E-ISSN: 2618-0618
P-ISSN: 2618-060X
© Agronomy
NAAS Rating (2025): 5.20
www.agronomyjournals.com
2025; 8(10): 535-542
Received: 15-08-2025
Accepted: 17-09-2025

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Influence of selected soil chemical properties on cassava and maize yield under traditional cropping systems in the forest zone of Kisangani, D.R. Congo

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DOI: https://www.doi.org/10.33545/2618060X.2025.v8.i10h.4022

Abstract
The analyses conducted in this study assessed the influence of soil chemical properties on the yields of cassava (*Manihot esculenta* Crantz) and maize (*Zea mays* L.) under different cropping systems (monocropping and intercropping).
The results showed that total organic carbon (TOC), soil organic matter (SOM), and total nitrogen (N) exhibited generally low variability between cropping systems and across soil depths (0-30 cm), with no statistically significant differences in most cases. However, a significant difference in the C/N ratio was observed in the 10-20 cm layer, indicating variation in the mineralization rate of organic matter depending on the type of crop.
Agronomically, mean yields differed significantly among treatments. Cassava grown in monocropping recorded the highest yield (24.9±7.06 t/ha), exceeding that obtained under intercropping (17.9±8.07 t/ha). Similarly, maize in monocropping showed an average yield of 2.33±0.24 t/ha compared to 1.44±0.26 t/ha under intercropping, confirming the impact of the cropping system on productivity.
Correlations between soil chemical parameters and crop yields revealed that, for monocropped maize, yield was positively correlated with organic nitrogen, TOC, and SOM ($r = 0.4$-0.5) but negatively correlated with the C/N ratio ($r = -0.4$). For monocropped cassava, a strong positive correlation ($r = 0.9$) was observed between yield and nitrogen, TOC, and SOM contents, while the correlation with the C/N ratio was negative ($r = -0.7$). Conversely, in the intercropping system, the combined yields of maize and cassava were negatively correlated with nitrogen, SOM, and TOC contents ($r = -0.9$) but positively correlated with the C/N ratio ($r = 0.7$), reflecting increased nutrient competition between the two species under this cropping system.

Keywords: Soil chemical properties, cassava, maize, cropping systems, crop yield

1. Introduction

Root, tuber, and cereal crops constitute a fundamental pillar for food security, the economy, and social stability in many regions of the world, particularly in the Democratic Republic of the Congo (Kourat, 2021) [10]. In this country, cassava (*Manihot esculenta* Crantz) and maize (*Zea mays* L., 1753) dominate the population's diet as the main energy sources. Cassava is consumed by approximately 74.4% of the population and maize by 68.8%, making them the most widely consumed staple foods. Their near-daily presence in meals around six days per week illustrates their crucial role in meeting the energy and nutritional needs of Congolese households (Tshingombe *et al.*, 2008) [15].
Beyond their nutritional importance, root, tuber, and cereal crops play a vital role in ensuring food security, especially in rural communities where they are cultivated using traditional farming practices. In such contexts, agricultural productivity largely depends on both the physical and chemical properties of soils, which determine crop yields (Bationo *et al.*, 2007; Lal, 2015) [3, 11].
However, the pedological and agronomic influence of soil chemical factors remains poorly understood in most of our forest ecosystems. This knowledge gap is particularly concerning in tropical regions, where soils exhibit high variability in characteristics such as texture,

structure, water retention capacity, and nutrient availability (Lal, 2006; Feller & Beare, 1997) [6, 11]. Consequently, soil responses to agricultural practices or human interventions vary considerably depending on their nature and composition.

The challenge for soil science, therefore, is to produce reliable and context-specific data to prevent the exploitation of unsuitable sites and to preserve, over the long term, the productive, ecological, and regulatory functions of soils (Alongo & Kombele, 2009; Sanchez, 2002) [2, 18].

In light of this pedological issue observed in traditional cropping systems, the present study aimed to evaluate the influence of soil chemical properties on cassava and maize yields in traditional farming systems. The goal is to contribute to the sustainable improvement of cassava and maize productivity by identifying the soil chemical characteristics most favorable to high yields, thereby guiding cropping practices toward better adaptation to local pedological conditions.

2. Study Area, Materials, and Methods

2.1. Description of Experimental Sites

The experimental site is located in the Tshopo Province of the Democratic Republic of the Congo, within the Ubundu Territory along the Ituri axis, in Bakilo village, 41 km from the city of Kisangani. The site's geographic coordinates, recorded using a Garmin 62S GPS (Global Positioning System), extend between 0°49'06'' and 0°48'59'' N latitude, and 25°53'08'' and 25°53'06'' E longitude (Figure 1).

