatments N100P37K100FY20 and N50P0K50FY0 resulted in higher yields, at 2.47 ± 0.61 $t.ha^{-1}$ and 2.43 ± 0.70 $t.ha^{-1}$ respectively. On the other hand, the treatments N0P37K100FY20 and N0P37K0FY20 produced lower yields, with 0.43 ± 0.21 $t.ha^{-1}$ and 0.57 ± 0.21 $t.ha^{-1}$ respectively.

Table 7: Cassava Root, Stem, and Leaf Yields According to Treatments

Treatments	**Root Yield**	**Stem Yield**	**Leaf Yield**
N0P0K50FY20	21,18±9,80 bcdef	1,53±1,15 a	1,07±0,49 a
N0P37K0FY20	7,14±0,04 f	3,55±1,14 a	0,57±0,21 a
N0P37K100FY20	10,20±2,88 ef	2,51±0,45 a	0,43±0,21 a
N0P37K50FY0	13,24±2,18 def	2,48±0,13 a	0,84±0,30 a
N0P37K50FY40	10,71±0,58 ef	2,39±0,48 a	1,01±0,08 a
N0P75K50FY20	7,99±0,43 ef	3,40±0,94 a	0,88±0,09 a
N100P0K50FY20	46,98±2,64 a	2,31±0,42 a	1,05±0,20 a
N100P37K0FY20	8,25±1,53 ef	3,29±1,14 a	1,48±0,86 a
N100P37K100FY20	42,46±7,93 ab	3,76±0,20 a	2,47±0,61 a
N100P37K50FY0	37,58±3,51 abc	2,51±1,16 a	1,76±0,07 a
N100P37K50FY40	41,83±3,86 ab	2,48±0,66 a	1,58±0,67 a
N100P75K50FY20	12,31±2,50 ef	3,14±0,64 a	2,10±0,86 a
N50K75K0FY20	7,76±2,27 f	3,12±0,99 a	1,33±0,06 a
N50P0K0FY20	9,68±2,06 ef	2,03±0,96 a	1,07±0,49 a
N50P0K100FY20	47,62±1,33 a	2,09±0,86 a	1,82±0,80 a
N50P0K50FY0	34,68±13,41abcd	1,60±1,57 a	2,43±0,70 a
N50P0K50FY40	47,72±1,47 a	2,51±0,26 a	0,93±0,44 a
N50P37K0FY0	7,28±1,10 f	3,24±0,91 a	1,52±0,29 a
N50P37K0FY40	10,82±1,46 ef	2,88±1,49 a	1,32±1,19 a
N50P37K100FY0	30,10±18,30 abcde	2,36±1,37 a	1,76±0,56 a
N50P37K100FY40	42,63±2,26 ab	3,22±0,32 a	1,94±1,25 a
N50P37K50FY20	45,90±1,82 a	3,01±0,86 a	1,59±0,37 a
N50P75K100FY20	15,96±5,27 cdef	3,21±0,90 a	1,12±0,61 a
N50P75K50FY0	15,24±0,17 cdef	3,16±1,20 a	1,12±0,09 a
N50P75K50FY40	11,75±1,36 ef	3,12±1,14 a	0,89±0,39 a

Note.: Means followed by the same alphabetical letter, with the same format and for the same factor, are not significantly different ($p > 0.05$) according to the Student-Newman-Keuls test.

3.3.3. Determination of the Optimum

The analysis of the response surface results showed that the model below is highly significant ($p = 0.000$, $R^2 = 0.91$) for estimating cassava root yield, with the following regression equation:Root yield (kg·ha⁻¹) = $-13{,}092 + 718.8\,N + 263\,P + 850.4\,K + 868\,FY - 5.206\,N^2 - 7.57\,P^2 - 6.203\,K^2 - 18.86\,FY^2$. By considering the partial derivatives with respect to the fertilizing units N, P, K, and FY and setting them equal to zero, the optimal values of N, P, K, and FY that maximize the yield can be obtained by simultaneously solving the resulting system of equations:

- $718.8 - 10.412\,N = 0$
- $263 - 15.14\,P = 0$
- $850.4 - 12.406\,K = 0$
- $868 - 37.72\,FY = 0$

Solving this system yields the following values: 68.68 kg of N, 17.42 kg of P, 68.69 kg of K, and 23.03 kg of FY (Figure 2). These application rates are estimated to produce a root yield of 53.1 t·ha⁻¹.

