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Full Length Research

A comparative effect of legume-based cropping association on the productivity of *Manihot esculenta* Crantz in the forest and savanna zones of the Central African Republic

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ABSTRACT: The objective of this study, conducted under integrated management in forest and savanna zones, is to improve cassava yields in rural areas of the Central African Republic using a comparative approach. The study design is a randomized block design with eight treatments (0 to 7) and four randomized replications, comprising 32 elementary plots. The different doses of PK or NPK fertilizers and/or those associated with legumes (0-0-0, legumes, legumes-30-180, legumes-90-30-180 and 90-30-180) were tested in the districts of Damara and Pissa. The trial was conducted over one agricultural season. The analyses were done using R software version 4.1.0 and Excel 2010. The results show that the doses of 90 kg.ha^{-1} of Nitrogen, 30 kg.ha^{-1} of Phosphorus and 180 kg.ha^{-1} of Potassium gave good productions in fresh roots at the scale of the two localities with average yields of 60 t. ha^{-1} (T_3: cassava + groundnut + NPK) compared to 29 t.ha^{-1} (T_0: cassava) in the forest zone and 37 t.ha^{-1} (T_3: cassava + groundnut + NPK) compared to 23 t.ha$_{-1}$ (T_0: cassava) in the savanna zone. Economically, after the sale in pods, the cassava + legume treatments (T_1: cassava + groundnut with a profit of 765,000 F CFA in the forest and 435,455 F CFA in the savanna and T_4: cassava + cowpea with a profit of 78,725 F CFA in the forest and 265,000 F CFA in the savanna) are profitable for the farmer-producers in the study area. The use of the results of this study in rural areas of the Central African Republic can improve the production of fresh roots and pods. In any case, a study on spatial arrangements in cropping associations (strip cropping, intercropping) can be envisaged in order to better manage the soil and optimize production in rural areas.

Keywords: Agroecology, cassava, Central African Republic, fertilizers, legumes.

INTRODUCTION

Association is the most widespread cropping system in the tropical world, particularly in Africa, Latin America and Asia (Boyeux and Magnard, 2013). It involves the simultaneous cultivation of two or more species on the same area during a significant period of their growth cycle (Willey, 1979). Associations have been practiced since the dawn of agriculture but gradually disappeared with intensification during the 20th century in favor of systems based on mono-specific cultivated stands (Duc *et al*., 2010). The regular presence of associated crops in family farming reflects their importance (Beauval, 2013; Yama *et al*., 2007; Naudin *et al.*, 2011). These cropping systems are an integral part of farmers' anti-randomization strategies to combat climatic hazards and optimize farm labor. They are also important means of managing soil fertility (Ouedraogo *et al*., 2014). In West Africa, cowpea, soybean and groundnut contribute to the maintenance and/or improvement of soil fertility (Kergna, 2001).

The establishment of the associated crops is staggered and carried out with plant material that is predominantly "new". Certain sowing methods as well as the disorganized spatial organization are at the origin of competition within the plant stand. The densities practiced are 15,000 plants/ha, on average for cassava and very variable for the other components. The lack of use of chemical fertilizers, sometimes not adapted to the associated crop, makes the cropping associations not very productive. However, the management of these associations should be improved to make them more productive (Project PerfCom, 2012).

In recent decades, the use of inputs has increased the productivity of agrosystems, but in the specific case of nitrogen (N) and phosphorus (P), this increase has been accompanied by a significant decrease in the efficiency of N and P (Hinsinger, 2012). This falls to N and P losses leading to negative environmental impacts such as surface water eutrophication, groundwater pollution, or greenhouse gas emissions (Hinsinger, 2012; Danhartigh and Metayer, 2015). Today, these systems are being challenged with the emergence of input saving concerns, the need to improve the efficiency of production factors, and to preserve the environment and biodiversity (Duc *et al.,* 2010).

Throughout the Central African Republic, farmers are accustomed to combining several crops on the same plot. The number of associated crops planted per area varies from 2 to 7 (Kafara, 2003; Bahan *et al*., 2012; Beninga, 2014). This cohabitation, often carried out randomly, does not take into account any specific criteria for a mutually beneficial association.

In order to maintain a high productivity of agrosystems, to stabilize it while minimizing these negative impacts on the environment, it is essential to develop innovations that focus on an "ecological intensification" of agrosystems for an efficient use of soil N and P resources (Hinsinger, 2012). Very few scientific advisors are available, or even non-existent, to help farmers.

Thus, the objective of this study is to evaluate the agronomic and economic performance of cassava (*Manihot esculenta* Crants.) cropping associations with groundnut (*Arachis hypogaea* L.), cowpea (*Vigna unguiculata* L.) and fertilizer on the productive potential of farmers in accordance with the savanna and forest agroclimatic zones of Central Africa.

MATERIALS AND METHODS

Experimental setting

The districts of Damara and Pissa (Figure 1), respectively characteristic of the Soudano-oubanguienne (savanna) and Guinean forest (forest) agro-climatic zones, were selected for this study:

Pissa site

The trial was set up on the plot of the agro-pastoral grouping of Pissa 2 located 03 km (N 04004.25'; E 018012.73'; Alt 379 m) from the town of Pissa on the way to Mbaïki. The dominant species at the site is *Imperata cylindrica* (L.). It is a fallow land of more than four (4) years.

Damara site

The second site is located in the village of Ndara 1, 5 km (N 04059.65'; E 018040.43'; Alt 432 m) from the town of Damara. The vegetation of the site is dominated by *Chromolaena odorata* (L.). It is a five (5) years old fallow.

Plant material

The plant material is composed of a cassava cultivar named "Togo" (Figure 2), which is a high-yielding cultivar, resistant to the African cassava mosaic disease, also appreciated by the farmers for its tender leaves and its availability in the study area (Gougodo De Mon-Zoni *et al*., 2021). Two food legumes (*Arachis hypogaea* L. and *Vigna unguiculata* L.), often grown in cultivated in association with cassava in rural areas (Figure 3 and Figure 4) were used. The groundnut seeds used were of the variety '57313' and the cowpea seeds were of the variety 'Lori 24-130', all supplied by the Central African Institute for Agricultural Research (ICRA).

Fertilizers

Mineral fertilizers namely Urea ($Co(NH_2)_2$,46% N; Triple Super Phosphate $Ca(H_2PO_4)_2$, 46% P and potassium sulfate (K_2SO_4), 50% K were used (Table 1). The dose, 90 N, 30 P, 180 K used was the one that gave the best yield (50t/ha) in an experiment on determining better fertilization options for cassava crop (Gougodo De Mon-Zoni *et al*., 2023).

