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Effect of a Typical Organo-Mineral Fertilization and of the Green Carpet Cultivation System with *Acacia Auriculoformis* Cunn ex Benth and *Pennisetum purpureum* K. Schum on Biomass Production of Forage Crops in the Hinterlands of Kisangani, Tshopo (DRC)

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ABSTRACT

In the present study, we tested the possibility of developing an appropriate technical itinerary for the green carpet crop system (ATV) involving pruning of grass hedges, composting of their clippings, direct seeding and fertiliser application that would ensure high overall productivity and major agroecological benefits. Compost with NPK 17- 17- 17 was applied to some plots of degraded soil in the ATV production system, while other plots were either treated with pig manure with NPK 17- 17- 17 on the side of the Slash and Burn production system. All treated plots are then used for maize (*Zea mays* L.) cultivation. A split-plot design was used with five replications per treatment. The study showed that the large amount of both forage and soil biomass was observed on the plots that received composts and chemical fertilizers in the ATV production system. These different results show that the ATV production system combined with organo-mineral fertilisation is a good source of mineral elements and make it possible to envisage its use in programmes to restore degraded soils.

Introduction

Soil fertility management is a topic of great importance in the Democratic Republic of Congo, where deforestation and erosion render the land unfit for agriculture every year. This is due to the abandonment of the traditional method of restoring soil fertility through fallowing (Gaiser et al., 2011, Maliki et al., 2017).

In Togo, work carried out to date in the field of soil fertilisation has mainly focused on the use of cover crops such as *Cajanus cajan* and *Vigna unguiculata* (Nurul et al. 2020). This work revealed that *Cajanus cajan* and *Vigna unguiculata* are effective in restructuring the soil and increasing maize yield (Nurul et al. 2020). According to the same work, the use of *Mucuna pruriens* as a cover crop has been shown to significantly increase soil nitrogen and phosphorus levels, just as the use of organic amendments increases maize productivity (Kaya, 2015).

Soil fertility research with the VLIR-UOS project at the University of Kisangani's Faculty of Renewable Natural Resource Management has been undertaken to address the main problems of agricultural land degradation in Tshopo Province and especially to increase the adoption of improved techniques in farming systems (Pyame et al, 2021a, b, c).

Improving practices such as the introduction of a legume under maize crops often not only helps to control erosion, but also to replenish the stock of soil organic matter and nutrients needed to re-establish sustainable cereal production on the land (Barthès et al, 2015). Another increasingly common practice leading to prodigious results in this area is composting.

Thus, given the importance of maize cultivation in the fight against food insecurity, it is appropriate to use cultivation practices that raise the level of soil fertility and circumvent the effects of short droughts that have become so frequent during the wet season.

Furthermore, in agroforestry, *Acacia auriculoformis* can, in general, be considered as a potential candidate for fertilisation as it produces a high biomass yield and is well adapted to the conditions of very poor degraded soils (Sofea et al., 2017; Abderrahmane et al., 2021).

The problem underlying this research is the very low and random productivity of the slash-and-burn system, maintaining unproductive forest/mixed fallows that are unsuitable for agricultural mechanisation, agriculture-livestock integration and climate-smart agroecological management. The solution would be to set up agroforestry fallows with a high potential for producing a diversified and richly valued biomass (Pyame et al, 2021a, b, c). In order to establish a clear research line, a research question is formulated below, followed by the related hypothesis and objective.

Will the ATV system lead to additional ecological, agro-technical and environmental benefits when compared to the CIB system in this specific context (organically fertilised maize)?

Compared to the local CIB system, and under conditions of low organo-mineral input, maize cultivation in

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the ATV system leads to a higher production of fodder in quantity and quality, but also to a higher fertilising potential through a considerable biomass restitution to the soil.

The present study aims to develop an appropriate technical itinerary for the ATV system, involving the pruning of herbaceous hedges, the composting of their clippings, direct seeding and the application of fertilisers, which can guarantee high overall productivity and major agro-ecological benefits.

Materials and Methods

Our research is carried out in the Democratic Republic of Congo, in the Province of Tshopo, the city of Kisangani, the annexed sector of Lubuya Bera, at kilometre point 12 on the Banalia road, more precisely in the Agro-sylvo-Pastoral Pyame concession.