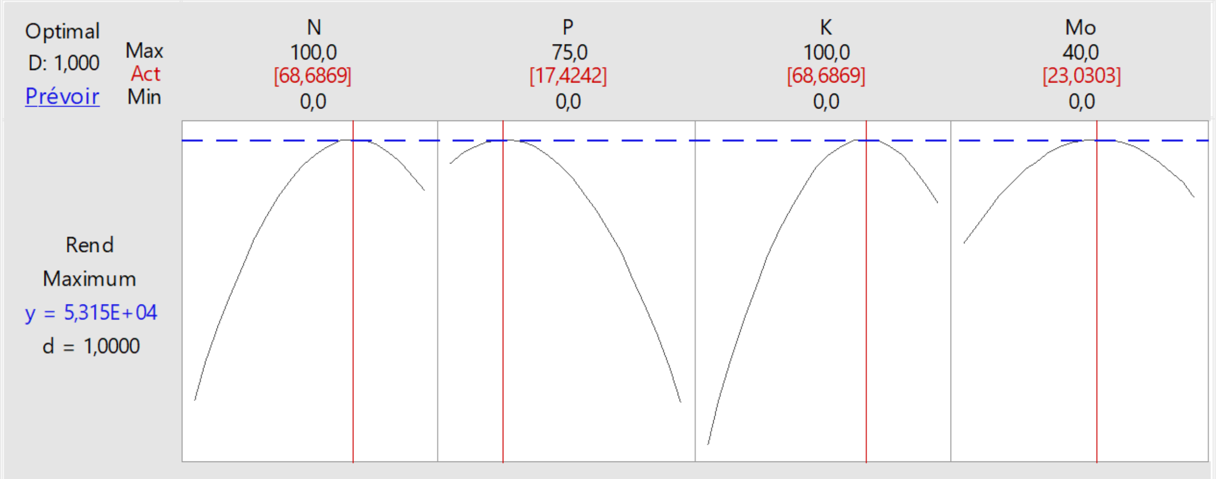

Figure 2: Maximum Levels of Nutrients and Organic Fertilizer Applied

To determine the optimum, each derivative must be set equal to the ratio of the nutrient unit price to the unit price of the product:

- $718.8 - 10.412\,N = 3.86$
- $263 - 15.14\,P = 1.93$
- $850.4 - 12.406\,K = 7.9$
- $868 - 37.72\,FY = 0.26$

Solving this system yields the following values: 68.66 kg of N, 17.24 kg of P, 67.92 kg of K, and 23 kg of FY.Considering the contour diagrams of the response surfaces (Figure 3):The PN graph illustrates the interaction between phosphorus (P) and nitrogen (N). Higher levels of both nutrients appear to result in greater yield values (up to 50,000), as indicated by the uppermost contour lines.The KN graph explores the interaction between potassium (K) and nitrogen (N). As in the previous graph, higher levels of K and N are associated with higher yields.Attention is then directed to the interaction between organic fertilizer (FY) and nitrogen (N). The trends show that greater amounts of FY and N promote high yields.The KP graph reveals the interaction between potassium (K) and phosphorus (P). The trend suggests that higher levels of both nutrients are necessary to achieve increased yields.The FY–P graph illustrates the combined effect of organic fertilizer (FY) and phosphorus (P). Yields increase as the levels of both inputs rise. Lastly, the FY–K graph depicts the interaction between organic fertilizer (FY) and potassium (K). As with the other combinations, higher levels of these nutrients are linked to increased yields.

