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Fertilization options for improved cassava productivity and economic profitability in the Pissa and Damara areas, Central African Republic: Comparative Approach

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This study aimed to identify fertilization options for improving cassava productivity and profitability in two contrasting regions of the Central African Republic. The Pissa (guinea forest) and Damara (savannah). The study adopted a randomized complete block design with four treatments replicated four times in a plot size of 7 m by 7 m. The treatments were; T1 (Control), T2 (Peasant practice), T3 (sole NPK), and T4 (Cow manure+NPK). We performed the analysis of variance (ANOVA) using R statistical software version 3.1.2. The yield attributes and growth parameters significantly varied (p=0.05) with application of NPK and NPK plus manure. The use of 3 t ha^{-1} of cow manure and 90N-30P-180 Kg ha^{-1} of mineral fertilizer gave the highest yield of 50 and 37 t ha^{-1} in Pissa and Damara respectively compared to their local controls (no input); This combination also resulted in high profitability with high value-to-cost ratios (RVC = 2 in Pissa and 1.3 in Damara). The variability study (48.11%) showed a correlation between growth and production parameters; the effects of fertilizers were much more expressed in the plant's circumference and the number of leaves. The use of organo-mineral fertilizer can give good productivity and profitability. Thus, T4 is a technology that resource-poor households can easily use, although the purchasing power of the peasant farmers in the study area is low.

Key words: Cassava, agro-climatic, fertilizers, yields, Central African Republic.

INTRODUCTION

Cassava (Manihot esculenta Crantz) is regarded as a dominant staple in the face of climate uncertainty due to

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its good yield potential and ability to withstand long drought periods and highly variable rainfall (Szyniszewska, 2020). However, despite the importance of cassava as a predominant staple in the Central African Republic, cassava crop production still receives limited or no use of manure or inorganic fertilizer inputs (Santo, 2021). Seemingly, most smallholder households consider the use of fertilizer inputs as costly and uneconomical, and sometimes unreachable (Santo, 2021). Deteriorating soil fertility is one of the main causes of sub-Saharan Africa's increasing cassava yield gaps (Enesi et al., 2022). The escalating soil fertility constraints are attributed to climatic variabilities and anthropogenic factors that result in soil degradation in the context of galloping demographic pressure (Youl et al., 2011). The International Centre for Soil Fertility and Agricultural Development (IFDC) highlighted that approximately 8 million metric tons of soil nutrients are lost annually. Also, More than 95 million hectares of land are deteriorated thus stagnating productivity (Zhou et al., 2022). Additionally, it is rated that approximately 85 percent of countries in Africa suffer from nutrient harvesting of more than 30 kg per hectare per year and 40 percent of nations suffer losses of more than 60 kg of nutrients per hectare annually (Zhou et al., 2022). The nutrient loss results from adverse climate variability effects (Bedeke, 2022). Many researchers have demonstrated the importance of soil fertility management by either the sole application of organic resources or mineral fertilizer to bridge the crop yield gaps (Imran, 2022; Ngetich et al., 2012). The use of mineral fertilizers plays a vital role in soil fertility restoration, and better essential nutrients (Zhou et al., 2022). Additionally, organic resources play a crucial role in soil fertility management over inorganic fertilizer in sustainability terms (Omenda et al., 2019). They can improve soil nutrients, physical properties, and water holding capacity contributing to organic matter formation and maintenance (Lazcano et al., 2013). The combined use of manure and mineral fertilizer has also been suggested as one of the effective ways of improving soil fertility in farming systems (Omenda et al., 2019). However, the fertilization recommendations found in the Central African Republic and elsewhere in SSA are at best-educated guesses. Inappropriate recommendations in cassava production are likely not to improve cassava productivity since cassava is cultivated on different agro-ecologies in CAR, and soils in farmers' fields are highly variable (Zinga et al., 2016). Additionally, deranged nutrition may lead to nutrient losses (Cassman et al., 2002), hindering the productivity and profitability of cassava (Angus et al., 2004). Thus, there is a dire need for more information about cassava production guidelines for fertilizer application rates. In Central Africa, cassava production in traditional agriculture is with no input of manure or mineral fertilizer (Vanlauwe et al., 2012). Hence, the wide yield gap between the yield received in farmers' fields and the cassava potential productivity (Ezui et al., 2016). For instance, CAR's average storage root yield is 10.8 t/ha, which is bleak compared to its yield potential of 75 to 90 t/ha (Fermont et al., 2010). Poor resource endowment is a factor that hinders the uptake of input-intensive innovations such as optimum nutrient application through the use of mineral fertilizers which have been proven effective in bridging the cassava yield gaps (Bationo et al., 2007). Therefore, the challenge for cassava production intensification is to adopt low-input innovations that fit the resource-poor farmers and that increase cassava productivity and profitability. The furtherance of organic inputs is the most practical option. Yet, this needs the determination of modest manure application rates to obtain better cassava yields for resource-poor farmers. The technical options integrated are; (a) modified crop spacing (peasant practice vs adjusted design 1 × 1 m) and (b) applying the modest manure and inorganic fertilizer rates. The improved cassava variety 'Gabon' is better than other local varieties because it is resistant to cassava mosaic. Additionally, the use of moderate fertilizer dozes for nutrient supply availability has been put forward. We carried out a study on the combined application of cow manure and inorganic fertilizer on cassava production and profitability in the Pissa and Damara areas of the Central African Republic.

MATERIALS AND METHODS

Study area

Two experiment stations were set up on-farm during the 2018/2019 cropping season at Pissa (4°20'712 N and18°11'022 E, 378 m altitude) and Damara (4°590622 N and 18°400442 E, 316 m altitude) (Table 1). In the Pissa area, the experiment was established in the plot of the agro-pastoral group of Pissa 2, located 3 km from the city of Pissa on the way to Mbaïki; It is a fallow of more than five years. The pizza is located in the forest zone with a mean temperature of 24°C and a total mean rainfall of 1300 mm, with rains mostly occurring from March through November. Another experimental site was established in Ndara 1 village, located 5 km from the city of Damara in the savanna zone and is characterized by a mean temperature of 25°C and a mean rainfall of 1600 mm. Rains mostly occur between May and October.