Involvement of producers in the demonstration trials

The study was carried out in a participatory and integrated approach with the members of the agro-pastoral groups

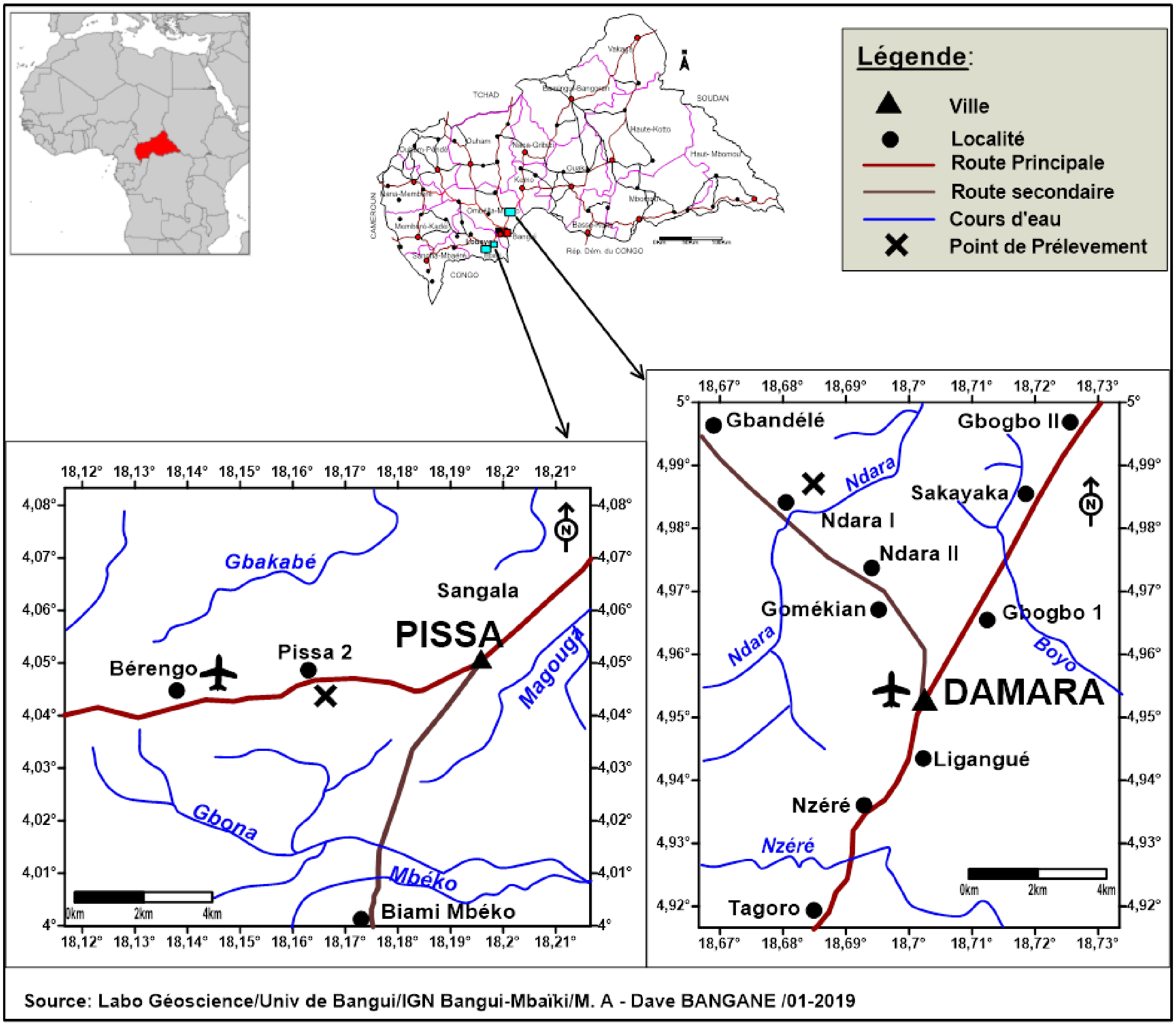


Figure 1. location of experimental sites.

Figure 2. Cutting of the accession 'Togo' *Manihot esculenta* Crantz.

Figure 3. Semen of variety 57313 (*Arachis hypogaea* L.).

Figure 4. Semen of variety Lori 24-130 (*Vigna unguiculata* L.).

"Toumba nzara" in the district of Damara and "GAPI 2" in the district of Pissa in order to allow them to take ownership and also to facilitate the immediate adoption of the good technology that will be recommended at the end of the experiment. The groups actively participated in the various cultivation activities, from the choice of land to harvesting and the various post-harvest processing activities, in order to evaluate the economic profitability of the treatments used**.**

Experimental design

The trials consisted in assessing the effect of different combinations of mineral fertilizers and legumes (groundnut and cowpea) on the cassava-based cropping system. The randomized block design with a total of eight (8) treatments in four (4) replications was adopted and agronomic parameters were evaluated over a period of twelve (12) months in order to assess the economic profitability. The distance between two blocks is 2 m and 1 m between the elementary plots. Each of the elementary plots has an area of 100 m^2 (10 m x 10 m).

Plot plan

The plot plan is as shown in Figure 6

Fertilizer treatments and rates used

The treatments presented in Table 2 with the different combinations of specific doses were used in this study. The experimental unit is an elementary plot of 10 m x 10 m, i.e. an area of 100 m^2 with a total of 100 cuttings (Figure 4). The methods and planting densities used are recorded in Table 3 and Figure 7.

Fertilizer application

In the context of Climate Adapted Agriculture (CAA), the optimal use of fertilizers consists of observing the four basic principles also known as "4G" that were used in the experimentation on the determination of the best fertilization options for cassava (Gougodo De Mon-Zoni *et al*., 2023). These are:

1. Good source (adapt the type of fertilizer to the needs of the crops): urea (Co(NH2)2, 46% of N the Triple Super Phosphate Ca(H2PO4)2, 46% of P and potassium sulfate (K2SO4), 50% of K;
2. Good dose and quantity of fertilizer: 90 kg of N, 30 kg of P, 180 kg of K for one (1) hectare;
3. Good timing of application (make nutrients available when crops need them). It is desirable that the fertilizer be split and that its application be done in two stages:
   - The application of triple super phosphate was done one day before planting as a background fertilizer for T2, T3, T5, T6 and T7;

Table 1. Quantity of fertilizer to be applied for cassava.

Fertilizer	Quantities of elements (kg)	Quantities to be spreadPer ha (kg)	Quantities per application per foot (g)	Number of bags for 1 ha
Urea	90 of N	195.65	9.5	4
TSP	30 of P	65.21	6.5	2
K2SO4	180 of K	360	17	8


K2SO4 Ca (H2PO4 CO(NH2)2

Figure 5. Types of mineral fertilizers used.

- Urea and/or potassium sulfate were applied at one month and then at three months for the same treatments. The fertilizers are applied to the feet of the plants in the morning after a rain that has wet the soil.