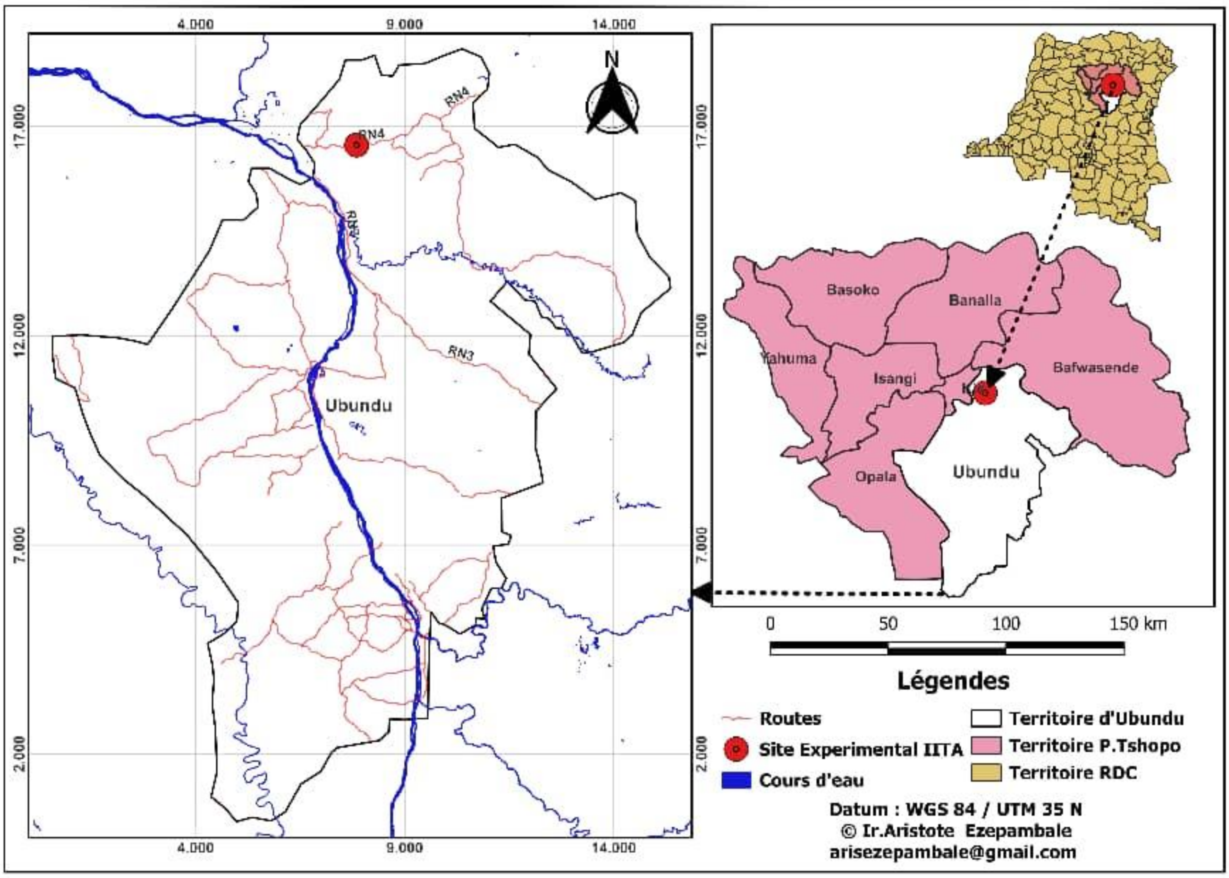

Fig 1: Location of the experimental site

2.2 Methods

2.3 Soil Sampling

Soil samples were collected under different crops during their vegetative growth cycle. According to the recommendations of Mathieu and Pieltain (1998) [12], the determination of sampling units within a sampling area can be performed randomly, systematically, by grid, along a diagonal, or in a zigzag pattern. For this study, a diagonal sampling method was adopted to obtain a homogeneous representation of each plot. Each experimental plot measured 10 m × 10 m. Three soil pits measuring 0.5 m × 0.5 m × 0.5 m were dug in each plot one at the beginning, one in the middle, and one at the end following an east-west axis. This arrangement takes into account root density and the presence of humus, characterized by the dark coloration of the soil (Kombele, 2002; Solia, 2016) [9, 16]. In total, 27 soil pits were excavated, distributed according to topographic levels. Figure 2 illustrates the experimental layout and the soil sampling points.

On each plot, soil samples were taken at different depths: 0-10 cm, 10-20 cm, and 20-30 cm. On average, nine individual samples were collected per plot, for a total of 81 samples across the entire experiment.

The soil samples were air-dried in the shade, then sieved through a 2 mm mesh at the WAVE/IFA-Yangambi Laboratory, and subsequently stored at room temperature, following the procedure described by Some *et al.* (2015) [17].