Field experiments

Plant and input materials

The accession "Gabon" (Figure 1) was selected for this experiment. It is recommended in peasant environments for its agronomic characteristics, which are the cycle duration of about one year, the good yield, and its resistance to cassava diseases (Zango et al., 2018). The soil physiochemical properties of the two study sites are summarised in Table 2. The soil texture at Pissa is sandy loam while at Damara it is sandy clay loam. We applied the composted cow manure and mineral fertilizer (Table 4). The mineral fertilizers were urea $(CO(NH2)_2$ (46% N); triple-super-phosphate (TSP) $(Ca(H2PO4)_2$ (46% P_20_4); and potassium sulfate (K_2S0_4) (50% K_20). Manure from cattle aged 3 to 4 years, collected from producers'

Table 1. Characteristics of the study sites (Mossoa and Nguimalet, 2008).

Characteristics	Site	
	Pissa	Damara
Province	Lobaye	Ombella M'poko
District	Pissa	Damara
Longitude	4°20'712 N	4°590622 N
Latitude	18°11'022 E, 378	18°400442 E
Elevation	378 m	316m
Agro-ecology	I	II
Rainfall type	Unimodal	Unimodal
Soil	Ferralitic and Hydrimorphic	Ferralitic
Vegetation	Forest	Savannah

Source: Authors

Figure 1. Accession "Gabon".
Source: Authors

farms, was used as organic inputs. The manure was sun-dried for seven days before the application.

Experimental layout

The experiment was set up in each location at the beginning of the rainy season in June 2018. The experimental setup was carried out in a participatory and integrated approach with the members of the agro-pastoral groups "Toumba nzara" of the municipality of Damara and "GAPI 2" of the municipality of Pissa to allow them to appropriate the recommended modern cultural techniques. The groups actively participated in the various cultivation works, from the choice of land to the harvest and the various post-harvest processing works, to assess the economic profitability according to the treatments used. We designed and established the experimental plots in Pissa and Damara during the experimental period of June 2018 to July 2019, making it a complete cropping cycle. The experimental design was a randomized complete block design with four treatments replicated four times. The plot dimension was 7 m by 7m with a 1 m wide alley separating plots within a block and a 2 m wide alley between blocks. The block size was 49 x 4m, and the whole experiment covered an area of 196 x 4 m per study site. The cassava 'Gabon' variety was the test crop as the dominant annual crop in the two areas. The treatments were; T1: Control (no input), T2: Peasant practice, T3: Sole NPK, and T4:Cow manure+NPK (Table 3). The agro morphological parameters were evaluated over 12 months for economic profitability.

Application of treatments

The T1: Cassava stem cutting was carried out manually on 13/05/2020 in Damara and on 15/05/2020 in Pissa by the peasant producers. Cuttings 20 to 30 cm long prepared for two days of planting were used as plant material by producers at one cutting per poquet. These cuttings were from the harvest of the producers' previous production. Thus, in the useful plots, the plant densities were 10404 plants/ha for Damara and 10506 plants/ha for Pissa. The plot was ploughed for T2, T3, and T4. After clearing, the seedling beds were prepared. The cassava cuttings of 10 to 15 cm served as planting plant material. These cuttings were taken a week before planting in a producers' field during harvest and kept in the shade to promote a good recovery. The planting was carried out at the same time as the peasant practice. The cassava cuttings of 10 to 15 cm were planted upright after manual tillage at 10,000 seedlings/ha density. The application of urea and potassium-sulphate was done at one month and then at three months for T4. As for the T3, the applications were made at one, three, and five months. The crown application technique was adopted. However, triple super phosphate and Cow manure are applied around each cassava plant a day of planting and are covered with soil. The urea fertilizer is applied around each cassava plant after a rainfall event. The experiments were maintained weed-free throughout the season. The harvesting was done 12 months after planting cassava (MAP) on each useful plot of 4 m^2 made in each elementary plot of 49 m^2 using the squares of yield. The average fresh tubers' weight based on the treatments was recorded in the field using the digital balance.

Yield in cossette for an evaluation of the economic profitability of cassava

In this study, we used one and a half bowls of fresh cassava of equivalence to 53 kg to obtain one bowl (NGAWI) of cossette of 11 kg according to the semi-improved retting steps (Figure 2).

Data collection

Agromorphological characterization was done using the eight

Table 2. Soil physiochemical properties of both experimental sites (0-20cm).

Parameter	Soil analysis	
	Pissa	Damara
pH (Water)	5.5	5.8
Organic carbon (%)	0.8	0.99
Total nitrogen (%)	0.06	0.03
C/N	13	33
Available P (mg/Kg)	1.54	0
CEC (cmol(+)/Kg)	3.27	3.54
Exchangeable bases (Cmol(+)/Kg)		
Ca	1.64	6.48
Mg	0.56	1.85
K	0.15	0.13
Na	0.05	0.06
Micronutrients (mg/Kg)		
Zn	0.5	0.45
Cu	1.45	1.45
Fe	34	15
Particle size (%)		
Sand	76	62
Silt	4	16
Clay	20	22
Texture Class	Sandy loam	Sandy clay loam

Source: Authors

Table 3. Combined experimental treatments and fertilization rates used in randomized complete block design in Pissa and Damara areas.

Treatment	Treatment abbreviation	Mineral Fertilizer rate (Kg/Ha)			Manure rate (Kg/ha)
		$(Co(NH_2)_2$	$(H_2P0_4)2$	K_2SO_4	Cow manure
Peasant practices	T1	0	0	0	0
Recommendation of the Ministry of Agriculture	T2	0	0	0	0
Recommendation University of Bangui	T3	80	40	120	0
IAEA Recommendation	T4	90	30	180	3000

IAEA: International Atomic Energy Agency.
Source: Authors

descriptors among those developed (Fukuda et al., 2010), as shown in Table 5.

Soil sampling and analysis: Before the establishment of the field experiments, the site was cleared by burning with local practices. For physiochemical soil analysis, samples were collected at 0 to 20 cm depth. Different soil cores were collected and mixed into composite samples. The composite soil samples were air-dried ground and sieved using the 2 mm sieve before the analysis. Soil particle size distribution was determined using the hydrometer method (Fukuda et al., 2010). Soil pH was determined in water at 1.2.5 solution using a pH meter (Okalebo, 2002). Organic carbon determination followed the method of (Heanes, 1984), and total nitrogen was determined by Kjeldahl digestion and colorimetric analysis (Bremmer and Mulvaney, 1982). Exchangeable cation, available macronutrients, and the available phosphorus were extracted using Melich 3 method. All the analyses were performed by Kenya Agricultural and Livestock Research Organisation (KALRO, NARL).