With a latitude of 0° 11' North, a longitude of 25° East and an altitude of 390 to 410 m with an average of 400 m, the city of Kisangani is located in the central basin straddling the Congo River. Its relief is a series of plateaus interspersed with river beds and streams (Pyame, 2015) (Figure 1)

During our investigation, three types of materials were used, namely: biological materials, technical materials and fertilisers. They are detailed through the different points aligned in the conduct of the trial. Before that, we present the experimental set-up while specifying the different related treatments.

The experimental period extends from 15 January to 15 December 2022, i.e. one year (12 months). Note that the afforestation was established 36 months earlier, in December 2018. The grass hedges installed at the same time were reinforced by 50% at the beginning of the experiment.

Experimental set-up

The set-up has been in place since May 2022 with the objective of studying the effects of increasing doses of NPK and hedge prunings compost on the growth and yield of maize under a *Pennisetum purpureum* and *Acacia auriculoformis* green cover. This system includes two cropping systems: Slash-and-burn and the innovative system called "Plate cultivation under green carpet" (ATV).

After clearing the land with a machete, careful stumping and hoeing followed immediately. A composite sample of the experimental soil was taken beforehand, considering 2 strata, namely from 0 to 15 cm and from 15 to 30 cm. This allowed us to characterise the initial state of the soil fertility in order to assess its evolution over time, the same device being used for the subsequent tests related to the doctoral phase of the study. The trial includes the following treatments: ATV- T0; ATV-T1; ATV- T2; CIB- T0; CIB- T1 and CIB- T2.

The experimental set-up is split-plot, the blocks being arranged perpendicular to the general slope of the land, and each comprising 6 plots of 25 m^2 representing the treatments, 3 of which are on the first half of the land bearing the Plates under Green Carpet (ATV) cropping system and the other 3 on the other half bearing the CIB cropping system;

The treatments were defined according to two factors: (1) the main factor: the production systems (ATV and CIB) and (2) the secondary factors: organic fertilisation (manure and compost) and mineral fertilisation (NPK 17-17- 17).

The experiment was carried out on a total area of 1044 m^2 or 0.1044 ha, i.e. 29 meters wide and 36 meters long (Figure 2).

Conducting the trial

Preparation of the experimental field

The *Acacia auriculoformis* afforestation of the experimental set-up has been installed since December 2018.

After clearing the land with a machete, followed by stump removal and ploughing with a hoe, the Pennisetum purpureum hedges were replanted to about 50%. Intercalated in bands of 4 dense hedges (0.5 m apart in the line) at 1.5 m intervals, they alternated with twin lines of Acacia auriculoformis, 1 m apart and planted at 4 m intervals in the line. There were thus three 1.5 m strips of land, divided every 5 m and intended to receive the crops (crop beds).

Sowing

Sowing took place on 12 May 2022, and the yellow-orange SAMARU variety, selected at INERA-Yangambi, was used, although it was bought in ears on the Kisangani market. After dehulling and severe sorting, sowing was done manually, with a hoe, following an alignment with nylon ropes. Two rows of maize, 0.7 m apart and centred on the alley, were interspersed with *Pennisetum purpureum* hedges held at a distance of 0.4 m on either side. Sowing was carried out at 4 grains per stake, every 0.5 m in the row, in a staggered pattern, with a two-plant removal planned at emergence.

Pruning of herbaceous and tree hedges

After reseeding, pruning of the herbaceous and tree hedges was carried out 15 days after sowing. After trimming the *Pennisetum purpureum* hedges to 10 cm from the crown, half of the biomass was removed from the field for composting and the other half was cut into 30-40 cm pieces and spread as mulch between the maize lines. The trees were severely pruned to 3-4 m high using a small bamboo ladder. All cut branches were removed from the field and stored for 7 days, after which half of the litter was collected to reinforce the mulch in the experimental field and the other half plus the twigs were used for composting, with the large branches being harvested as firewood.

Hoeing and second pruning of the herbaceous carpet

The first weeding, which covered the entire system, was carried out 20 to 25 days after sowing. The second, which took place at 45-50 days, was limited to half of the system relating to the slash-and-burn system, while it was replaced on the part of the ATV system by a weed cut at 10 cm from the ground between the maize rows and mainly concerned the *Pennisetum purpureum* hedges.This time, all the grass clippings were used to reinforce the mulching of the soil under the Green Carpet system, and its usefulness as an organic input (humus) with implications even beyond the crop cycle.