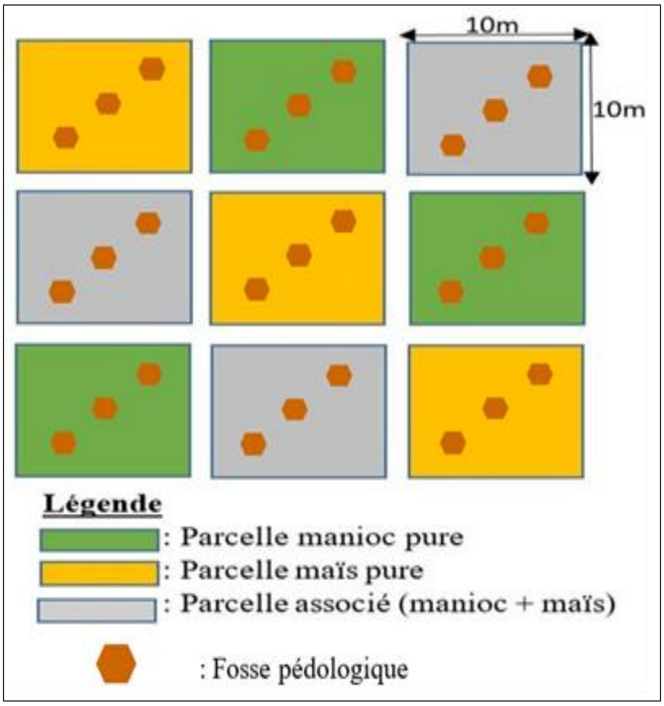

Fig 2: Experimental layout and soil sampling design

2.4 Soil Analysis

2.4.1 Total Organic Carbon (TOC): The determination of Total Organic Carbon (TOC) was carried out using the Walkley and Black method, modified according to Springer-Klee, as applied by Kombele (2004) [8]. This method is based on the oxidation of organic carbon with a 1 N potassium dichromate solution ($K_2Cr_2O_7$) in the presence of concentrated sulfuric acid (95% H_2SO_4), which induces an exothermic reaction that promotes oxidation.

The excess unreacted dichromate is then quantified by titration with a 0.2 N Mohr's salt solution [$Fe(NH_4)_2(SO_4)_2 \cdot 6H_2O$], using diphenylamine as an indicator.

Figure 3 illustrates the TOC titration process.

Fig 3: Carbon titration

2.4.2 Estimation of Soil Organic Matter: Soil organic matter (SOM) contains on average 58% organic carbon under humid tropical conditions (Kombele, 2004; Alongo, 2013) [1, 8]. To estimate soil organic matter from TOC determined by the Walkley and Black method (wet oxidation), a conversion factor of 1.33 was used, assuming a 75% oxidation rate. Thus, for each gram of organic carbon, approximately 1.33 grams of soil organic matter is estimated. When TOC is expressed as a percentage, the conversion formula is:

$$SOM\,(\%) = TOC\,(\%) \times 1.33 \quad (1)$$

This method provides a reliable estimate of the organic matter content in the soils studied.

2.4.3 Total Nitrogen

Soil total nitrogen content was determined using the Kjeldahl method, as applied by Solia (2016) [16]. In this study, 5 g of soil were digested with 5 ml of concentrated sulfuric acid (95%), followed by heating with a catalyst (a mixture of potassium sulfate and selenium or copper) to oxidize the organic matter. After digestion, organic nitrogen was converted into ammonium ions (NH_4^+). Following cooling and dilution, the distillate was collected by steam distillation into a boric acid solution containing an indicator. The presence of ammonia, revealed by a color change, was then quantified by titration with a standard acid to determine the total nitrogen content.

2.4.4 C/N Ratio

The carbon-to-nitrogen ratio (C/N) is a key indicator of the rate of organic matter decomposition in the soil. It directly influences nitrogen mineralization and nutrient availability for plants. Soil microorganisms use carbon as an energy source and nitrogen for protein synthesis (Brady *et al.*, 2008; Sylvia *et al.*, 2005; Recous *et al.*, 1990) [5, 19, 20].

In this study, the C/N ratio was calculated using the simple formula:

$$C/N = \frac{Soil\ Total\ Organic\ Carbon\ Contentl\ (\%)}{soil\ total\ nitrogen\ contant(\%)} \quad \textbf{(2)}$$

3. Results

3.1 Total Organic Carbon Content across Different Soil Layers

The results of TOC in the different treatments, according to soil depth, are presented in Figure 4.

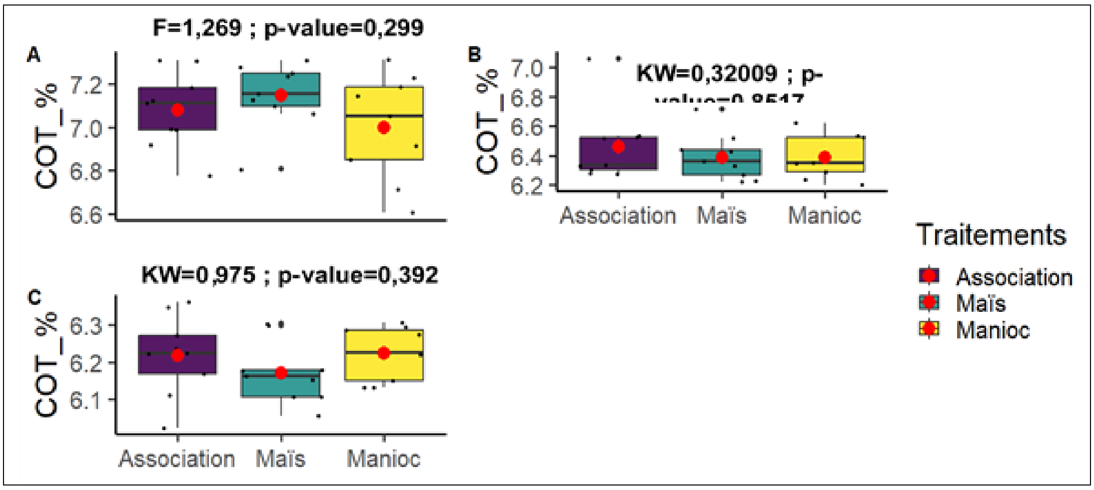

Fig 4: Mean TOC (%) according to treatments: A = 0-10 cm layer, B = 10-20 cm layer, and C = 20-30 cm layer

The analysis of TOC content across soil depths and treatments, as well as the results of the Kruskal-Wallis (K-W) test and ANOVA, showed no significant differences between treatments for the variables studied.