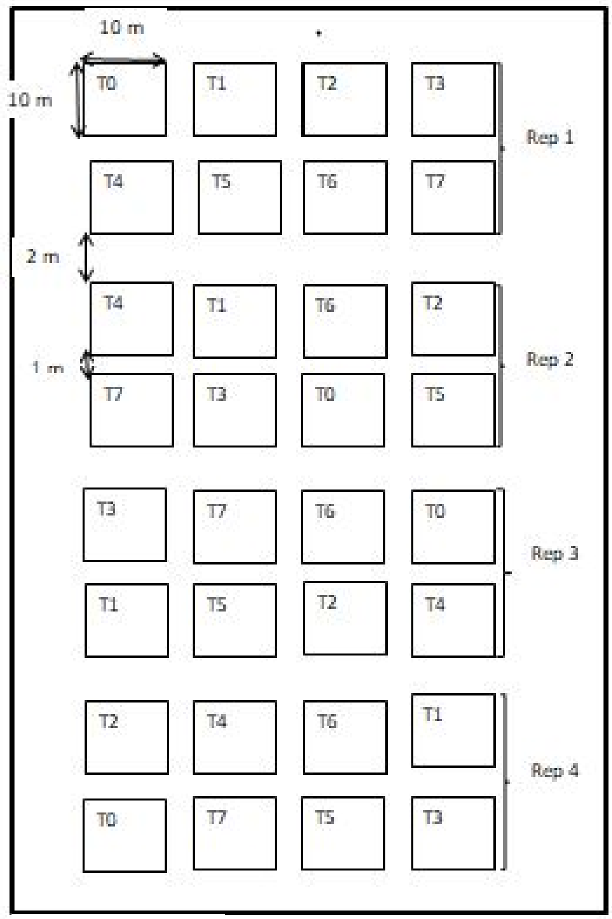
4. Good application method (keep nutrients where the crops can use them): Scrape the soil to make a furrow in the form of a circle (horizontal cuttings) or a semicircle (vertical or oblique cuttings) around the cassava plants at a distance of 10-20 cm, apply the correct measure of fertilizer in the furrow and cover the applied fertilizer with soil.

Sampling

For each treatment, and taking into account border effects, 15 central plants were initially selected per elementary plot and marked (with labels) after emergence for regular measurements of growth and development throughout the growing season. Disease and pest incidence are assessed on the 15 core plants as well as the other plants in the plot. The general appearance (situation) of each plot, the degree of uniformity or variation was evaluated every three months. Agronomic data were collected regularly throughout the growing season for statistical analysis.

Data collection

Eight (8) descriptors among those developed by Fukuda *et al.* (2010), listed in the Tables 4 to 7 were used for agronomic characterization.



Rep = repetition

Figure 6. Experimental setup in complete randomized block.

Cossette yield and assessment of economic profitability of cassava

During this study, we started from the basis where, one and a half bowl of fresh cassava roots of 53 kg yielded one bowl of cossette of 11 kg using semi-improved retting steps (Gougodo De Mon-Zoni *et al*., 2023).

Economic data

The economic analysis was conducted on cossette

Table 2. Types of treatments and different combinations of mineral fertilizers.

Treatments	Meaning	Mineral fertilizers (Kg/ha)		
		(Co $(NH_2)_2$	$(H_2P0_4)_2$	K_2SO_4
T0	cassava	0	0	0
T1	cassava + groundnut	0	0	0
T2	cassava + groundnut + PK	0	30	180
T3	cassava + groundnut + NPK	90	30	180
T4	cassava + cowpea	0	0	0
T5	cassava + cowpea + PK	0	30	180
T6	cassava + cowpea + NPK	90	30	180
T7	cassava + NPK	90	30	180

NB: NPK = urea (N) (Co(NH2)2) + triple super phosphate (P) (H2P04)2) + potassium sulfate (K) (K2SO4); PK = triple super phosphate (P) (H2P04)2) + potassium sulfate (K) (K2SO4).

Table 3. Methods and planting densities of the various crops

Parameters	Cassava	legumes (cowpeas and groundnut)
Planting methods	1 cutting in oblique position. 15 cm long cuttings, 2/3 of them in the ground	In bunches, 1 seed/bunch
Planting densities	1 m/1 m (10000 plants/ha)	25 cm / 25 cm

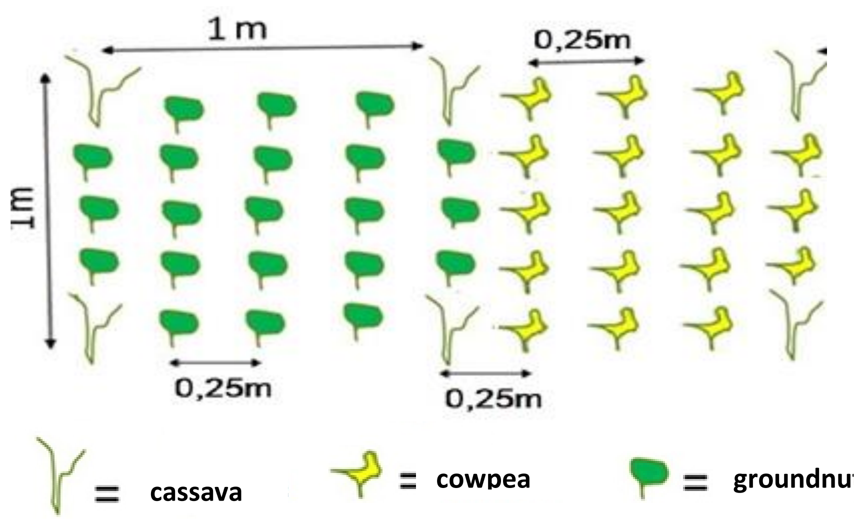


Figure 7. Planting density plots.

production. To determine the economic profitability of the treatments, the following variables were used: gross revenue, gross expenses and gross margins.

Gross products

Gross products are the value of agricultural production estimated at the local market price. As this is a gross product, the data concerned the selling price of podded crops per hectare (Penot *et al*., 2010). The formula is as follows:

PB = **(**P* Pu)

Where: GP = Gross Product; P = Production per hectare; Pu: Unit price

The GP per hectare was determined by assigning a value to cassava pod production based on average local market

Table 4. List of agro-morphological descriptors at 3 months

Descriptors N°	Descriptors	Codes
1	Height of the plants	HP
2	Plant diameter	DP

Table 5. List of agro-morphological descriptors at 6 months

Descriptors N°	Descriptors	Codes
3	Height of the plants	HP
4	Root diameter	DR
5	Chlorophyll rate	TC

Table 6. List of agro-morphological descriptors at 9 months

Descriptors N°	Descriptors	Codes
6	Height of the plants	HP
7	Root diameter	DR
8	Chlorophyll rate	TC

Table 7. List of agro-morphological descriptors at 12 months

Descriptors N°	Descriptors	Codes
9	Height of the plants	HP
10	Plant diameter	DP
11	Chlorophyll content	TC
12	Root length	LR
13	Root diameter	DR
14	Root weight	PT
15	Number of marketable roots per plant	NRCP
16	Number of Residual Roots per Plant	NRRP

prices. Following surveys of producers, the average price of cassava pods sold on local markets is 1250 CFA francs per "NGAWI" bowl, or 115 CFA francs per kg.