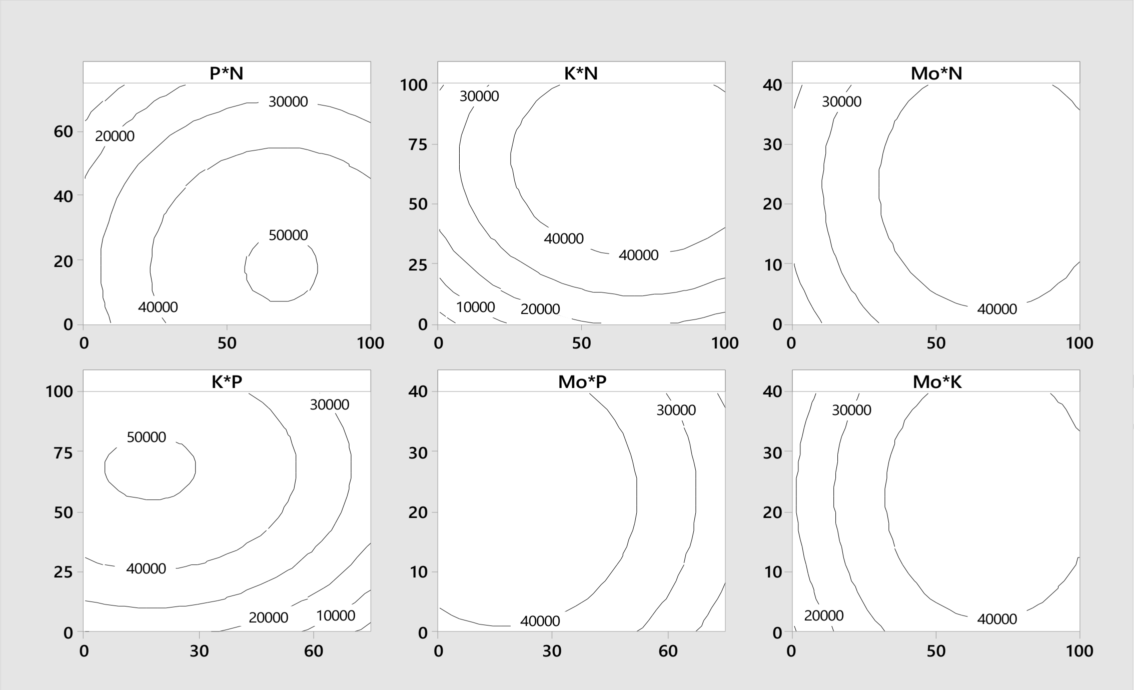

Figure 3: Contour Diagram

3.4. Treatment Performance on Cassava Productivity in the Savannah Zone

3.4.1. Evolution of Height Parameters According to the Different Fertilizer Formulas Applied

Table 7 presents the evolution of height growth parameters of cassava plants at different measurement periods, based on various treatments including nitrogen (N), phosphorus (P), potassium (K), and organic matter (FY). The analysis of variance reveals significant differences in plant height across the different measurement periods (p = 0.000). Furthermore, the applied treatments also had a significant impact (p = 0.002) on plant height at each measurement period.Initial cassava plant heights were relatively low, ranging from 0.13 m to 0.92 m. The treatment N0P75K50FY20 resulted in the highest height (0.92 ± 0.01 m), suggesting rapid initial growth, while the treatment N50P0K0FY20 had the lowest height (0.13 ± 0.01 m), indicating slow initial growth.During the second measurement period, plant heights increased across all treatments, reaching values between 0.40 m and 1.67 m. The treatment N100P75K50FY20 yielded the greatest height (1.67 ± 0.05 m), closely followed by N50P75K50FY0 (1.60 ± 0.05 m), indicating a positive response to these combinations. The lowest growth was observed with treatment N50P0K100FY20 (0.40 ± 0.10 m).In the third measurement period, plant heights continued to rise, ranging from 1.26 m to 2.91 m. The treatments N0P75K50FY20 (2.91 ± 0.09 m), N50P75K50FY40 (2.88 ± 0.11 m), and N50P75K100FY20 (2.68 ± 0.05 m) showed the greatest heights, indicating strong and sustained growth. The treatment N50P0K0FY20 remained the least effective (1.26 ± 0.07 m).