At 0-10 cm, TOC contents were 7.15±0.153% for maize monoculture, 7.08±0.177% for intercropping, and 7.00±0.242% for cassava monoculture. Between 10-20 cm, values were 6.46±0.250% for intercropping and cassava monoculture, while maize monoculture recorded 6.39% (±0.159 and ±0.144). In the 20-30 cm layer, intercropping and cassava monoculture each presented 6.22% (±0.108 and ±0.071), whereas maize monoculture had 6.17±0.084%.

3.2 Variation of Soil Organic Matter According to Treatments

The values of soil organic matter (SOM) for the different soil layers under the various cropping systems are presented in Figure 5.

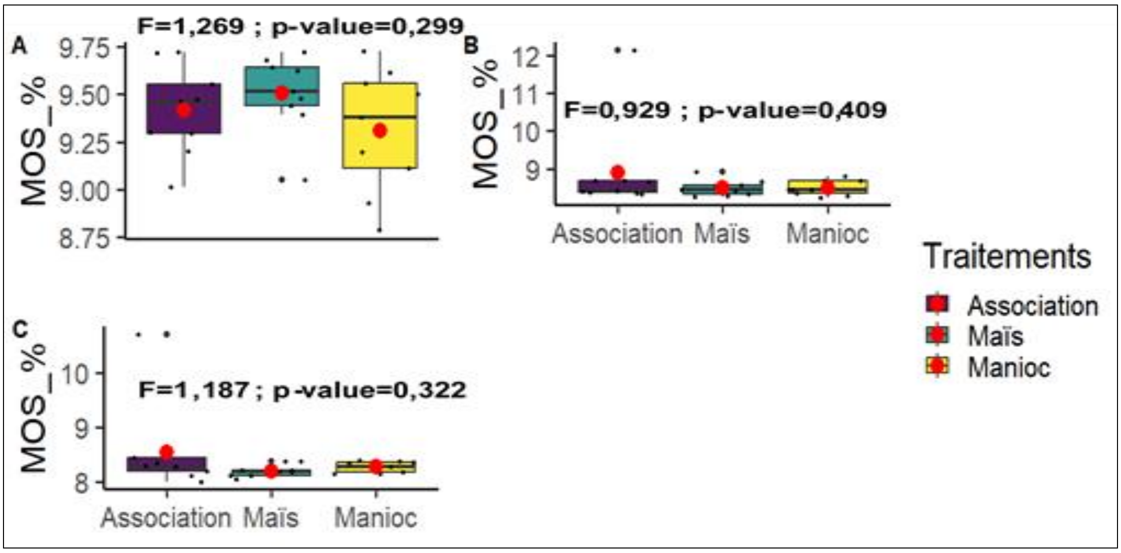

Fig 5: SOM (%) values according to treatments: A = 0-10 cm layer, B = 10-20 cm layer, and C = 20-30 cm layer

Overall, SOM contents in the 0-30 cm soil layer showed low variability between the different cropping systems, and no significant differences were detected by statistical analysis. The SOM data measured in the 0-10 cm layer (A) were as follows: 9.50 ± 0.203 % for maize monoculture, 9.41 ± 0.236 % for intercropping, and 9.31 ± 0.322 % for cassava monoculture (Figure 5). However, ANOVA revealed no significant differences between treatments at this depth (p-value = 0.299).

In the 10-20 cm layer (B), SOM contents were 8.90 ± 0.212 % for intercropping, 8.50 ± 0.21 % for maize monoculture, and 8.49 ± 0.192 % for cassava monoculture. Again, ANOVA indicated no significant differences (p-value = 0.409).

Finally, in the 20-30 cm layer, SOM contents were 8.54 ± 0.823 % for intercropping, 8.28 ± 0.094 % for maize monoculture, and 8.21 ± 0.112 % for cassava monoculture, with no significant differences detected statistically between treatments.

3.3 Soil Total Nitrogen Content across Different Soil Layers

The results of total nitrogen (TN) across the different treatments according to soil depth are presented in Figure 6.