Gross expenses

The gross expenses correspond to those which disappear in the act of production. They were obtained by summing the basic costs of inputs (seeds and fertilizers) and labor (from the clearing of the plot to the transformation into cossettes). The different prices were collected during a survey conducted in the districts of Pissa and Damara and from cossette sellers. The price of fertilizer was 35,000 F.CFA francs per 50 kg bag for urea and triple super phosphate, or 700 F.CFA francs per kg. However, K_2SO_4 was priced at 45,000 F.CFA francs/50 kg, or 900 F.CFA francs/kg. The price of manure was 10 F.CFA/kg. Cassava cuttings were purchased from producers at 500 F.CFA francs per bunch, and groundnut and cowpea seeds were purchased at 1400 F.CFA per kg, or 35,000 F.CFA per seed. Labor for the various agricultural works was 500 F.CFA for 100 m^2. However, it is 250 F.CFA per 100 m^2 for land clearing.

$$CB = \sum Ce$$

Where: CB = Gross load; Ce - Elemental loads

Gross margin

The gross margin also called gross profit represents for each treatment, the value of its production decreased by its gross expenses.

$$MB = P = - CB$$

Where: MB = Gross margin; P = Production.

Statistical analysis of the data

The collected data, entered in a Microsoft Excel table (2010) were discriminated according to the studied parameters:

1. Plant height, plant and tuber diameter, and chlorophyll levels were measured according to the data collection protocol. Thus, to test the effect of treatments and zones on the variation of these growth parameters as a function of time, a three-factor analysis of variance (treatment, district, and date of measurement) was performed on each variable. This model tested the main effects of the three factors as well as all possible interactions. The conditions of application of this model, notably normality and equality of variances-populations were verified with the Shapiro-Wilks test and the Levenne test (Crawley, 2012). Finally, the coefficient of determination R^2 for each model was calculated to assess how much of the variation in the response variable is explained by all factors in the model.
2. Tuber length, tuber weight, number of marketable tubers and number of residual tubers were collected at the end of the trial (12 months). Thus, to test the effect of treatment and district on the variation of these yield parameters, a two-factor analysis of variance (treatment, and district) was performed on each variable. This model tested the main effects of the two factors as well as their interaction. The conditions of application of this model, including normality and equality of population variances were checked using the Shapiro-Wilks and Levenne test (Crawley, 2012). The coefficient of determination R^2 for each model was also calculated to assess how much of the variation in the response variable is explained by the two factors in the model.
3. The relationship between growth and production variables was revealed through Principal Component Analysis - PCA (Bro and Smilde, 2014). The mean values of plant height, plant diameter, tuber diameter, plant chlorophyll content, tuber length, tuber weight, number of marketable tubers, and number of residual tubers were calculated for each of the 16 combinations of treatments (8 in total) and district (2 in total) at the end of the trial (12 months). This resulted in a matrix with 8 columns (the 8 growth and yield parameters) and 16 rows (the treatment and district combinations). This matrix describes the relationships between the growth and yield parameters on the one hand and characterizes each combination of treatments and districts on the other hand. This analysis was performed in the Facto Mine R package (Le *et al*., 2019).

All analyses were done with R software version 4.1.0 (R Core Team, 2021).

RESULTS

Growth parameters

Height of the plants

Plant height growth at three (3) and nine (9) months did not show any significant difference according to the agro-ecological zones. However, significant differences were recorded at six (6) and twelve (12) months in the savanna zone (Figure 8a). According to the treatments (Figure 8b), T7 (cassava + NPK) showed a significant difference from 6 months onwards throughout the vegetative development. However, the other treatments did not show any significant difference. The plants in the savanna zone have a more pronounced growth in height.

Plant diameters

There was a highly significant difference (p = 2.2e-16) in the variation of plant diameters with time (months). There was a significant difference (p = 0.0143) between zones (Figure 9a). The seedlings in the forest have large diameters compared to those in the savannah. According to the treatments, there is a highly significant difference (p = 0.0001) from 3 months (Figure 9b) to 12 months, this difference is much more marked by T7 (cassava + NPK) followed by T3 (cassava + groundnut + NPK). There is a difference in time depending on the zone.

Root diameters

There is a highly significant difference (p = 2.2e-16) in root diameters as a function of time. At 6 months, savannah roots have larger diameters than forest roots, and from 7 months to at harvest, forest roots have larger diameters (figure 10a). There is a highly significant difference (P=3.33e-06) in all treatments at both sites. Plants that produced large roots at harvest were those from treatments T6 (cassava + cowpea + NPK), followed respectively by T5 (cassava + cowpea + PK), T7 (cassava + NPK), T3 (cassava + groundnut + NPK) and T0 (Figure 10b).

Chlorophyll contents

The difference in chlorophyll content between the two agro-ecological zones (Figure 11a) is highly significant (p = 5.6e-10). The plants from the forest zone have a high content compared to those from the savannah zone. A significant difference (p = 0.0015) is also observed in the variation of chlorophyll content over time according to the zones. However, the effect of the treatments does not affect the chlorophyll content of the plants (Figure 11b).

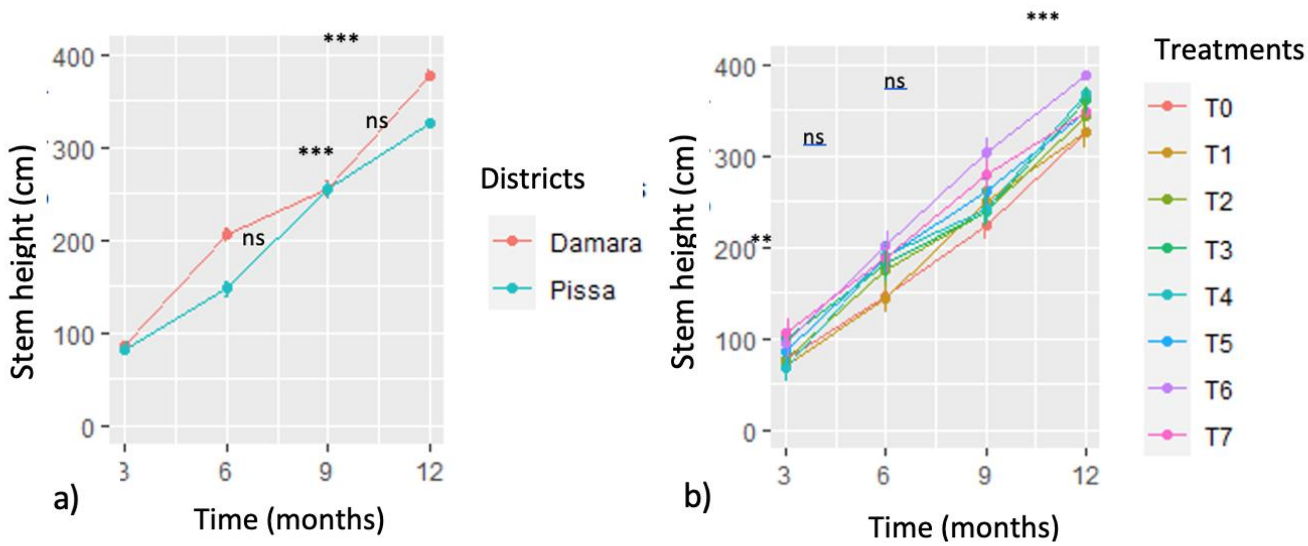


Figure 8. Evolution of heights as a function of time ('***' Probability significant at 0.001; '**' Probability significant at 0.01; '*' Probability significant at 0.05; ns Probability not significant).