Table 8: Evolution of Cassava Plant Height Growth Parameters According to the Different Fertilizer Formulas Applied in the Savannah Zone

Treatments	Measurement Frequency 1	Measurement Frequency 2	Measurement Frequency 3
N0P0K50FY20	0,20±0,04 a	0,57±0,05 de	1,45±0,27 bcd
N0P37K0FY20	0,35±0,21 a	1,11±0,89 abcde	2,26±1,01 abcd
N0P37K100FY20	0,41±0,14 a	1,06±0,47 abcde	2,20±0,36 abcd
N0P37K50FY0	0,53±0,01 a	0,83±0,14 abcde	1,78±0,19 abcd

N0P37K50FY40	0,28±0,08 a	0,85±0,02 cde	1,78±0,19 abcd
N0P75K50FY20	0,92±0,01 a	1,58±0,21 abcd	2,91±0,09 a
N100P0K50FY20	0,24±0,10 a	0,79±0,12 de	1,53±0,17 bcd
N100P37K0FY20	0,18±0,07 a	0,60±0,26 de	1,50±0,21 bcd
N100P37K100FY20	0,47±0,36 a	0,90±0,09 abcde	2,19±0,25 abcd
N100P37K50FY0	0,51±0,42 a	1,16±0,26 abcde	1,96±0,44 abcd
N100P37K50FY40	0,23±0,01 a	0,83±0,19 cde	1,73±0,38 abcd
N100P75K50FY20	0,76±0,07 a	1,67±0,05 a	2,60±0,28 abc
N50K75K0FY20	0,19±0,01 a	0,56±0,20 de	1,61±0,20 abcd
N50P0K0FY20	0,13±0,01 a	0,55±0,01 de	1,26±0,07 d
N50P0K100FY20	0,18±0,03 a	0,40±0,10 e	1,48±0,24 bcd
N50P0K50FY0	0,17±0,05 a	0,97±0,87 abcde	1,57±0,23 bcd
N50P0K50FY40	0,18±0,07 a	0,58±0,29 de	1,73±0,38 abcd
N50P37K0FY0	0,23±0,01 a	0,87±0,16 de	1,93±0,10 abcd
N50P37K0FY40	0,17±0,07 a	0,74±0,31 de	1,40±0,35 cd
N50P37K100FY0	0,23±0,02 a	0,48±0,11 bcde	1,83±0,25 abcd
N50P37K100FY40	0,47±0,33 a	0,77±0,03 de	1,99±0,02 abcd
N50P37K50FY20	0,32±0,15 a	0,66±0,38 de	2,06±0,23 abcd
N50P75K0FY20	0,21±0,01 a	1,35±0,20 abcde	2,01±0,20 abcd
N50P75K100FY20	0,71±0,14 a	1,63±0,15 ab	2,68±0,05 ab
N50P75K50FY0	0,89±0,21 a	1,60±0,05 abc	2,68±0,04 ab
N50P75K50FY40	0,83±0,14 a	1,49±0,22 abcde	2,88±0,11 a

Note: Means followed by the same alphabetical letter, in the same format and for the same factor, are not significantly different (p > 0.05) according to the Student-Newman-Keuls test.

3.4.2. Effect of Treatments on Cassava Root, Stem, and Leaf Yields

Table 8 presents the results of cassava root, stem, and leaf yields under various treatment combinations involving nitrogen (N), phosphorus (P), potassium (K), and organic fertilizer (FY). The analysis of variance conducted on yield parameters showed significant differences for root yields only ($p = 0.000$).The treatments N100P37K50FY40 and N50P37K100FY0 produced the highest root yields, with 41.65 ± 0.10 t·ha^{-1} and 41.68 ± 2.18 t·ha^{-1}, respectively. Conversely, the treatments N0P37K0FY20 and N50P37K0FY0 yielded the lowest root production, with 7.99 ± 2.50 t·ha^{-1} and 8.39 ± 1.05 t·ha^{-1}, respectively.Most treatments showed relatively similar stem yields, typically around 2 to 4 t·ha^{-1}. However, the treatments N100P37K50FY0 (4.76 ± 0.22 t·ha^{-1}) and N50P75K50FY40 (4.78 ± 0.27 t·ha^{-1}) stood out with higher stem yields.Regarding leaf yields, the treatments N100P37K100FY20 and N100P37K0FY20 recorded the highest values (2.64 ± 0.99 t·ha^{-1} and 2.14 ± 0.21 t·ha^{-1}, respectively). In contrast, N50P75K0FY20 and N0P75K50FY20 showed the lowest leaf yields, with 0.24 ± 0.08 t·ha^{-1} and 0.33 ± 0.08 t·ha^{-1}, respectively.