Composting of green carpet prunings

Given the abundance of rainfall in this equatorial region, especially during the cropping season, we opted for composting in windrows (piles) rather than in pits. Tall grasses and thin tree branches were cut with a machete and reduced to 5-10 cm long particles.

On a platform of 1.5 m x 3 m, we first made a bed of palm twigs and dry banana leaves, and stabilised it with logs of false banana trunks. A layer of cut grass (30 cm), a layer of a mixture of fresh and decomposed manure (10 cm), a layer of fine branches mixed with *Acacia auriculoformis* litter (5 cm) and a layer of organic soil taken from the surface around the compost heap mixed with 3 buckets of kitchen ashes (5 cm) were then placed alternately. The pile was then watered copiously before a subsequent layer of composts was added, and so on until it reached a height of about 1.8m.

Spreading fertiliser and organic inputs

We used the complete fertilizer NPK 17-17-17 because of its richness and balance of fertilizing elements. The application was done in one operation immediately after the first weeding at 25 days from sowing, for the treatments of 50 kg/ha or 5 g/ m^2 (T1) and 100 kg/ha or 10 g/ m^2 (T2), then spread as a cover crop, in the immediate vicinity of the foot (radius of 5-10 cm), then covered with top soil or compost. A second application was made after the second weeding at 50 days from sowing, with 5 g/ m^2 (2 maize plants) to bring the total dose to 100 kg/ ha for treatments T2-ATV and T2- CIB.

Note that the manure applied at 5t DM (Dry Matter) /ha corresponded to 10 t of the manure used (50% moisture), i.e. 10,000 kg/ha equivalent to 1 kg/ m^2. The compost used was worth 3 times the mass of the manure, i.e. 2.5 kg/ m^2, as it was less wet (drier) than the manure. The organic input, compost (ATV system) or manure (slash-and-burn system), was thus used to cover the fertiliser, which was spread on the surface, to avoid losses through volatilisation.

Phytosanitary treatments

A widespread attack on maize was noted at 45 days of the cycle due to stem-boring caterpillars. This was due to the fact that the seed was of dubious origin and had not been treated with any pest control. Two applications were then made using two insecticides, namely actara (10 ml/water gallon), supplemented by Dipel (60 g per 5 gallons).

Data collection on the measurement of total biomass (epigeal and hypogeal)

The weight of the above-ground and below-ground biomass of maize was determined on all plots using a 20-kilogram suspension scale with an accuracy of 50 g. The above-ground or forage biomass (stalks and leaves) and the below-ground or soil-retaining biomass (roots) were immediately weighed to determine the weight of fresh matter (FM). They were then oven-dried at 105°C to constant weight, which occurred after 5-6 days due to the irregular supply of electrical energy, to determine the dry matter (DM).

The yield squares method was used to assess the above-ground or forage biomass of *Pennisetum purpureum* (the leaves) in the trial, which consisted of cutting flush with the ground, then weighing 6 or 10 plants found in the 1m2 in the middle of the plot and repeating twice per plot. The cutting was done three times during the experiment, the first at one month (1), the second at two and a half months (2.5) and the third or last at four months (4). Following the continuity of the research, we did not proceed by stump removal of *Pennisetum purpureum*, to determine the weight of fresh material of the biomass of restitution to the soil, we took the coefficient of ¼ of the weight of stems and leaves of *Pennisetum purpureum*. For dry matter, we used a coefficient of 29%. For maize, the above-ground and below-ground parts of plants were harvested from the entire plot and weighed separately to obtain the fresh weights (MF). To find the dry weights of the biomasses, we had deducted from 71% thus the coefficient of 29% too (Pyame, 2015).

It should be noted that, soil texture, water pH, KCl pH and exchangeable aluminium were analyzed in the laboratory before the installation of the experimental set up.

Statistical Analysis

The data of the different variables (treatments) were entered in Excel. The software Past, allowed us to calculate the ANOVA test at the threshold $\alpha = 0.05$ and, after the calculation, when the difference is significant, the Tukey test was used to compare two by two the different treatments.

Results

Fodder Biomass

Production of maize fodder biomass by the CIB : fresh material

Figure 3 summarizes the results of the observations on maize fodder biomass production in the slash-and-burn system (fresh material).