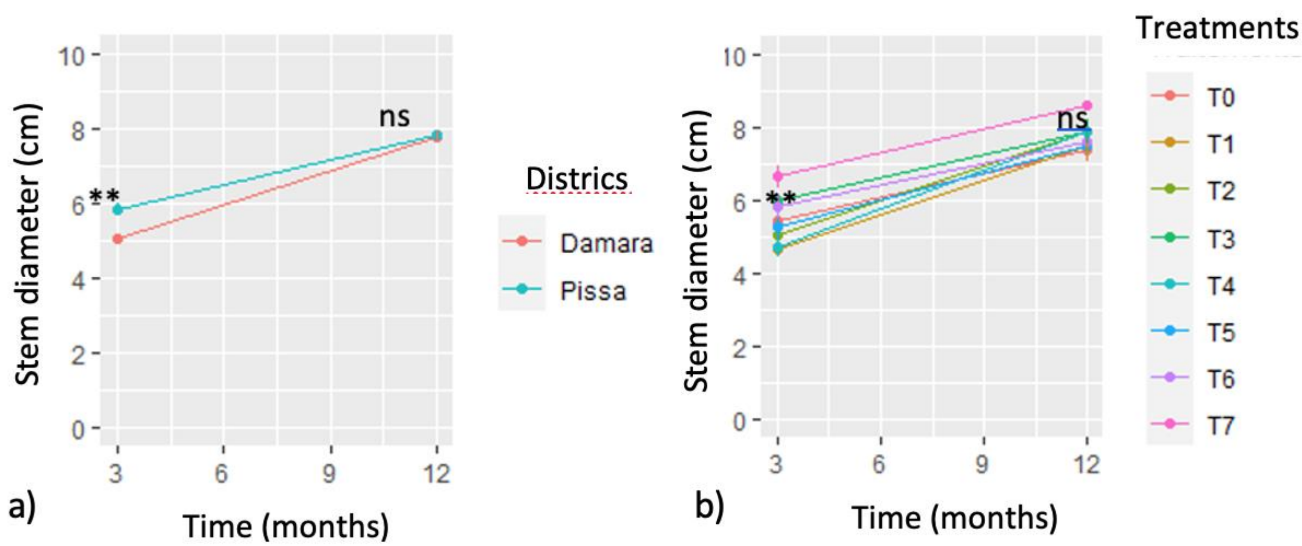


Figure 9. Stem diameters as a function of time ('***' Probability significant at 0.001; '**' Probability significant at 0.01; '*' Probability significant at 0.05; ns Probability not significant).

Root length

There was a highly significant difference (P = 5.04 e-6) in root lengths between zones (Figure 12a). The roots of the plants from savanna are longer than those from forest. However, treatments did not affect root length (Figure 12b).

Relationships between growth and production variables

A series of variations observed in Figure 13 for all growth and production parameters on the 3 correspondence axes and explains 75.5% of the overall variability. This demonstrates a close relationship between ¾ of the parameters studied. The component analysis of these 3 axes shows that 7 of the 8 descriptors have a partial contribution explaining this relationship. The first axis contributes 43.1% with the parameters that concern: root weight, residual root number, root diameter and chlorophyll content. On this same axis, a negative correlation is observed between root length and stem height. Axis 2, however, has a low contribution (17.1%) with stem diameters and heights. The contribution of axis

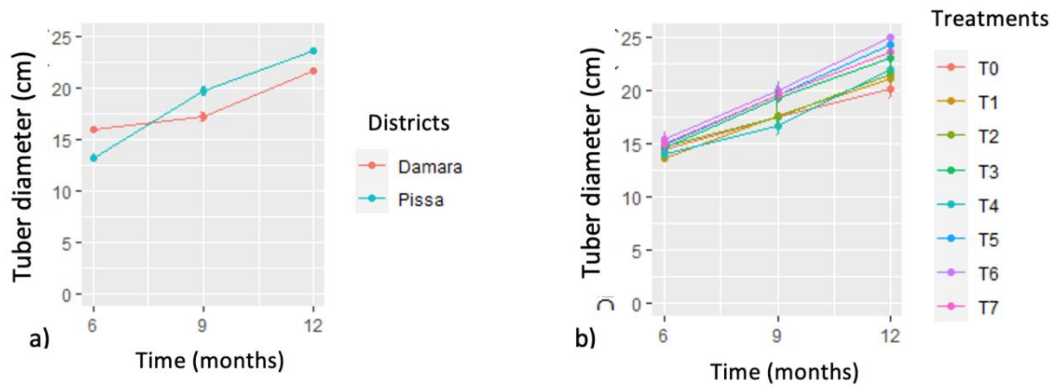


Figure 10. Evolution of tuber diameter as a function of time according to district (a) and treatments (b) ('***' Probability significant at 0.001; '**' Probability significant at 0.01; '*' Probability significant at 0.05; ns Probability not significant).

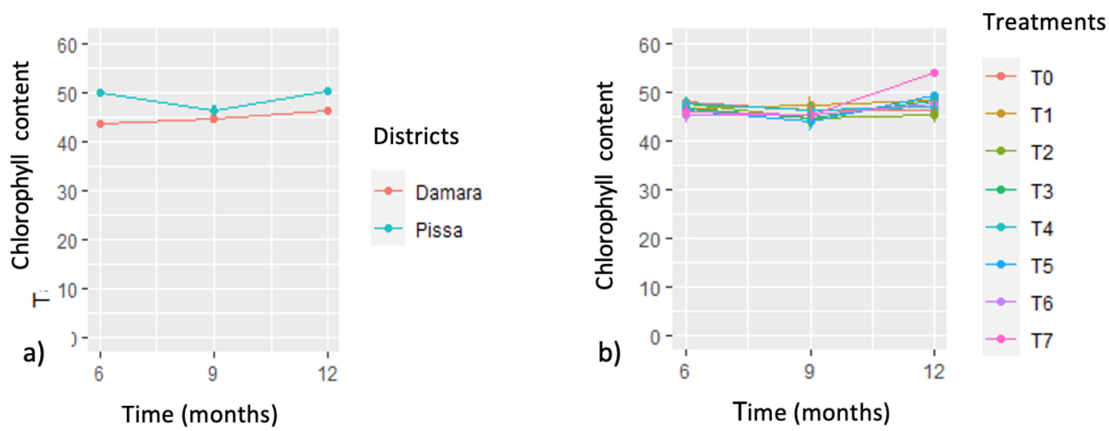


Figure 11. Evolution of chlorophyll levels as a function of time according to districts (a) and treatments (b) ('***' Probability significant at 0.001; '**' Probability significant at 0.01; '*' Probability significant at 0.05; ns Probability not significant).