Evaluation of the economic profitability of cassava

The economic analysis was carried out on cossette production. For profitability analysis, the value-to-cost ratio (CVR) was used, and for the calculation of the profit, the following variables were used: gross income, gross expenses, and gross margins. The gross products are the value of agricultural production estimated at the local market price. The gross product calculations followed the method of Penot et al. (2010) we used the data to calculate the selling price of cossette produced per hectare.

GP = (P* UP)

GP: Gross Product; P: Production per hectare; UP: Unit price

Table 4. Fertilization rates used in pizza and Damara areas.

Treatment	Mineral fertilizer	Fertilizer rate vv`(Kg/ha)	Quantity applied (Kg/Ha)	Quantity applied/plant (g)	Number of bags used/ha
T3	Urea	80N	174	5.7	4
	TSP	40P	87	8.7	2
	K_2SO_4	120K	240	8	5
T4	Urea	90N	195.65	9.5	4
	TSP	30P	65.21	6.5	2
	K_2SO_4	180K	360	17	8
	Cow manure	3000	3000	300	12

TSP: Tripple super phosphate, K_2SO_4: Pottasium sulphate.
Source: Authors

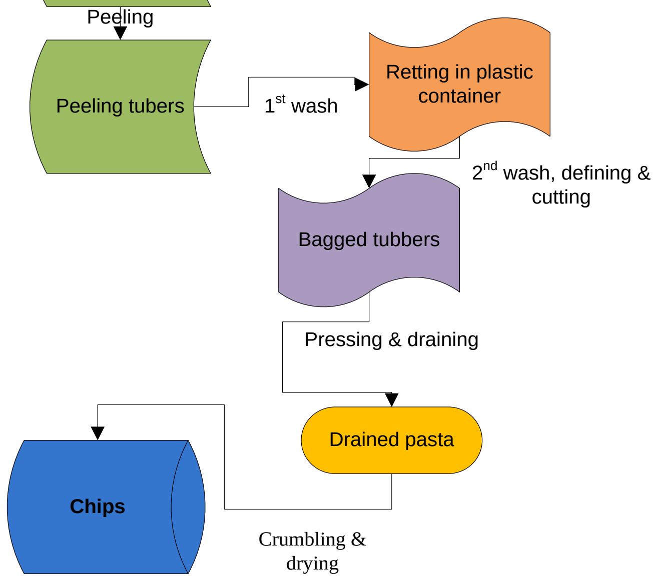

Figure 2. Process for transforming fresh tubers into cossette.
Source: Authors

Table 5. Agro morphological descriptors used during the study period for pizza and Damara areas.

S/N	Descriptor	Code
01	Plant diameter	DP
02	Length of seedlings	LP
03	Length of the nodes	LEN
04	Height of seedlings	HP
05	Number of sheets	NF
06	Total number of roots	NTR
07	Number of marketable roots	NRC
08	Fresh weight of tubers	PFT

Source: Authors

The GP per hectare was determined by assigning a value to cassava cossette production based on average local market prices. Following surveys of producers, the average price of cassettes sold on local markets is 1500 CFA francs per "Ngawi" bowl. Or 160 FCFA per Kg. The Gross Charges correspond to those that disappear in the act of production. They were obtained by summing the elementary loads of inputs (seeds and fertilizers) and labor costs (from the clearing of the plot to the transformation into a cassette). The prices were collected during a survey carried out in the municipalities of Pissa and Damara and among cossette sellers. Thus, the price of fertilizer was 35000F. CFA/50 Kg the bag of urea and Triple Super Phosphate or 700 F.CFA / kg. However, the K_2SO_4 was at 45000F. CFA / 50 Kg or 900F. CFA/kg. The price of manure was 10F. CFA/kg. The cassava cuttings were purchased from producers at a rate of 500 CFA francs per root. The workforce for the various agricultural works was 500 F.CFA per 100 m^2.

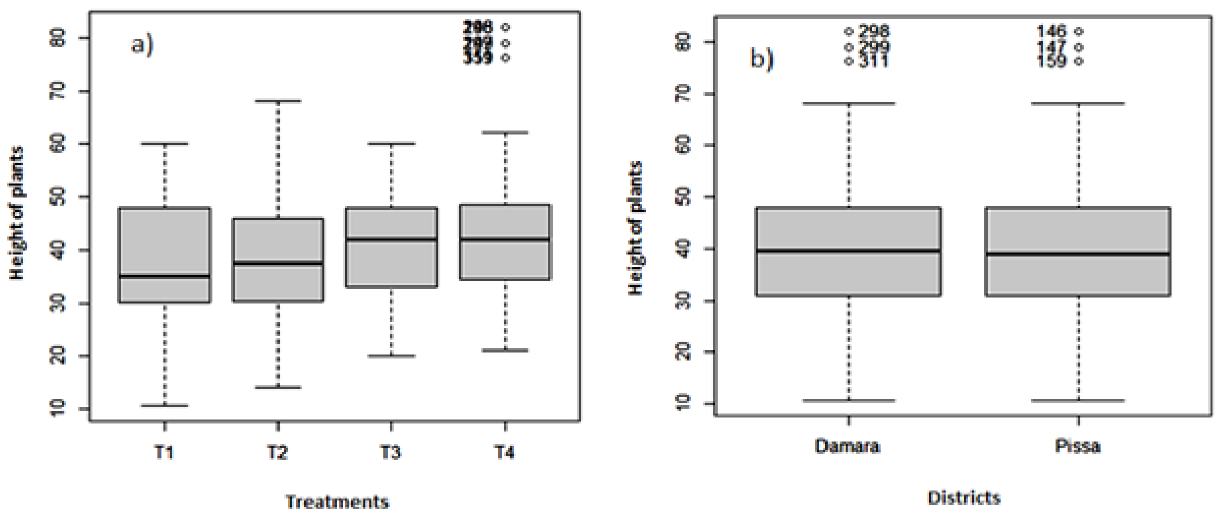

Figure 3. Plant height variation with a) treatments and b) study sites.
Source: Authors

However, it is 250 F.CFA per 100 m^2 for defrichage.