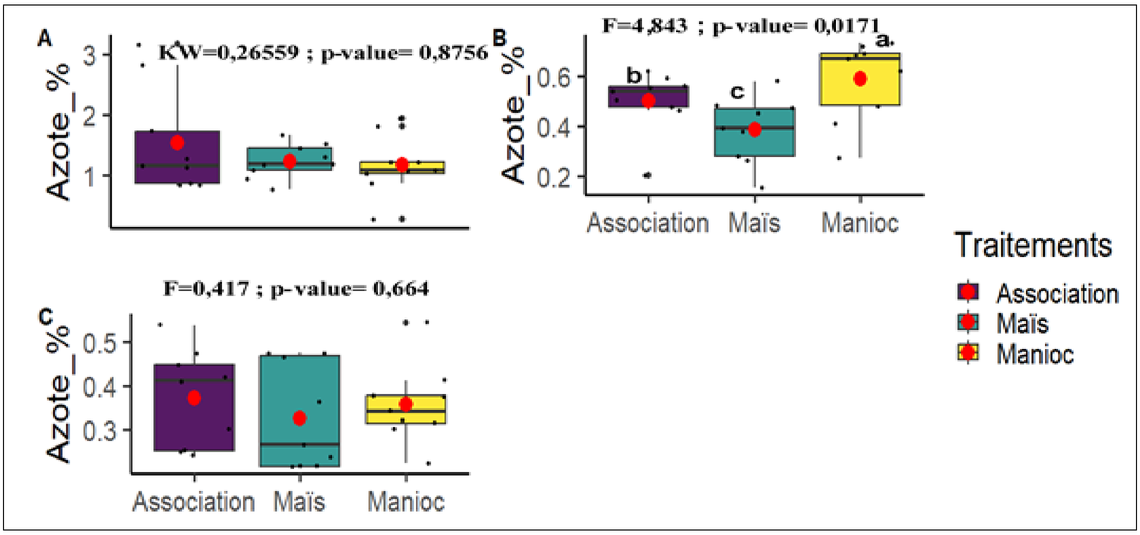

Fig 6: Mean soil TN values, where: A = 0-10 cm layer; B = 10-20 cm layer; and C = 20-30 cm layer

The analysis of soil total nitrogen (TN) content across depths and treatments, along with the results of the Kruskal-Wallis (K-W) test and ANOVA, showed no significant differences in the 0-10 cm, 20-30 cm, and 30-40 cm layers between treatments for the variables studied. However, a significant difference was detected in the 10-20 cm layer, with a p-value of 0.0171.

At 0-10 cm, TN contents were 1.54±0.877% for intercropping, 1.23±0.284% for maize monoculture, and 1.17±0.491% for cassava monoculture. Between 10-20 cm, values were 0.59±0.162% for cassava monoculture, 0.50±0.124% for intercropping, and 0.38±0.133% for maize monoculture. In the 20-30 cm layer, TN contents were 0.37±0.111% for intercropping, 0.36±0.089% for cassava monoculture, and 0.33±0.119% for maize monoculture.

3.4 Variation of the Carbon-to-Nitrogen (C/N) Ratio According to Treatments

Mean C/N ratios were determined for the different soil layers, as illustrated in Figure 7.

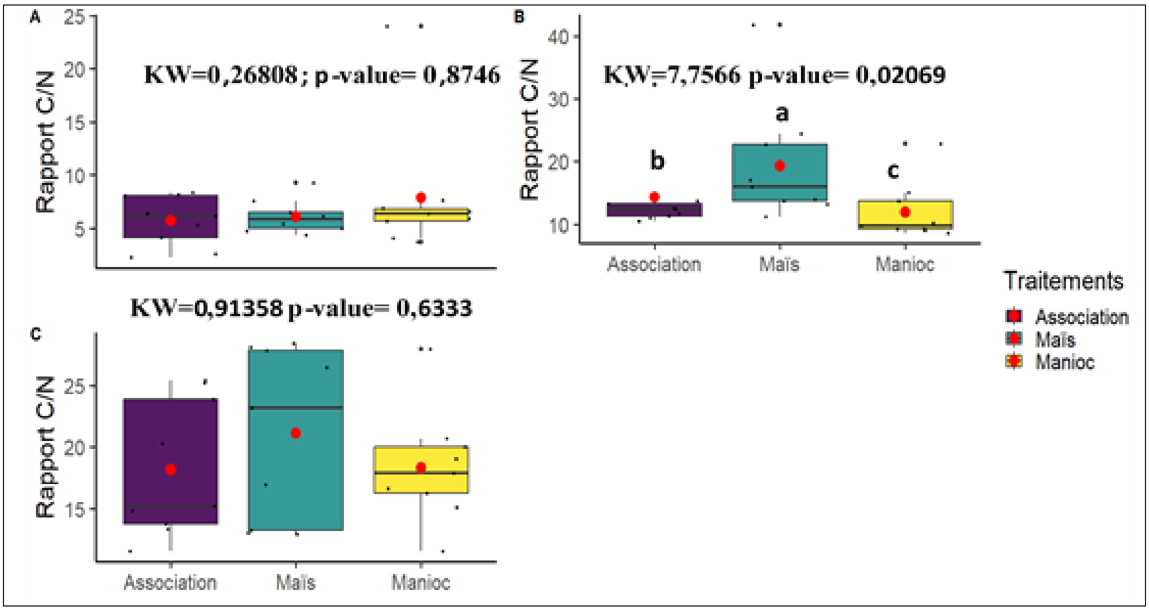

Fig 7: C/N ratio values, where: A = 0-10 cm layer; B = 10-20 cm layer; and C = 20-30 cm layer

Indeed, for the 0-10 cm layer (horizon A), the Kruskal-Wallis test revealed no significant differences between treatments (p-value = 0.8746). The observed means were 7.86±0.491 for cassava monoculture, 6.10±0.284 for maize monoculture, and 5.72±0.877 for intercropping (maize + cassava). In the 10-20 cm layer (horizon B), the K-W test indicated a significant difference between treatments (p-value = 0.02069). The Dunn post hoc test showed that maize monoculture had the highest mean C/N ratio (19.3±9.50), followed by intercropping (14.3±6.79) and cassava monoculture (11.9±4.66). For the 20-30 cm layer (horizon C), no significant differences were observed between treatments. The means were 21.1±7.03 for maize monoculture, 18.3±4.57 for cassava monoculture, and 18.2±5.56 for intercropping.