The results presented in Figure 5 show that CIB-T2 stood out from the other treatments with an average production of 13.7 tonnes of fresh matter per hectare (tFM/ha) followed by CIB-T1 (11.3 tFM/ha) and finally, the lowest yields were produced by CIB-T0 (8.0 tFM/ha). There was a significant difference between the three treatments (F= 66.41 and p = 3.27 E- 07). Comparing the treatments in pairs, there was a significant difference between CIB-T0 and CIB-T1 (p = 0.0002323), CIB-T0 and CIB-T2 (p = 0.0001903) and CIB-T1 and CIB-T2 (p = 0.001709).

Forage biomass production of maize by CIB: dry matter

Figure 4 summarizes the results of the observations on maize fodder biomass production in the slash-and-burn system (dry matter).

The results presented in this figure 4 show that CIB-T2 stands out from the other treatments with an average production of 9.7 tonnes of dry matter per hectare (DMt/ha) followed by CIB-T1 (8.1 DMt/ha) and finally the lowest yields were produced by CIB-T0 (5.6 DMt/ha) ($p<0.001$). There was a significant difference between the three treatments (F= 68.22 and p = 2.79 E- 07). Comparing the treatments in pairs, there was a significant difference between CIB-T0 and CIB-T1 (p =0.0002278), CIB-T0 and CIB-T2 (p = 0.0001903) and CIB-T1 and CIB-T2 (p = 0.001534).

Forage biomass production by ATV: fresh material

Figure 5 summarizes the results of the observations on maize forage biomass production in the green carpet system (fresh matter).

The results presented in this figure 5 show that ATV-T2 differs from the other treatments with an average production of 11.8 tonnes of fresh matter per hectare (tMF/ha) followed by ATV-T1 (11.0 tMF/ha) and finally, the lowest yields were produced by ATV-T0 (6.4 tMF/ha). There was a significant difference between the three treatments (F= 118 and p = 1.28 E- 08). Comparing the treatments two by two, there is a significant difference between ATV-T0 and ATV-T1 (p =0.0001904), ATV-T0 and ATV-T2 (p = 0.0001903) and ATV-T1 and ATV-T2 (p= 0.001051)

Forage biomass production by ATV: dry matter

Figure 6 summarizes the results of the findings on maize forage biomass production in the green carpet system (dry matter).

The results presented in this figure 6 show that ATV-T2 deviates from the other treatments with an average production of 8.4 tonnes of dry matter per hectare (DMt/ha) followed by ATV-T1 (7.1 DMt/ha) and finally, the lowest yields were produced by ATV-T0 (4.5 DMt/ha) (F= 118 and p = 1.28 E-08). Applying Tukey's test to compare the treatments two by two, we find that there is the significant difference between all three treatments.

Forage biomass production by ATV: fresh material

Figure 7 summarizes the results of the observations on *Pennisetum purpureum* forage biomass production in the green carpet system (fresh matter).

The results presented in this figure 7 show that ATV-T2 differs from the other treatments with an average production of 36.2 tonnes of fresh matter per hectare (tFM/ha) followed by ATV-T1 (29.1 tFM/ha) and finally, the lowest yields were produced by ATV-T0 (21.8 tFM/ha). There was a significant difference between the three treatments (F= 7.369 and p = 0.008173). Comparing the treatments two by two, there is a significant difference between ATV-T0 and ATV-T2 (p = 0.006306).

Soil return biomass

Quantity of maize biomass returned to the soil by the CIB: fresh material

Figure 8 shows the results of the observations on maize soil biomass production in the slash-and-burn system (fresh material).

The results presented in this figure 8 explain that CIB-T2 takes the lead over the other treatments with an average production of 8.1 tonnes of fresh matter per hectare (tFM/ha) followed by CIB-T1 (5.2 tFM/ha) and finally the lowest yields were produced by CIB-T0 (4.1 tFM/ha). There is a significant difference between the three treatments (F= 7.378 and p = 0.008137). Comparing the treatments in pairs, there is a significant difference between CIB-T0 and CIB-T1 (p = 0.005095), CIB-T0 and CIB-T2 (p = 0.0001903) and CIB-T1 and CIB-T2 (p = 0.0001903).