GE = ∑ eL
CB: Gross Load; This: Elementary Loads

The Gross Margin, also called gross profit, represents for each treatment the value of its total Gross Product minus its Gross Expenses: GM = GP - GE.

Where; GM is the Gross Margin; GP: is the gross Product. The RVC compares the cost-effectiveness of new treatments to the reference treatment well known by farmers (Useni et al., 2013). In this study, the new technologies are T3 and T4. However, the reference treatment well known by peasants is T1. The RVC is, therefore, the ratio between the increase in the yield of the new treatment and the cost of the fertilizers of the same treatment: RVC = value of the increase in yield/cost of the fertilizer. If the value/cost ratio exceeds 1, the fertilizer is an altarpiece, but the cost-effectiveness is excellent when RVC is ≥ 3 (FAO, 2000). Thus, for this study, the RVC compares the profitability of T3 and T4 to that of T1.

STATISTICAL ANALYSIS

Data management was performed in Microsoft Excel and XLSTAT-pro software version 2013.5.01, which was used for multi-component analysis. Principal Component Analysis (PCA) was also performed on several agronomic parameters. Data were then subjected to analysis of variance using the generalized linear model in R statistical software version 3.1.2 to determine the treatments' effect, and the mean separation was done using Tukey-Kramer Honest Significant Difference Test P≤ 0. 05.

RESULTS

Effect of treatments on plant growth

Figure 3b shows that the average heights of the plants do not differ from one municipality to another. However, there is a difference (0.01418) depending on the treatments (Figure 3a) between T4 and T1. Using 3000 Kg/ha manure integrated with 90 N-30 P-180 K Kg/ha significantly increased cassava growth during the first three months. This period corresponds to the embryonic phase of the plant, where all organs are formed. It is also marked by the beginning of the tuberization of the roots. There is a highly significant difference (6,664e-06) between plant circumferences according to treatments (Figure 4a) and according to municipalities (Figure 4b). According to the Tukey multiple comparison tests (Table 6), these differences are observed between T1-T3, T1-T4, and T2-T4 treatments. However, no difference is observed between T3 and T4. Figure 5b shows a highly significant difference (2e-16) between the nodes. However, treatments have no statistically significant difference (Figure 5a). This assumes that the environmental factors specific to each study site of savannah and forest area could affect the variations of the internodes regardless of the treatments applied. Figures 6-a and 6-b show significant differences between the number of leaves depending on the municipality (0.003702) and the treatments (0.001479). According to the TUKEY multiple comparison tests (Table 6), this difference is observed between T3-T1 and T4-T1. This variation may be justified by applying fertilizers combined with an appropriate technical route for T3 and T4 and the total absence of fertilizers and technical routes in T1.

Effect of treatments on root production

Statistical analysis of the average number of tubers per plant showed no significant difference (0.754521) between the two study sites (Figure 7b). However, the

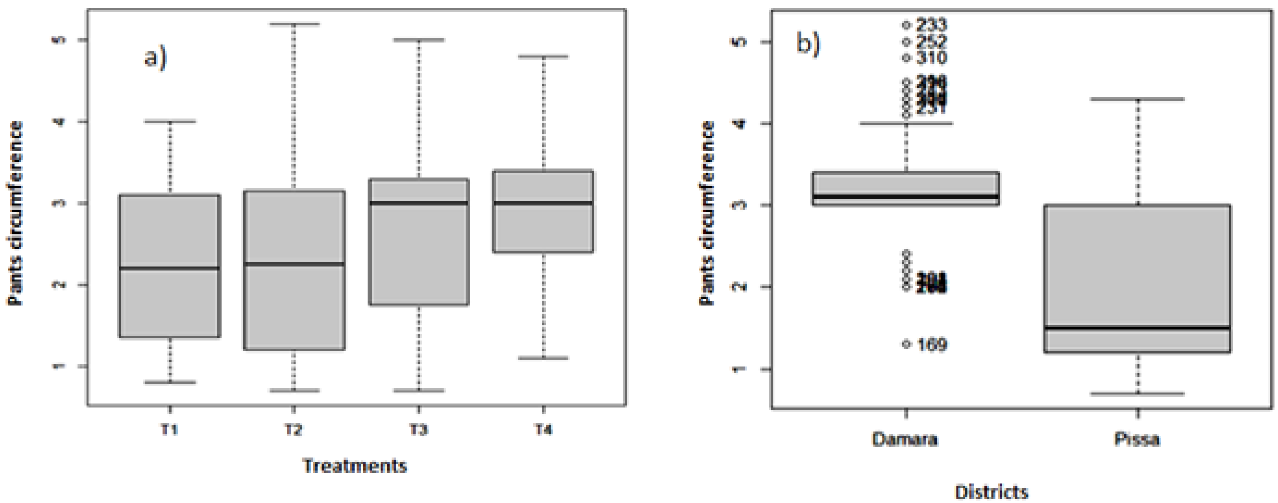

Figure 4. Variation of plant circumference with a) treatments and b) study sites.
Source: Authors