3.5 Observations of Cassava and Maize Yields

The mean yields (t/ha) were determined according to cropping system, as illustrated in Figure 8.

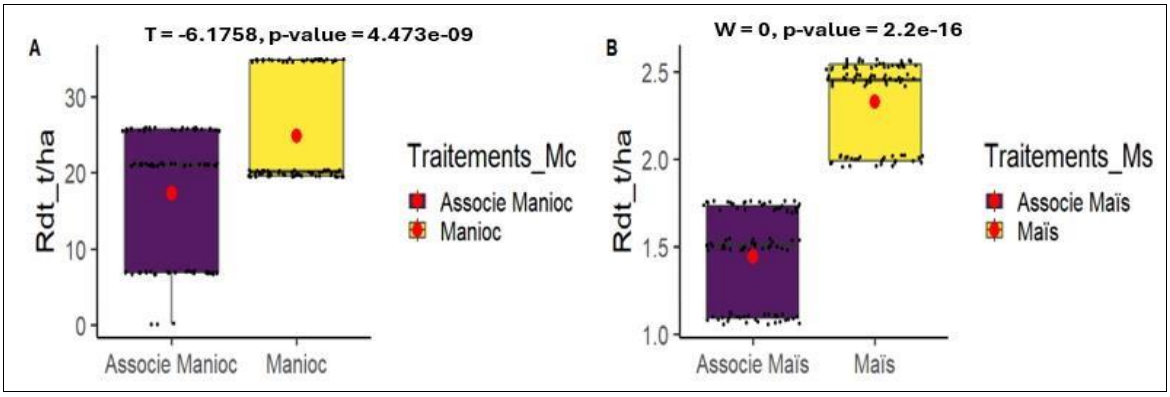

Fig 8: Mean yields (t/ha), where: A = cassava; B = maize

Statistical analyses of cassava yield data revealed a significant difference between treatments, as shown by the Student's t-test (t = -6.18; p-value = 4.47e-9). The mean yield observed was 24.9±7.06 t/ha for cassava grown in monoculture, compared to 17.9±8.07 t/ha for cassava grown in intercropping (Fig. 9). For maize, the Student's t-test detected a highly significant difference between treatments (p-value = 2.2e-16), with a mean yield of 2.33±0.242 t/ha in monoculture versus 1.44±0.267 t/ha under intercropping. Overall, these results highlight the significant impact of the cropping system (monoculture versus intercropping) on the agronomic performance of both cassava and maize.