Table 9: Effect of Treatments on Cassava Root, Stem, and Leaf Yields in the Savannah Zone

Treatments	Root Yield	Leaf Yield	Stem Yield
N0P0K50FY20	16,15±0,90 bcdef	0,55±0,51 cd	1,69±0,32 a
N0P37K0FY20	7,99±2,50 f	0,53±0,32 cd	1,99±0,18 a
N0P37K100FY20	27,97±1,04 abcdef	0,95±0,38 bcd	4,51±0,09 a
N0P37K50FY0	12,29±1,50 def	0,72±0,30 cd	2,60±0,33 a
N0P37K50FY40	18,95±3,39 abcdef	0,70±0,24 cd	3,57±0,41 a

N0P75K50FY20	10,44±2,43 ef	0,33±0,08 d	2,10±0,57 a
N100P0K50FY20	36,89±0,46 abcd	1,12±0,13 abcd	1,72±0,20 a
N100P37K0FY20	15,21±1,21 def	2,14±0,21 abc	3,31±0,60 a
N100P37K100FY20	37,18±1,65 abcd	2,64±0,99 a	4,30±0,30 a
N100P37K50FY0	37,90±3,38 abcd	1,01±0,29 bcd	4,76±0,22 a
N100P37K50FY40	41,65±0,10 ab	1,64±0,85 abcd	4,29±0,53 a
N100P75K50FY20	20,57±6,08 abcdef	2,07±0,28 abc	3,14±0,16 a
N50K75K0FY20	14,36±1,50 abcdef	1,29±0,10 abcd	4,88±0,42 a
N50P0K0FY20	12,45±6,75 def	1,20±0,01 abcd	3,05±0,27 a
N50P0K100FY20	30,86±1,02 abcdef	1,26±0,02 abcd	2,25±0,60 a
N50P0K50FY0	23,25±5,15 abcdef	1,81±0,25 abcd	0,51±0,32 a
N50P0K50FY40	34,50±8,19 abcde	1,01±0,25 bcd	2,02±0,59 a
N50P37K0FY0	8,39±1,05 f	0,88±0,11 bcd	1,97±0,35 a
N50P37K0FY40	13,69±3,29 def	1,22±0,17 abcd	3,97±1,54 a
N50P37K100FY0	41,68±2,18 ab	1,24±0,05 abcd	4,70±0,17 a
N50P37K100FY40	41,05±1,16 abc	2,45±0,74 ab	3,60±0,43 a
N50P37K50FY20	37,84±50 a	1,65±0,45 abc	3,56±0,93 a
N50P75K0FY20	7,58±1,02 def	0,24±0,08 cd	4,67±0,51 a
N50P75K100FY20	33,20±9,10 abcdef	1,26±0,08 abcd	4,74±0,32 a
N50P75K50FY0	29,40±7,60 abcdef	1,16±0,25 abcd	4,37±0,96 a
N50P75K50FY40	15,48±1,75 cdef	1,26±0,07 abcd	4,78±0,27 a

Note: Means followed by the same alphabetical letter, with the same formatting and for the same factor, are not significantly different ($p > 0.05$) according to the Student-Newman-Keuls test.

3.4.3. Determination of the Optimum and Maximum Yield

The analysis of the response surface results showed that the model below is highly significant ($p = 0.000$, $R^2 = 0.86$) for estimating cassava root yield, and the regression equation is as follows:

Root yield (kg/ha) = $-7800 + 466.0\,N + 391\,P + 555.2\,K + 372\,FY - 3.059\,N^2 - 6.24\,P^2 - 3.165\,K^2 - 8.02\,FY^2$.Based on this equation, by taking the partial derivatives with respect to the fertilizing units N, P, K, and the quantity of organic fertilizer applied (FY), and setting them equal to zero, one can determine the values of N, P, K, and FY that provide the maximum yield by simultaneously solving the resulting system of equations:

- $466.0 - 6.118\,N = 0$
- $391 - 12.48\,P = 0$
- $555.2 - 6.33\,K = 0$
- $372 - 16.04\,FY = 0$

Solving this system yields the following values: 75.75 kg/ha of N, 31.06 kg/ha of P, 87.87 kg/ha of K, and 23.03 kg/ha of FY (Figure 4). These respective doses are estimated to result in a yield of 44.8 t/ha.