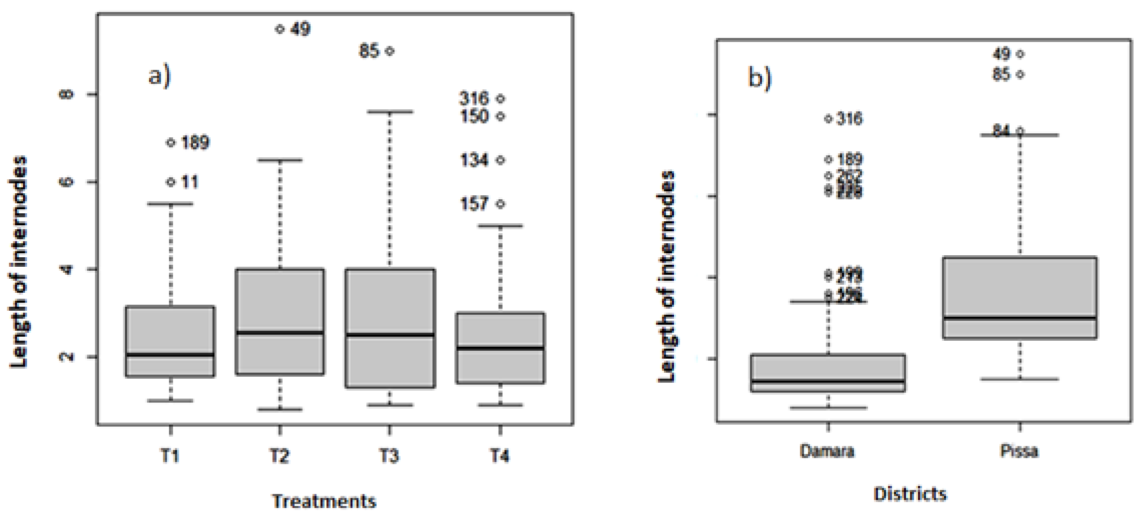

Figure 5. Variation of the length of internodes with a) treatments and b) study sites.
Source: Authors

difference is significant (0.009088) with the treatments (Figure 7a). According to the TUKEY test (Table 6), the difference is significant between T3 - T1, T3 - T2, T4 - T1, and T4 - T2. There is no difference between T1 - T2 and T3 - T4. Fertilizer inputs increased in the number of roots. Figures 8a and b show differences between the average root weights per plant according to treatments and municipalities (0.07996). According to Tukey's test, this difference is highly significant between T3-T1, T3-T2, T4-T1, T4-T2, and T4-T3. However, they are not observed between T1 and T2. At the end of these results, applying fertilizers benefits the increase in weight regardless of the agro-climatic zones. However, differences in fertilizer doses and types impact root yield differently, such as T4>T3. Figure 9 shows that the T4 treatment yielded the best yield (50 t.ha-1), followed by T3 (32.64 ha-1), T2 (18.36 ha-1), and T1 (15.3 ha-1), respectively. There is a highly significant difference (2.2e-16) depending on the treatments and municipalities (0.00001909). The yields of the trials in forest areas are higher than those in savannah areas.

Variability with different parameters

Figure 10 shows a series of variables observed across the growth and production parameters on the two axes of correspondence. It explains 48.11% of the overall

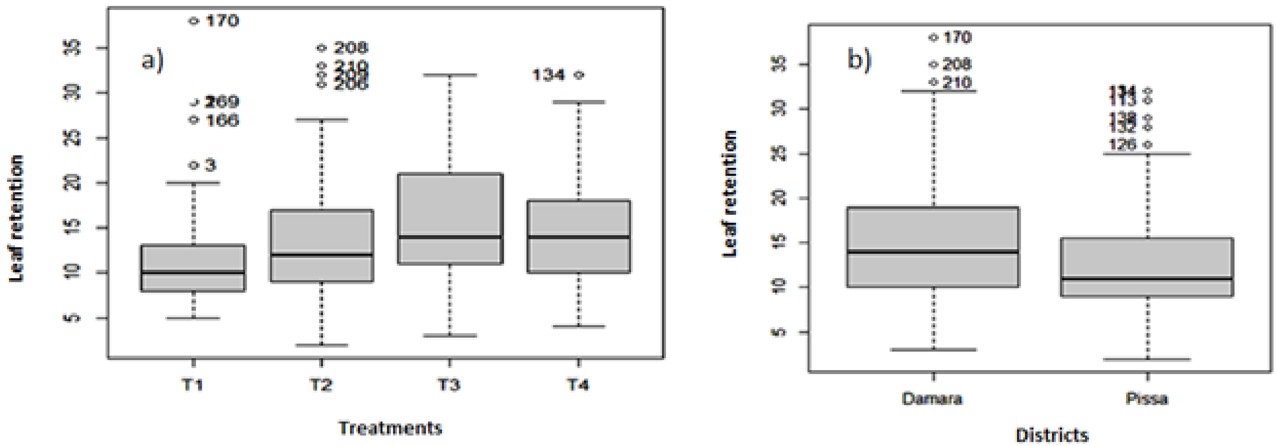

Figure 6. Variation of leaf retention with a) treatments and b) study sites.
Source: Authors

Table 6. Tukey test for different yield components.

Treatments	Plant circumference	No. of leaves	No. of roots	Fresh root weight
		P- value		
T3-T1	0.04*	0.003**	0.001***	0.001***
T4-T1	<0.001***	0.03*	0.001***	0.001***
T4-T2	<0.001***		0.001***	0.001***
T3-T2			0.001***	0.001***