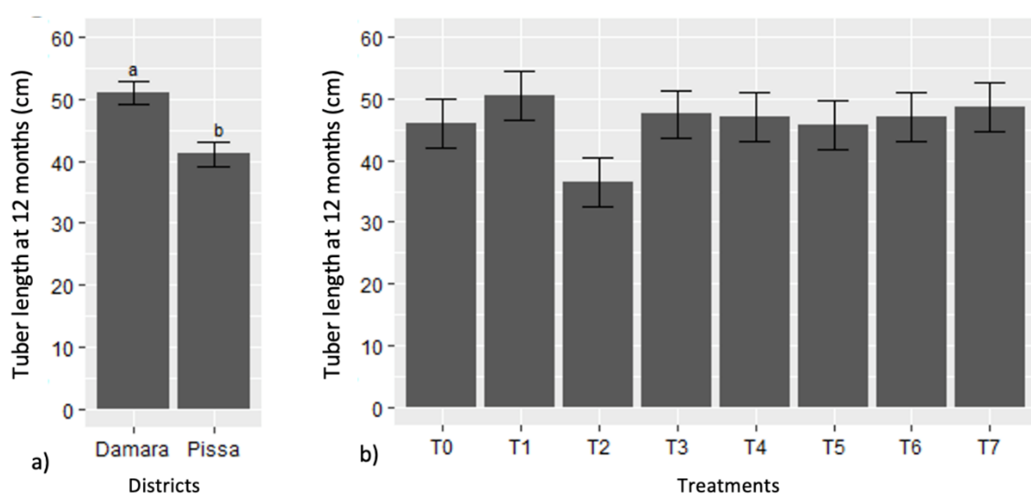
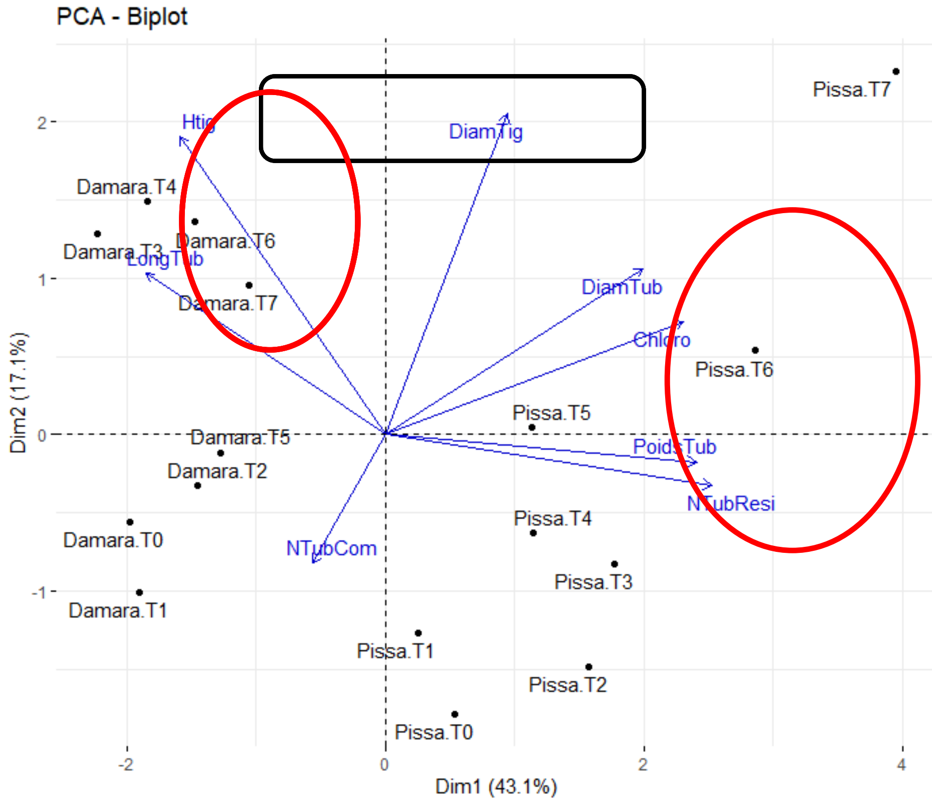


Figure 12. Root lengths according to districts and treatments.



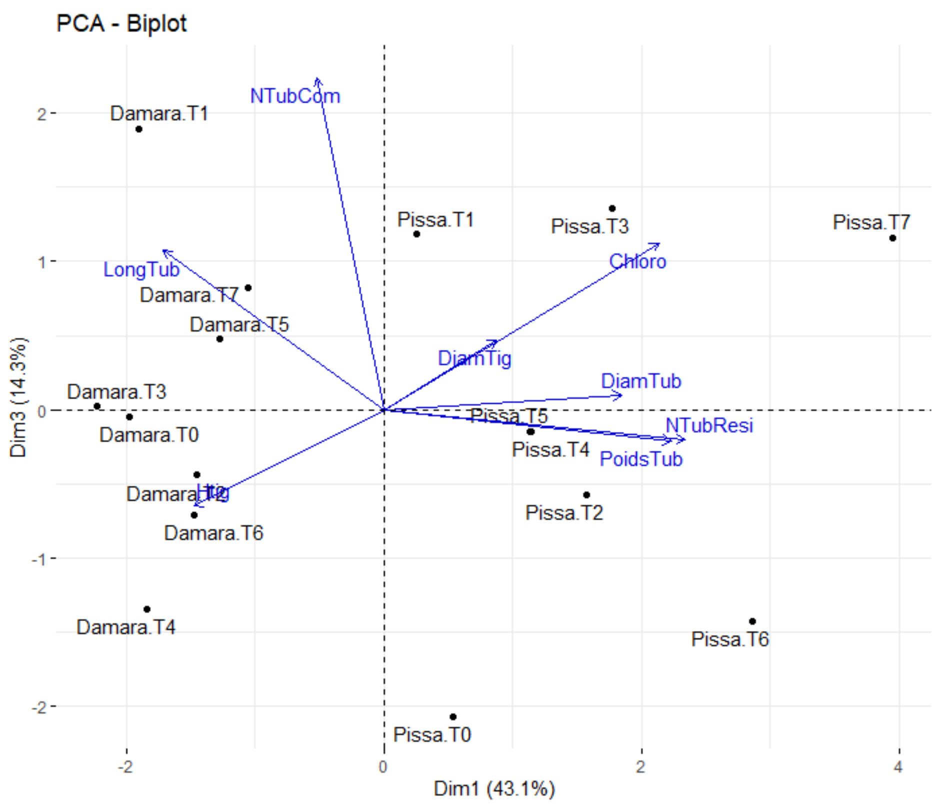


Figure 13. Correlations and projection of treatment combinations and districts.

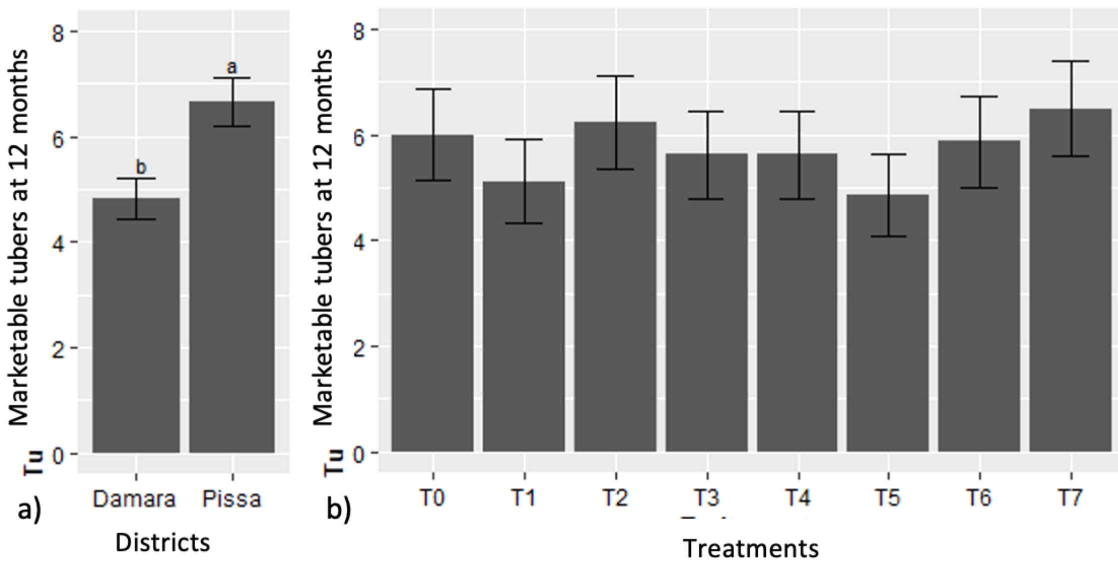


Figure 14. Number of marketable tubers according to districts and treatments.