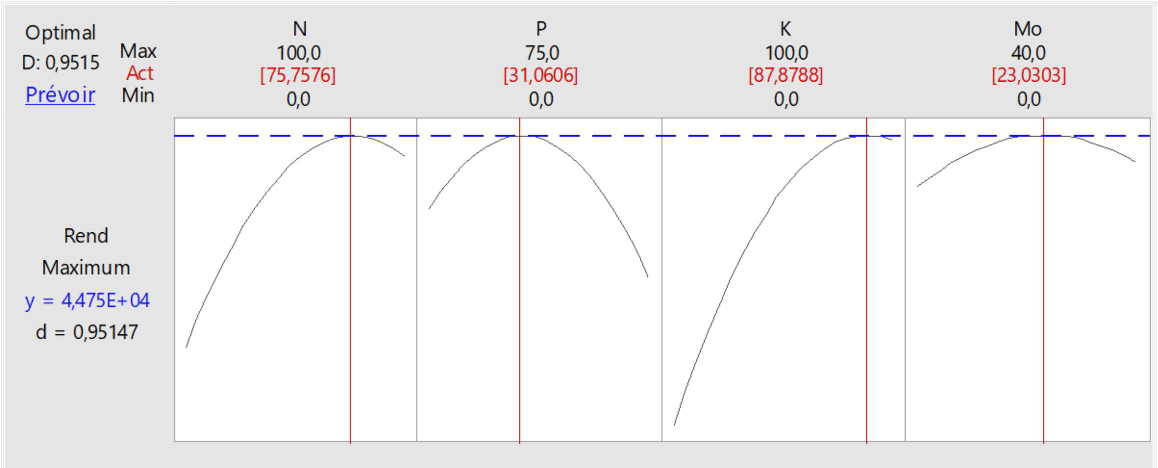

Figure 4: Graph Showing the Levels of the Determined Optimal Doses

To determine the optimum, each derivative must be set equal to the ratio of the unit price of the nutrient to the unit price of the product:

- $466.0 - 6.118\ N = 3.86$
- $391 - 12.48\ P = 1.93$
- $555.2 - 6.33\ K = 7.9$
- $372 - 16.04\ FY = 0.26$

Solving this system of equations yields the following values: 75.57 kg·ha^{-1} of N, 31.18 kg·ha^{-1} of P, 86.47 kg·ha^{-1} of K, and 23.17 kg·ha^{-1} of FY.The contour diagram of the response surface is shown in Figure 5.

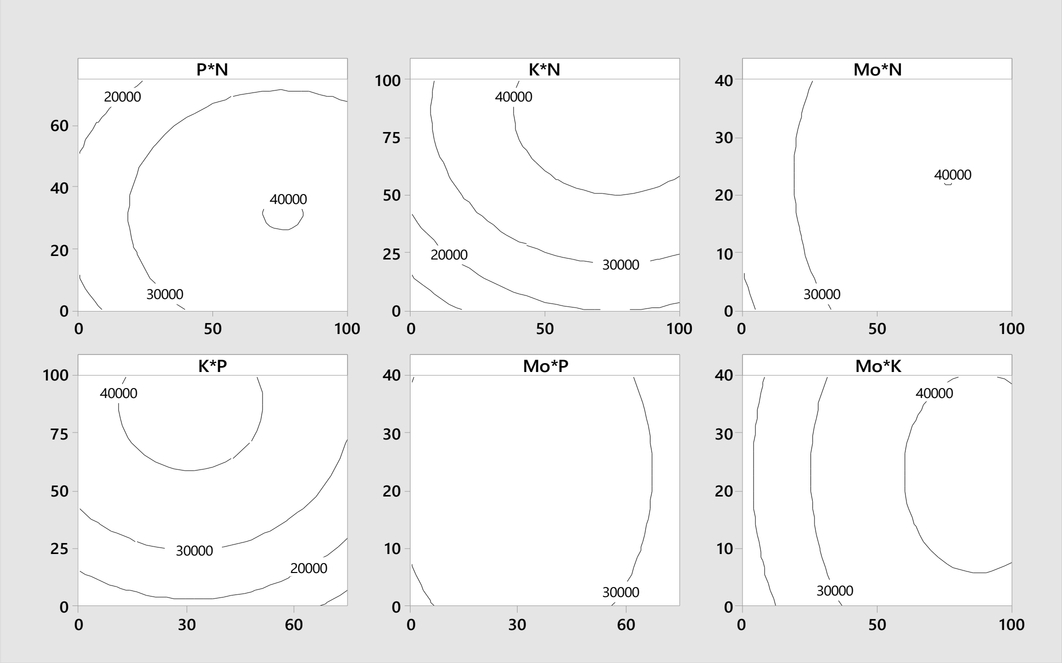

Figure 5: Contour Diagram for Nutrients and the Amount of Organic Fertilizer Applied