*P<0.05 **P<0.005 ***P<0.001.
Source: Authors

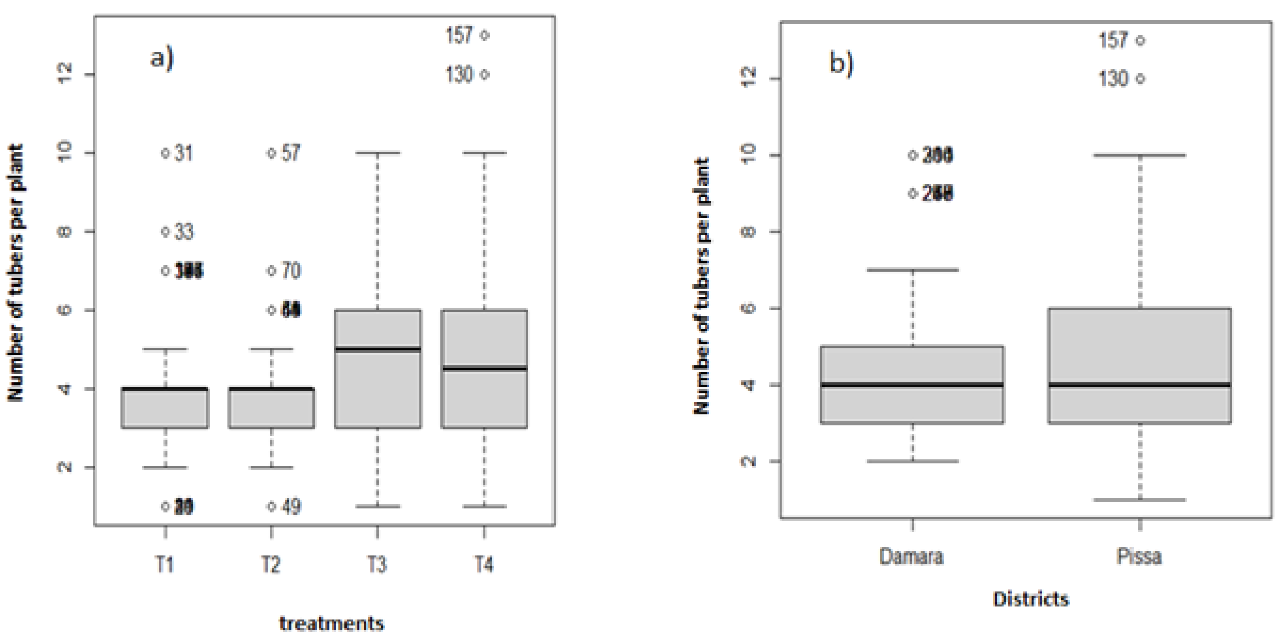

Figure 7. Variation of the number of tubers per plant with a) treatments and b) study sites.
Source: Authors

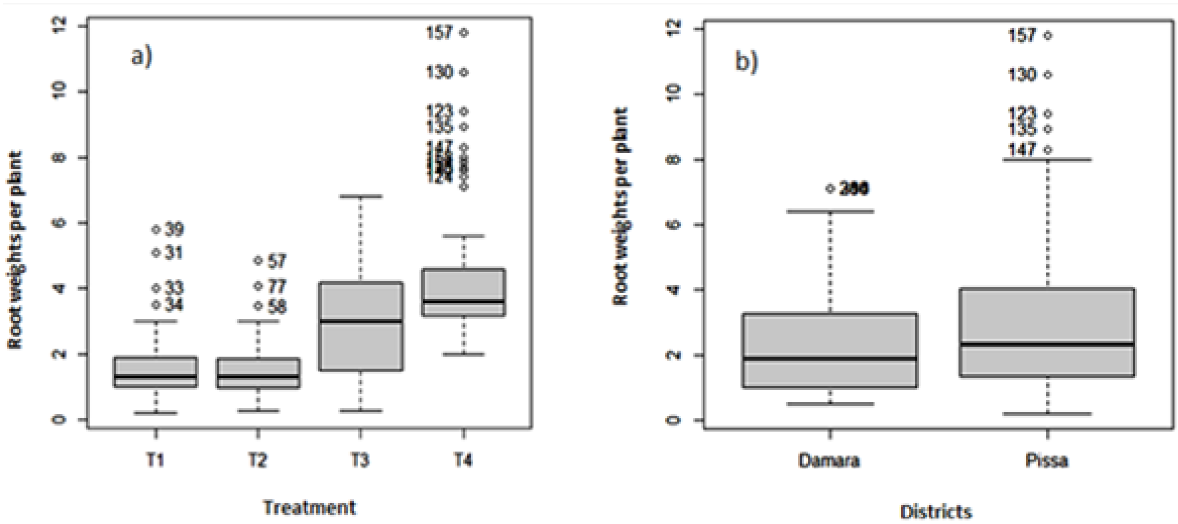

Figure 8. Variation of root weight per plant with a) treatments and b) study sites.
Source: Authors

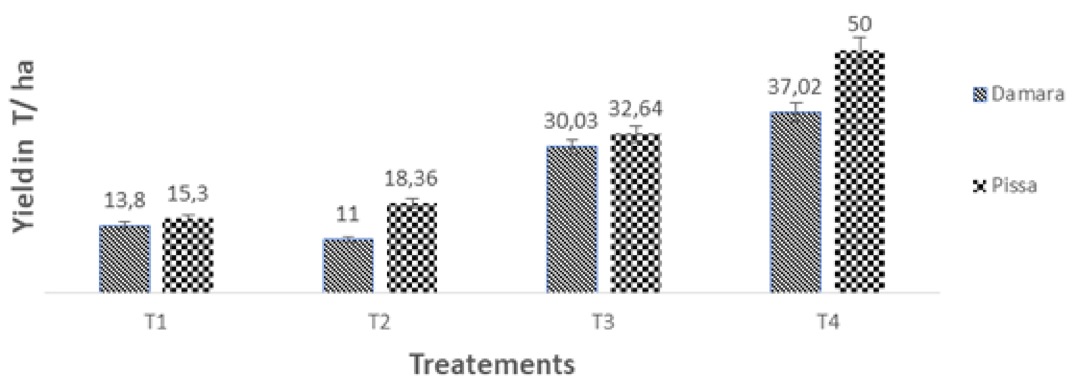

Figure 9. Variation of yield under different treatments in Pissa and Damara areas.
Source: Authors

variability, indicating no great variation between the growth and production parameters. A weak correlation is observed on the x-axis (25.99%) between the number of tubers and their weight. There is also a weak correlation on the y-axis (22.12%) between the number of leaves, the length of the petioles, and the circumference of the plants. However, the length of the nodes is distant from the other parameters.

Economic analysis

Table 7 shows that using mineral fertilizer doses applied alone (T3) or combined with organic manure (T4) is cost-effective in both municipalities. On the other hand, the high dose of mineral fertilizer combined with Cow manure gave Pissa good profitability in forest areas (RVC=2). According to Table 8, the results of the trials generated different benefits following the cultivation operations under the treatments and the two study sites. The greatest benefits obtained in the savannah area (municipality of Damara) were with T4 treatments (261000 F.CFA); T3 (120300 F.CFA). In the forest area (municipality of Pissa), these benefits were observed in T4 (604045 F.CFA) and T3 (168800 F.CFA) treatments. There was a correlation between treatments at the municipal level. The T4 treatment generated the best benefit despite the high cost of fertilizer inputs.