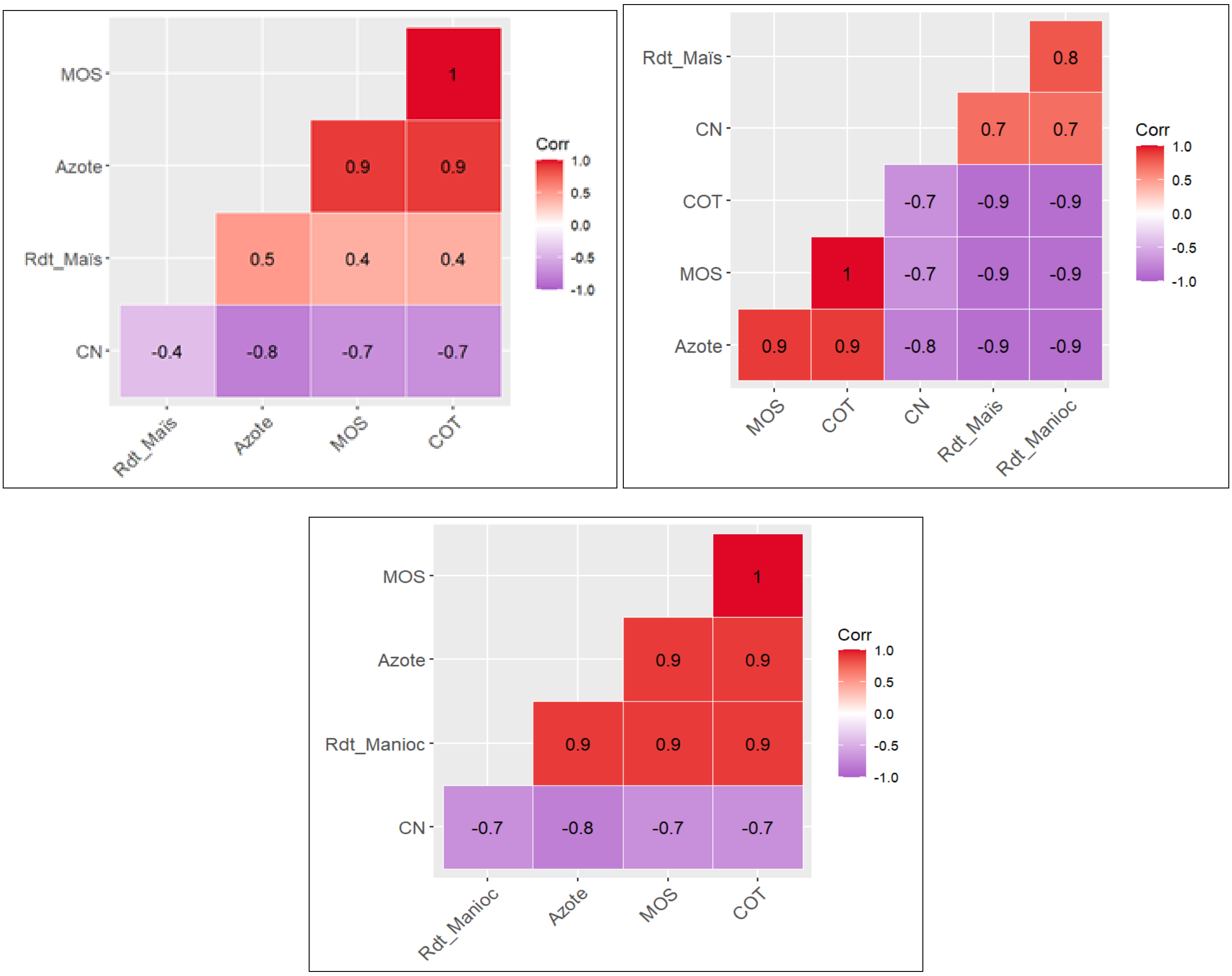

Fig 9a-c: Relationships between crop yields according to cropping systems and soil chemical variables in their organic form

3.5.1 Relationship between Agronomic and Edaphic Parameters by Pearson Correlation

The results of Pearson correlations between crop yields according to cropping systems and soil chemical variables in their organic form are presented in Figure 9.

The correlation matrix presented in Figure 9a illustrates the relationships between soil chemical properties and the yield of maize grown in monoculture. The matrix shows that maize yield in monoculture is positively correlated with soil organic nitrogen (r = 0.5), as well as with soil organic matter (SOM) and total organic carbon (TOC) (r = 0.4). Conversely, a negative correlation is observed between the C/N ratio and maize yield in monoculture (r = -0.4). This relationship suggests that rapid mineralization of organic matter may lead to a decrease in maize yield in monoculture, likely due to a temporarily imbalanced availability of nutrients.

Figure 9b highlights the relationship between soil chemical properties and the yields of maize and cassava in intercropping systems. The analysis reveals a strong negative correlation (r = -0.9) between intercropped yields and the contents of nitrogen, TOC, and SOM. In contrast, a strong positive correlation (r = 0.7) is observed between intercropped yields and the C/N ratio. This indicates that, in intercropping systems, nutrient competition between the two species may limit mineral nutrient availability, especially when the C/N ratio is high, which reduces mineralization and thus nitrogen availability.

Finally, Figure 9c shows that for cassava grown in monoculture, yield exhibits a strong positive correlation with nitrogen, TOC, and SOM (r = 0.9), while a negative correlation (r = -0.7) is observed with the C/N ratio. These results suggest that cassava in monoculture benefits from better nutrient availability, promoting higher growth and yield when organic matter mineralization is optimal.

Table 1: Multiple regression analysis of cropping systems and soil chemical properties

	Rdt Manioc		
Predictors	*Estimates*	*CI*	*p*
(Intercept)	-43.12	-69.58 – -16.67	**0.001**
MOS	7.36	4.05 – 10.67	**<0.001**
Azote	5.70	1.46 – 9.95	**0.008**
Observations	27		
R^2	0.909		

3.5.2 Multiple regression analysis

The linear regression model shows a strong relationship between soil fertility and cassava yield, with an R^2 of 0.909, indicating that 91% of yield variation is explained by soil organic matter (SOM) and nitrogen. Both variables have a positive and significant effect on fresh tuber yield: SOM has a highly significant influence ($p < 0.001$) with an average increase of 7.36 yield units per unit of SOM, while nitrogen also contributes notably (p = 0.008) with a gain of 5.70 units. Overall, the model highlights that enhancing soil organic matter and nitrogen levels is key to improving cassava productivity, with SOM having a slightly stronger effect, underscoring its crucial role in sustainable yield improvement.

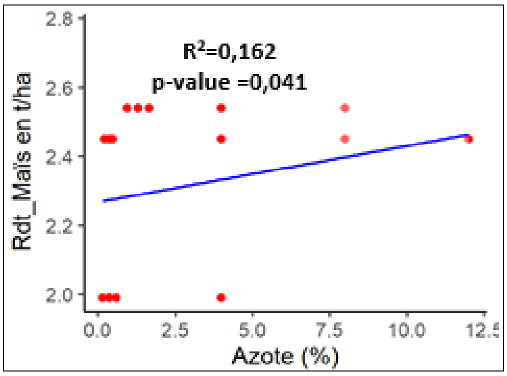

Fig 10: Relationship between maize grain yield and organic nitrogen content

3.5. Simple regression between maize grain yield and organic nitrogen content

The analysis shows that an increase in nitrogen percentage is statistically significantly associated with an increase in maize yield. However, this relationship is weak, as nitrogen explains only a small portion (16.2%) of the observed yield variation. This suggests that many other factors have a much greater influence on maize yield.