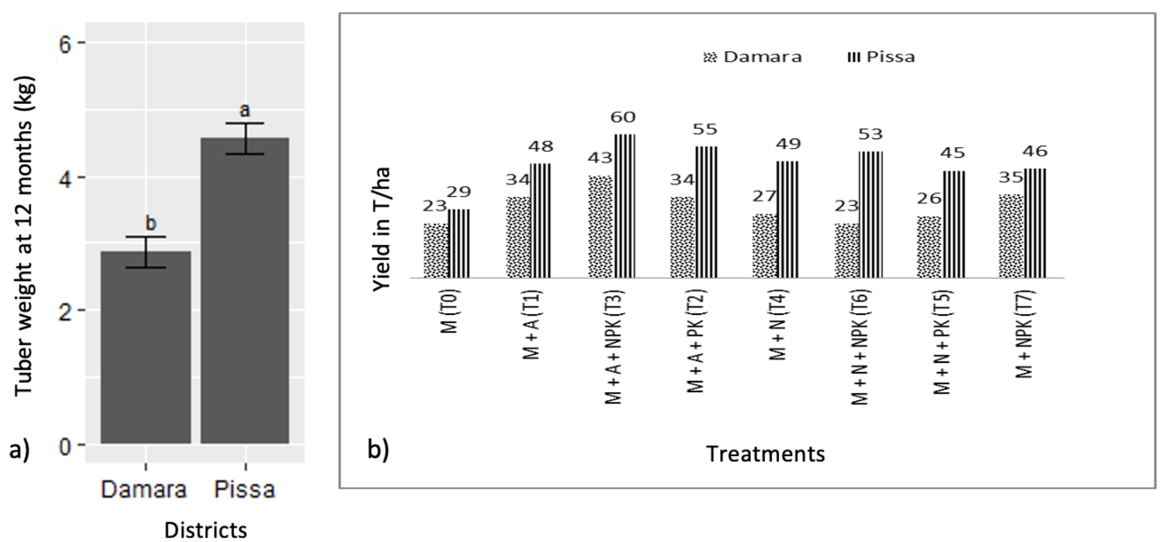


Figure 15. Root weight and fresh root yield.

3 is 14.3% for the parameters number of marketable roots and root length, stem diameter, root diameter and chlorophyll content.

Production parameters

Number of marketable roots and residual roots

There is a significant difference (p= 0.002025) in the number of marketable roots depending on the zone (Figure 14a). There are more in the forest than in the savannah. However, there was no difference between treatments (Figure 14b).

Fresh root yields

There is a highly significant difference (5.043e-06) between zones and treatments (Figure 15a). However, depending on the treatment, the best yield was obtained with treatment T3 (cassava + groundnut + NPK), which was 60 t/ha in the forest and 43 t/ha in the savanna (Figure 15b). The evaluation of root and pod yields (Table 8)

Table 8. Rate of increase in fresh root and cossette yields relative to the control (T0) to the control treatment (T0)

Zones	Treatments	Yields in fresh roots (t/ha)	Growth (%)	Yields in pods (t/ha)	Growth (%)
Pissa	T0	29	0	6	0
	T1	48	65.5	9.9	39.3
	T2	55	89.6	11.4	47.3
	T3	**60**	**106.8**	**12.4**	**51.6**
	T4	49	68.9	10.1	40.9
	T5	45	55 .1	9.3	35.4
	T6	53	82.7	11	45.4
	T7	46	58.6	9.5	36.8
Damara	T0	23	0	4.7	0
	T1	34	47.8	7	32.8
	T2	34	47.8	7	32.8
	T3	**43**	**86.9**	**8.9**	**47.1**
	T4	27	17.3	5.5	14.5
	T5	26	13	5.3	11.3
	T6	23	00	4.7	00
	T7	35	52.1	7.2	34.7

shows that T3 (cassava + groundnut + NPK) gave the best growth rates of 106.8% in forest and 51.6% in savanna.

Economic parameters

Expenses incurred are highlighted in Tables 9 and 10, showing the results obtained at the end of the year (after-sales in cossettes) and the increases compared with the control (T0) according to treatments. The treatments that generated the best results (profits) compared to the T0 control (cassava), both in the forest and in the savanna, were cassava combined with legumes (T1 = cassava + groundnut, with a profit of 765 000 F.CFA an increase of 46.8% in the forest; T4 = cassava + cowpea, with a profit of 787 725 F.CFA an increase of 48.3%). The lowest is T6 (cassava + cowpea + NPK with a loss of 450910 FCFA).

DISCUSSION

The study of the cassava crop association based on legumes (groundnut and cowpea) and mineral fertilizers showed variability at the scale of the agroecological zones and cropping systems (treatments). Variations in the parameters evaluated could be justified in relation to the characteristics of the soils, as well as the cropping history and the specific characteristics of each environment.

Chlorophyll levels, plant and root diameters, root numbers and yields of fresh roots and cossettes for forest treatments are statistically higher than that of savanna treatments. Rainfall could be one of the causes. Indeed, rainfall in the district of Pissa, which is characteristic of the forest (1600 to 1800 mm/year), is higher than that of Damara, which is characteristic of the savanna (1200 to 1600 mm/year). Vine *et al*. (1985) confirm this by stating that a certain level of soil moisture is necessary for successful crop association. Hence, the importance of rainfall at the time of plot establishment. The work of Sharkawy-El (2003) have shown the impact of changes in photosynthetic activity of cassava under stress conditions. This can impact on production. For example, in the dry season, cassava may, despite its adaptive qualities, show a decrease in photosynthetic activity and consequently a weakening of metabolic activities.