DISCUSSION

The study assessed the effect of fertilizers on growth, production, and economic profitability and gave

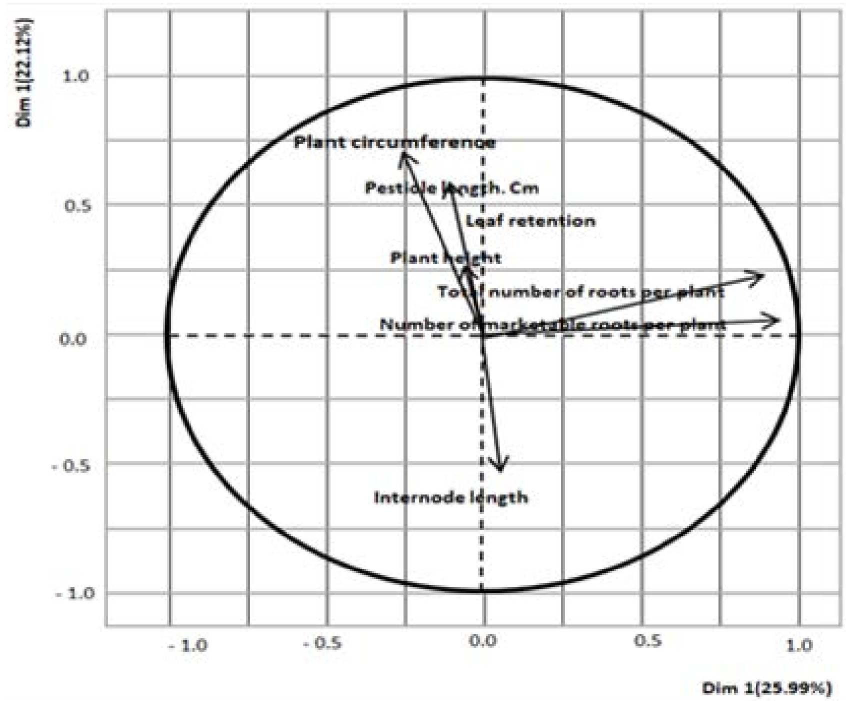

Figure 10. Agro morphological variability as a function of treatments and Common.
Source: Authors

Table 7. Economic analysis of different treatments.

Location	Treatments	Fertilizer costs (FCFA)	Yield in cossette (T /ha)	Increased yield (T/ha)	Increase in Yield value (FCFA)	RVC
	T1	0	3.175	-	-	-
	T2	0	3.810	0.635	86590	-
Pissa	T3	398700	6.774	3.599	490770	1.2
	T4	476000	10.377	7.202	982090	2
	T1	0	2.864	-	-	-
	T2	0	2.283	- 0.581	- 79225	-
Damara	T3	398700	6.232	3.368	459272	1.1
	T4	476000	7.683	4.819	657135	1 .3

Source: Authors

significant results depending on the selected treatments and the sites. Thus, the data obtained made it possible to address the following aspects:

Effects of fertilizers on growth

The cow manure integrated with organic fertilizer gave a significantly higher performance in cassava yield attributes, e.g. leaf retention, plant height, plant circumference, number of tubers per plant, and number of roots. These findings are consistent with Stephanie et al. (2005), Engonga (2007) and (Padem et al., 1998) after working on six foliar fertilizers: Bravo (200 g hl^{-1}); Real (350 ml hl^{-1}); urea (0.4%); Biamine (500 g hl^{-1}); KNO_3 (1%) and $Ca(NO_3)2$ (1%), with three sprays spaced 15 days apart during vegetative plant growth, also revealed that Biamine promotes stem thickening. Both sites gave a good performance of these attributes with the T4 technology (90 N + 30 P + 180 K + 3000 kg/ha of Cow manure). These variables are a good measure of cassava development; for instance, plant circumference

Table 8. Generation of income account per hectare according to treatments.

Treatments		Labeled	Pissa	Damara
	Input costs	Cuttings	10000	10000
		Clearing	25000	25000
		Ploughing	50000	50000
		Seedling	10000	10000
		Weeding	75000	50000
	Cost of the work	Harvest	50000	50000
T1		Transport	15000	15000
		Peeling	20000	20000
		Washing and pressing	10000	10000
		Emiettage and packaging	10000	10000
	Total expenses		**275000**	**250000**
	Production (Cossette)	**Variable**	**432000**	**390000**
	Net profits		**157000**	**140000**
	Input costs	Cuttings	10000	10000
		Clearing	25000	25000
		Ploughing	50000	50000
		Sowing	10000	10000
	Cost of the work	Weeding	75000	50000
		Harvesting	50000	50000
T2		Transport	15000	15000
		Peeling	20000	20000
		Washing and pressing	10000	10000
		Crumbling and packaging	10000	10000
	Total expenses		**275000**	**250000**
	Production (Cossette)		**519000**	**310500**
	Net profits		**244000**	**60500**
	Input costs	Cuttings	10000	10000
		Fertilizers	398700	398700
		Clearing	25000	25000
		Ploughing	50000	50000
		Weeding	75000	50000
		Sowing	10000	10000
	Cost of the work	Spreading	80000	80000
T3		Harvesting	50000	50000
		Transport	15000	15000
		Peeling	20000	20000
		Washing and pressing	10000	10000
		Crumbling and packaging	10000	10000
	Total expenses		**753700**	**728700**
	Production (Cossette)		**922500**	**849000**
	Net profits		**168800**	**120300**
	Input costs	Cuttings	10000	10000
		Fertilizers	476000	476000
		Clearing	25000	25000
T4		Ploughing	50000	50000
	Cost of the work	Sowing	10000	10000
		Spreading	60000	60000
		Weeding	75000	50000

Table 8. Contd.

	Harvesting	50000	50000
	Transport	15000	15000
	Peeling	20000	20000
	Washing and pressing	10000	10000
	Crumbling and packaging	10000	10000
Total expenses		**811000**	**786000**
Production (Cossette)		**1441500**	**1047000**
Profits		**604045**	**261000**