The PN graph shows the interaction between phosphorus (P) and nitrogen (N). Higher levels of both nutrients appear to lead to increased yield values (40,000 kg·ha^{-1}), as indicated by the outer contour lines. This trend suggests a complementary effect between phosphorus and nitrogen.The KN graph examines the interaction between potassium (K) and nitrogen (N). As in the previous graph, higher levels of both K and N are associated with increased yields (40,000 kg·ha^{-1}). This reflects a synergistic relationship between these two nutrients in enhancing yield.The MoN graph explores the interaction between organic matter (Mo) and nitrogen (N). The trends indicate that higher levels of Mo and N promote increased yields, although the effect of Mo appears more pronounced at lower nitrogen levels.The KP graph illustrates the interaction between potassium (K) and phosphorus (P). The trend shows that higher levels of both nutrients are necessary to achieve maximum yields (40,000 kg·ha^{-1}).The MoP graph demonstrates the combined effect of organic matter (Mo) and phosphorus (P). Yields increase with higher levels of both nutrients, although Mo seems to exert a more dominant influence in zones of low availability.The MoK graph analyzes the interaction between organic matter (Mo) and potassium (K). Similar to the other combinations, higher levels of Mo and K are associated with increased yields.

4. Discussion

The results of this study revealed a differential response in plant vegetative growth depending on the treatments and sites (forest and savannah zones). For instance, in the forest zone, treatments combining nitrogen, phosphorus, potassium, and organic fertilizer (N50P75K50FY40) induced maximum plant growth, reaching 3.52 ± 0.28 m after the third measurement period. In contrast, less balanced treatments (N0P37K0FY20) resulted in limited growth (1.63 ± 0.02 m). Similar trends were observed in the savannah zone, where the greatest heights were achieved with phosphorus- and potassium-rich treatments combined with moderate nitrogen doses (N0P75K50FY20), allowing maximum plant height of 2.91 ± 0.09 m.These results highlight the key role of nutrient interactions in promoting optimal vegetative growth. Nitrogen and potassium play crucial roles in protein synthesis and sugar transport, while organic matter improves soil structure and nutrient availability (Nguyen et al., 2021), which may explain the observed outcomes.Root yields varied significantly depending on the treatments. In the forest zone, the highest yields (47.72 ± 1.47 t·ha⁻¹) were recorded with treatment N50P0K50FY40, while in the savannah zone, the N100P37K50FY40 treatment yielded the highest root output (41.65 ± 0.10 t·ha⁻¹). These findings underscore the importance of precise doses of nitrogen, phosphorus, and potassium combined with substantial organic fertilizer input to maximize cassava productivity.However, stem and leaf yields showed less variability, indicating that cassava plants are less sensitive to organo-mineral fertilization in this regard. For example, in the savannah zone, leaf yields did not exceed 2.64 ± 0.99 t·ha⁻¹, even with treatments including all nutrients.Response surface analysis made it possible to determine the optimal fertilizer and organic input doses. In the forest zone, the doses that maximized yields were: 68.68 kg·ha⁻¹ of nitrogen, 17.42 kg·ha⁻¹ of phosphorus, 68.69 kg·ha⁻¹ of potassium, and 23.03 kg·ha⁻¹ of organic fertilizer. In the savannah zone, slightly higher doses of nitrogen and phosphorus were required (75.57 kg·ha⁻¹ and 31.18 kg·ha⁻¹, respectively), reflecting differences in baseline soil fertility (Lal, 2020).