The eight (8) treatments used had different impacts on cassava growth, production and economic profitability. Legumes (groundnut and cowpea) and fertilizers proved to be effective in the development and growth of cassava plants. The plants from treatments: T6 (cassava + cowpea + NPK) followed by T5 (cassava + cowpea + PK), T7 (cassava + NPK) and T3 (cassava + groundnut + NPK) respectively are more robust and have a more efficient growth in height compared to plants from treatments T0 (pure cassava), T1 (cassava + groundnut) and T4 (cassava + cowpea) that did not receive mineral fertilizers. The residues of the legume harvest at 3 months (biomass), buried in the plots for the association treatments gave positive combined effects in production with mineral fertilizers based on N, P and K. Coulibaly *et al.* (2017) in their work on the effects of maize-legume associations and the fertility of a tropical ferruginous soil in Burkina Faso obtained results along the same lines. Similarly, by looking at the work of Zydelis *et al.,* (2019), it was found that the

Table 9. Operating account per hectare according to treatments

Treatments	Labels	Forest (price in FCFA)	Savannah (price in FCFA)
T0 (cassava)	Input costs	10000	10000
	Cost of cultivation operations	160000	160000
	Cost of harvesting and processing into pods	105000	105000
	Total expenses	275000	275000
	Production in pods	681818	534090
	Results	**406818**	**259090**
T1 (cassava + groundnut)	Input costs	45000	45000
	Cost of cultivation operations	210000	210000
	Cost of harvesting and processing into pods	105000	105000
	Total expenses	360000	360000
	Production in pods	1125000	795455
	Results	**765000**	**435455**
T2 (cassava + groundnut + PK)	Input costs	475000	475000
	Cost of cultivation operations	250000	250000
	Cost of harvesting and processing in pods	105000	105000
	Total costs	830000	830000
	Production in pods	1295455	795455
	Results	**465455**	**-34545**
T3 (cassava + groundnut + NPK)	Input costs	615000	615000
	Cost of cultivation operations	265000	265000
	Cost of harvesting and processing into pods	105000	105000
	Total Expenses	985000	985000
	Production in pods	1409090	1011365
	Results	**424090**	**26365**
T4 (cassava + cowpea)	Input costs	45000	45000
	Cost of cultivation operations	210000	210000
	Cost of harvesting and processing in pods	105000	105000
	Total expenses	360000	360000
	Production in pods	1147727	625000
	Results	**787725**	**265000**
T5 (Cassava + cowpea + PK)	Input costs	475000	475000
	Cost of cultivation operations	250000	250000
	Cost of harvesting and processing in pods	105000	105000
	Total costs	830000	830000
	Production in pods	1056818	602275
	Results	**226818**	**-227725**
T6 (Cassava + cowpea + NPK)	Input costs	615000	615000
	Cost of cultivation operations	265000	265000
	Cost of harvesting and processing in pods	105000	105000
	Total expenses	985000	985000
	Production in pods	1250000	534090
	Results	**265000**	**-450910**

Table 9. Contd.

T7 (Cassava + NPK)	Input costs	580000	580000
	Cost of cultivation operations	215000	215000
	Cost of harvesting and processing in pods	105000	105000
	Total expenses	900000	900000
	Production in pods	1079545	818185
	Results	**179545**	**-81820**

Table 10. Rate of increase in results compared to the control treatment (T0).

Zones	Treatments	Gross results (CFA)	Growth (%)
Pissa	T0	406818	0
	T1	**765000**	**46.8**
	T2	465455	12.5
	T3	424090	4
	T4	**787725**	**48.3**
	T5	226818	-79
	T6	265000	-53.5
	T7	179545	-126
Damara	T0	259090	0
	T1	**435455**	**40.5**
	T2	-34545	-650
	T3	26365	-882
	T4	265000	2.2
	T5	-227725	-78.6
	T6	-450910	-19.3
	T7	-81820	-68.4

height growth of the accession is related to the leaf mass (number of leaves, leaf area), its photosynthetic activity and the rate of translocation of nutrient reserves from the leaves to the tuberized roots. This implies that these aspects could be one of the causes of variation within treatments as well as across areas.

Treatment effects did not statistically impact root numbers. The seven (7) treatments that received fertilizers had the same root numbers as the control (T0). However, contrary results were proven by the work of Ognalaga *et al*. (2016) in Southern Gabon on the effect of cow dung, NPK 15 15 15 and urea on cassava growth and production where treatments that received both mineral and organic fertilizers have more tubers compared to the controls.

Cassava yields were significantly improved by combinations of mineral (N, P and K) and organic (legume) manures. It would seem that this combination makes mineral elements more readily available to the plant, thus promoting its growth and the proper development of its organs. These results are close to those of Akanza and Yao (2011) showing the effectiveness of the combination of organic fertilizer (poultry manure) and mineral fertilizers (NPK + urea + dolomite) on cassava yields. Treatments that received the fertilizers had higher yields compared to the control (T0). These results are more or less consistent with those of Engonga (2007) who showed the effectiveness of the combination of chicken droppings and urea on the stem diameter of black nightshade, and those of Giller *et al.* (2002) who reported that organic fertilizer combined with mineral fertilizer constitutes a fertilizer that can ensure a balance between inputs and plant needs.

The best yields in fresh roots and cossettes are obtained with the treatments having received NPK + legumes (T3 and T6) followed respectively by legumes + PK (T2 and T5), cassava + NPK (T7) and cassava + legumes (T1 and T4). However, after sale in cossettes, the best economic profitability is obtained with cassava + legumes (T1 and T4) for growth rates of 46.8% for T1 and 48.3% for T4. This situation could be explained by the high cost of fertilizers, which would have absorbed the profits made from the treatments concerned.

The 8 descriptors used in this study allowed to evaluate the structuring of growth and production parameters according to treatments. The series of variations observed at 75.5% of the global variability on the 3 correspondence axes with a partial contribution of 7 descriptors out of 8 explains that there is a close relationship between the growth and production parameters. This relationship is marked much more by root weight, root diameter and chlorophyll levels which contributed 43.1% in the overall variability. Emperaire *et al*. (2003) in a study on cassava obtained a contrary result showing an overall variation of 66% in the first two factorial axes with a partial contribution (CP>10) of 9 descriptors out of 20. The work in its context highlights a morphological and genetic structuring within the cassava accessions inventoried in Brazil and Guyana (Amazonia). This could justify the differences between the two types of studies conducted over time. Padonou (2009) also has a contrary opinion with respect to his work on the eco-phenotypic variability of *Jatropha curcas* seeds that show a great morphological variation of the seeds depending on the phytogeographic zones. These results attest that the structuring within the diversity of accessions in general is a function of several parameters and study objectives. In other words, the expression of certain descriptors may be a function of ecological factors.

Conclusion

The objective of this study was to evaluate cassava yields in an integrated management approach combining legumes (groundnut and cowpea) and fertilizers in savanna and forest. The application of mineral fertilizers associated with legumes (groundnut and cowpea) impacted cassava production with yields ranging from 23 t.ha^{-1} (T0) to 60 t.ha^{-1} (T3). Based on the lowest and highest yields, production increased by 106.8%.

A fertilization resulting from the association of leguminous plants (groundnut, cowpea) and mineral fertilization at the dose of 90 N, 30 P and 180 K is well indicated for an efficient production of tuberous root in forest and savannah zones and would be one of the solutions for the improvement of cassava agricultural yield. However, Central African farmers are reluctant to adopt this fertilization formula because of the high cost of fertilizers, which are still an imported product in the Central African Republic.

The study recommends the combination of cassava and legumes (groundnut and/or cowpeas) being economically profitable after processing and sale in cossettes.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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