Source: Authors

(Figure 4) between 2 and 8 cm and a height of between 1.2-3.7 m are regarded as good growth measures (Alves, 2002). The use of cow manure integrated with mineral fertilizer gave desirable plant height, circumference, and many tubers were achieved. It is always thought that the use of fertilizer in cassava cropping systems produces little response; however, in considerably marginal soils the crop shows a good response to the applied optimum fertilizer rates (Szyniszewska, 2020). In his findings Gichuru (1991) mentioned that cassava has much higher N and P requirements for maximum growth than many other crops, and Ca and K requirements are similar to those of other crops. The current study provides evidence that using mineral fertilizer solely or in combination with animal manure can give higher cassava roots in the Pissa and Damara areas of the Central African Republic. These results are consistent with other studies that reported increased cassava root yield with fertilizer application (Chaisri et al., 2013; Biratu et al., 2018). This can be explained by the many secondary and micronutrients in manure that enhances the soil conditions, hence improved nutrient uptake in treatment with manure compared to the sole use of mineral fertilizer (Adekiya and Agbede, 2017). The interaction between the cow manure and the mineral fertilizer also showed significant increases in the fresh root weight. However, there is still variation in different research findings indicating the need for site-specificity in integrated soil management. For instance, Ayoola and Adeniyan (2006) did not find any treatment effect in cassava yield after applying NPK solely or in combination with chicken manure in Nigeria. Contrarily, Biratu et al. (2018) reported high cassava yield with the use of chicken manure in Zambia. Our results confirm that T4: 3000Kg/ha manure integrated with 90 N-30 P-180 K Kg/ha and T3: 80 N-40 P-120 K Kg/ha further improves cassava root and biomass yield.

Effect of salaries on production and economic profitability

Crop yield is an essential indicator for any producer. Several parameters can affect the agricultural yield of cassava, including diseases, inappropriate technical routes, nutrient-poor soil, weeds, etc. The results again showed that the T4 treatment gave the highest yield, followed by T3 in both sites (50 t /ha in forest, 37.02 t/ha in savannah for T4, and 32.64 t/ha in forest, 30.03 t/ha in savannah for T3). In another study, Ballot et al. (2016) on the effect of mineral manure on cassava yield and organoleptic quality (Manihot esculent Crantz) in the savannah zone in the Central African Republic, obtained 40 t/ha for the best treatment. The higher yields of T4 and T3 compared to T2 and T1 in this study are justified by applying mineral and organic fertilizers that have impacted cassava growth. Fertilizers alone do not remain the essential means for improving agricultural production. In addition, there are technical itineraries that are not well controlled by the peasant producers and the factors specific to each environment. The best performance in terms of root yields (50 t/ha) and profit (615500 F.CFA) was recorded by the T4 treatment relative to the control T1 and compared to the other T3 and T2 treatments. These performances obtained by T4 are explained by the fact that Cow manure combined with mineral fertilizer releases important nutrients essential for the growth and development of cassava and improves soil conditions. Indeed, the combined use of these manures would improve the availability of nutrients and create favourable conditions for the proper development of the roots. For instance [37 to 38] observed increases in the yield of corn crops with the combined use of poultry droppings and mineral manure compared to the application of organic or mineral manure alone. Nyembo et al. (2014) on maize cultivation confirms that organic manure (poultry manure) has great potential for improving the availability of soil nutrients and providing the nutrients needed for cultivation. Similarly, Sanginga et al. (2009) stated that combining organic and mineral fertilizers creates the best production conditions because organic matter improves soil properties, while mineral fertilizers provide plants with the nutrients they need and increase agronomic efficiency. Mineral fertilizers have 10 to 20 times higher concentration of nitrogen, phosphorus, and potassium that are most important for cassava tuberization (Odedina et al., 2015) but manure also contain many secondary microelements (Howeler, 2002). Indeed, the use of 90 N + 30 P + 180 K + 3000 kg/ha of Cow manure greatly increased the availability of nutrients and promoted soil water accumulation. Ballot et al. (2016) used a similar approach in the Central African Republic in the savannah zone with the same accession of cassava "Gabon", reported the best yield of (40.02 t / ha) with the dose of 80N-40P-120K kg/ha, or a ratio in N-P-K = 1-2-3. However, in the present study, the best yield (50 t/ha) is obtained in the forest zone with the combination of 90 kg/ha of N + 30 kg/ha of P + 180 kg/ha of K + 3000 kg/ha of Cow manure, with a ratio in N-P-K = 3-1-6.

The yield variation of (9.98 t/ha) between the two results can be justified by the effects of Cow manure integrated with chemical fertilizers and the intense microbial activity in forest areas. It would also be possible that the high amounts of N and K used in this study would contribute to the better yield obtained in T4. In addition, the yield obtained in the savannah (37.02 t/ha) is lower than that reported by Ballot et al. (2016) (40.20 t/ha) in the same area. This difference could be justified by the history of the plots used in the two sites, for example, the fallow time of the plots being allocated for testing. Given that the high total cost (811000 FCFA in forest and 786000 in savannah) of T4, of which 58.69% is forest and 60.55% in savannah represent fertilizer costs, the net profit (Bn) that this treatment gave is acceptable (604045 FCFA in forest and 261000 FCFA in savannah). Therefore the Cost Values Report confirms it. Kouame et al. (2014) however, obtained a contrary opinion that the economic profitability of fertilizers decreases with increasing doses, leading to an increase in the total cost and consequently a decrease in RVC. T4 treatment is in the category of technologies to be advised. However, the expenditure on the acquisition of mineral fertilizers in the study area is enormous, as stated by Kelly (2006) that the use of fertilizers in Africa is low, particularly because of their high cost, due to the importation cost, unit quantities, and high transport costs.

Conclusion

The study shows that combining mineral fertilizer and cow manure is suitable for enhancing crop productivity and profitability in cassava cropping systems. However, the extent of such effects is site-specific. The most effective integrated soil fertility technology was T4: the use of 3000Kg/ha manure integrated with 90 N-30 P-180 K Kg/ha, followed by the T3: 80 N-40 P-120 K Kg/ha. Additionally, T4 gave higher net benefit (T4 = 615500F. CFA in forest areas) than other treatments (T3 = 173800, T2 = 169000 and T1 = 82000). The T4 treatment with a cost value ratio (RVC) of 2 in Pissa and 1.3 in Damara has great potential to improve both the vegetative and cassava yield components in savannah and forest areas. Based on the obtained results, we recommend using 3000 Kg/ha manure in combination with 90 N-30 P-180 K Kg/ha in agro-climatic zones of savannah and forest areas. The differences in the results under the savannah and forest characteristics indicate environmental factors' influence on production. Since the results obtained in this study are characteristic of a single campaign, long-term studies that evaluate the effect of different soil fertility management regimes on yield and economic profitability are needed.

CONFLICT OF INTERESTS

The author has not declared any conflict of interests.

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