Table 2: Multiple regression analysis of cassava and maize yield in relation to cropping systems and soil chemical properties

	Rdt Maïs Ass		
Predictors	*Estimates*	*CI*	*p*
(Intercept)	3.76	2.98 – 4.53	**<0.001**
MOS	-0.25	-0.33 – -0.17	**<0.001**
CN	-0.01	-0.02 – -0.01	**<0.001**
Observations	27		
R^2	0.593		

	Rdt Manioc Ass		
Predictors	*Estimates*	*CI*	*p*
(Intercept)	82.66	57.03 – 108.30	**<0.001**
CN	-0.34	-0.48 – -0.19	**<0.001**
MOS	-6.95	-9.67 – -4.23	**<0.001**
Observations	27		
R^2	0.511		

3.2.5 Multiple regression analysis of cassava and maize yield

The two statistical models analyze the yield of cassava and maize grown in association, based on two variables: the carbon-to-nitrogen ratio (C/N) and soil organic matter (SOM). For the yield of cassava tubers in association, the model explains 51.1% of the observed variability. Both variables, C/N and SOM, have a highly significant negative effect ($p < 0.001$), with a stronger impact for SOM (–6.95) than for C/N (–0.34). For the yield of maize grain in association, the model shows a slightly better fit ($R^2 = 0.593$), explaining 59.3% of the yield variation. The effects of C/N and SOM remain negative and significant ($p < 0.001$). These results indicate that an increase in C/N or SOM is associated with a decrease in yield for both crops. The negative effect of C/N can be explained by slower nutrient mineralization, resulting in delayed release of nutrients essential for growth. As for SOM, its increase promotes enhanced vegetative growth, at the expense of the development of harvestable organs (tubers for cassava and grains for maize), directly reducing marketable yield.

Discussion

The results of this study show a progressive decrease in the C/N ratio with soil depth, reflecting a higher accumulation of fresh organic matter in surface layers. In this surface zone, the C/N ratios obtained are similar to those reported by Verchot *et al.* (2020), who observed values of 15.2 in secondary forest, 14.9 in cocoa plantations, and 16.4 in cultivated soil, associated with a high concentration of organic matter at the surface.

Similarly, Baumgartner *et al.* (2020) [4] reported slightly lower C/N ratios in forest soils, with mean values of 10.12±1.27 in mountainous areas and 13.36±1.57 in Miombo woodlands.

These similarities suggest comparable organic matter dynamics across different ecosystems, despite contrasts due to vegetation cover and land use.

Moreover, Garnier *et al.* (2011) [7] reported organic matter contents of 2.8% and total nitrogen of 1.19% in two land use types, values lower than those obtained in the present study. Likewise, Makelele *et al.* (2022) [13] highlighted relatively low TOC contents in various vegetation contexts agricultural sites, 5-60-year-old secondary forests, and old-growth forests also lower than those observed here.

The high values of soil chemical properties recorded in this study could be explained by better nutrient availability, favored by traditional slash-and-burn practices and early agricultural exploitation after forest conversion. Regarding yields, cassava in monoculture outperformed the cassava-maize intercropping system, with values higher than those reported by Alongo and Kombele (2009) [2], who attributed the yield reduction in intercropping to root competition between species. Maize shows a similar trend: monoculture averaged 2.33 t/ha, values comparable to those reported by Musaba and Shema (2013) [14] and Kalonji *et al.* (2018). This superiority of monoculture is explained by better resource availability (water, light, and nutrients) and more favorable soil aeration, stimulating root growth and crop productivity.

Conclusion

The results of this study demonstrate that soil chemical properties, particularly nitrogen, organic matter, and total organic carbon contents, significantly influence the yields of cassava and maize, depending on the cropping system adopted.

Monoculture systems are more productive than intercropping systems, likely due to better nutrient availability and utilization for each species. Conversely, intercropped crops face more intense nutrient competition, reducing the availability of nitrogen and easily mineralizable organic matter, especially when the C/N ratio is high.

These results highlight the need for sustainable management of soil chemical fertility in traditional agricultural systems in the Kisangani region. Sustainable improvement of cassava and maize productivity could involve: regular application of well-decomposed organic matter, balanced management of the C/N ratio to enhance mineralization, and selecting suitable crop associations based on local pedological conditions. This study contributes to a better understanding of the interactions between soil chemical fertility and staple crop productivity, providing a scientific basis for optimizing cropping practices in humid tropical environments.

Acknowledgments

We express our deep gratitude to Professor Godefroid Monde, Country Director of the WAVE-Yangambi program, for the material support provided to the laboratory. We also thank Professor Ferdinand Kombele Bishosha M. for his continuous guidance, rigorous supervision, and quality mentoring throughout this work. Finally, we thank Engineer M.Sc. Éliezer Batshambale for his valuable assistance in performing part of the statistical analyses.

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