Overall, the study emphasizes the importance of region-specific fertilization strategies. Forest-zone soils, richer in organic matter, enabled cassava to respond better to moderate fertilizer doses. Conversely, savannah soils, being comparatively poorer, required higher inputs to achieve significant yields. This observation aligns with findings from Nziguheba *et al.,*2022, which showed that incorporating organic matter into tropical soils significantly improves nutrient availability.Furthermore, nutrient interactions (e.g., nitrogen–phosphorus, potassium–organic matter) highlight the synergistic effect of these elements. Nitrogen, though essential, must be paired with adequate doses of phosphorus and potassium to prevent nutritional imbalance.This study reinforces the importance of supplying nutrients in combination with organic fertilizer to improve cassava yields and safeguard soil nutrient levels across both study zones.

5. Conclusion

The results of this study clearly demonstrated that organo-mineral fertilization is an effective strategy for improving cassava yields in both forest and savannah zones of the Central African Republic. Indeed, the highest root yields were achieved through the combined application of mineral fertilizers containing the nutrients N, P, and K, along with organic amendments made from cattle manure, thus highlighting the synergistic effects of this approach on cassava productivity and soil fertility. In the forest zone, the treatments $N_{50}P_0K_{100}FY_{20}$ and $N_{50}P_0K_{50}FY_{40}$ led to maximum yields of approximately 47.62 and 47.72 t·ha⁻¹, respectively. Meanwhile, in the savannah zone, the best performances were observed with treatments $N_{100}P_{37}K_{50}FY_{40}$ and $N_{50}P_{37}K_{100}FY_0$, resulting in yields of 41.65 and 41.68 t·ha⁻¹, respectively. These findings confirm the importance of potassium and organic fertilizer inputs in cassava fertilization.Response surface analysis helped define the optimal fertilization formulas for yield maximization. The recommended doses in the forest zone are: N = 68.68 kg·ha⁻¹, P = 17.42 kg·ha⁻¹, K = 68.69 kg·ha⁻¹, and FY = 23.03 t·ha⁻¹, for an estimated yield of 53.1 t·ha⁻¹. In the savannah zone, the optimal doses were slightly higher: N = 75.75 kg·ha⁻¹, P = 31.06 kg·ha⁻¹, K = 87.87 kg·ha⁻¹, and FY = 23.03 t·ha⁻¹, leading to an estimated yield of 44.8 t·ha⁻¹.These formulas reflect both the agronomic efficiency and economic profitability of the nutrients. The study recommends these doses and formulas as technical reference points for the sustainable intensification of cassava cultivation. Therefore, correcting specific nutrient deficiencies identified in each agroecological zone through targeted applications of combined fertilizers is a priority path toward restoring and enhancing the productive potential of both soil types.The adoption of these fertilization strategies by farmers—accompanied by good agricultural practices—will ensure a significant and sustainable improvement in cassava productivity and contribute to food security.

Références bibliographiques

Akanbi, W. B., Adebooye, C. O., Togun, A. O., Ogunrinde, J. O., & Adeyeye, S. A. (2007). Growth, herbage and seed yield and quality of Telfairia occidentalis as influenced by cassava peel compost and mineral fertilizer. World Journal of Agricultural Sciences, 3, 508-516.

Bakayoko, S., Tschannen, A., Nindjin, C., Dao, D., Girardin, O., & Assa, A. (2009). Impact of water stress on fresh tuber yield and dry matter content of cassava (Manihot esculenta Crantz) in Côte d'Ivoire. African Journal of Agricultural Research, 4, 21-27.

El-Sharkawy, M. A. (2004). Cassava biology and physiology. Plant Molecular Biology, 56(4), 481-501.

Fermont, A. M., Van Asten, P. J. A., Tittonell, P., Van Wijk, M. T., & Giller, K. E. (2009). Closing the cassava yield gap: An analysis from smallholder farms in East Africa. Field Crops Research, 112, 24-36.

Nziguheba, G., et al. (2022). Nitrogen budgets and nitrogen use efficiency as agricultural performance indicators in Lake Victoria basin. Frontiers in Sustainable Food Systems, 6, 1023579.

Vanlauwe, B., et al. (2010). Integrated soil fertility management: Operational definition and consequences for implementation and dissemination. Outlook on Agriculture, 39(1), 17-24.

Zinga, I., et al. (2013). Epidemiological assessment of cassava mosaic disease in Central African Republic reveals the importance of mixed viral infection and poor health of plant cuttings. Crop Protection, 44, 6-12.

Zingore, S., et al. (2011). Integrated soil fertility management: An operational definition and consequences for implementation and dissemination. Better Crops, 95(3), 4-7.