Amount of biomass returned to the soil by the CIB: dry matter

Figure 9 illustrates the results of the observations on maize soil biomass production in the slash-and-burn system (dry matter).

The results shown in this figure 9 explain that CIB-T2 takes the lead over the other treatments with an average production of 5.7 tonnes of dry matter per hectare (DMt/ha) followed by CIB-T1 (3.7 DMt/ha) and finally the lowest yields were produced by CIB-T0 (2.9 DMt/ha). There was a significant difference between the three treatments (F= 109.6 and p = 1.96 E-08). Comparing the treatments two by two, there is a significant difference between CIB-T0 and CIB-T1 (p =0.005858), CIB-T0 and CIB-T2 (p = 0.0001903) and CIB-T1 and CIB-T2 (0.0001903).

Amount of maize biomass returned to the soil by ATV: fresh material

Figure 10 shows the results of the observations on the soil biomass production of maize in the green carpet system (fresh matter).

The results shown in this figure 10 explain that ATV-T2 is far superior to the other treatments with an average production of 9.4 tonnes of fresh matter per hectare (tFM/ha) followed by ATV-T1 (6.3 tFM/ha) and finally the lowest yields were produced by ATV-T0 (4.4 tFM/ha). There was a significant difference between the three treatments (F= 66.34 and p = 3.26 E-07). Comparing the treatments in pairs, there is a significant difference between ATV-T0 and ATV-T1 (p = 0.0003118), ATV-T0 and ATV-T2 (p = 0.0001903) and ATV-T1 and ATV-T2 (p = 0.002196).

Amount of maize biomass returned to the soil by ATV: dry matter

Figure 11 shows the results of the observations on maize soil biomass production in the green carpet system (dry matter).

The results shown in figure 11 clearly show that ATV-T2 is superior to the other treatments with an average production of 6.7 tonnes of dry matter per hectare (tDM/ha) followed by ATV-T1 (4.5 tDM/ha). The lowest yields were found in ATV-T0 (3.1 tDM/ha). There was a significant difference between the three treatments (F= 64.71 and p = 3.73 E-07). Comparing the treatments in pairs with Tukey's test, there was a significant difference between ATV-T0 and ATV-T1 (p =0.0003118), ATV-T0 and ATV-T2 (p = 0.0001903) and ATV-T1 and ATV-T2 (p = 0.002196).

Amount of Pennisetum *purpureum* biomass returned to the soil by ATV: dry matter

Figure 12 shows the results of the observations on maize soil biomass production in the green carpet system (dry matter).

The results shown in figure 12 clearly show that ATV-T2 is superior to the other treatments with an average production of 51.9 tonnes of dry matter per hectare (tDM/ha) followed by ATV-T1 (44.6tDM/ha). The lowest yields were found in ATV-T0 (38.3 tDM/ha). There was a significant difference between the three treatments (F= 6.918 and p = 0.01004). Comparing the treatments in pairs with Tukey's test, there was a significant difference between ATV-T0 and ATV-T2 (p = 0.007801).

Discussion

Forage biomass

Biomass quantities varied significantly between the two production systems (p < 0.05). The average biomass amount (20.1tDM/ha) of two production systems produced by *Pennisetum purpureum* was significantly higher than that produced by *Zea mays* (1.3 times). The ranking of these different species in relation to biomass production would be as follows: *Pennisetum purpureum*>*Zea mays*. This is lower than that found by Ntamwira (2021) (29.3 tDM/ha). High above-ground biomass production is of interest for the production of organic matter and fodder.

Biological nitrogen fixation by diazotrophic bacteria associated with *Pennisetum purpureum* as hypothesised by Kirchhof et al (2001) could play an important role in the nitrogen supply of this crop in poor soils. In addition, some plant species can have high productivity due to good assimilation coefficients, good photosynthetic activity and well adapted root development. However, yields cannot increase significantly on degraded soils without fertiliser. In the Sudanian region of Benin, a higher biomass of *Pennisetum purpureum* was recorded in fields that were fertilised for cotton crop production (Kirchhof et al, 2001).

Soil return biomass

Looking at the results, we notice that the restitution biomass varied significantly between species independently of the production system (p < 0.05).

Pennisetum purpureum (22.5 tDM/ ha) and *Zea mays* (4.8 tDM/ ha) had significantly higher average root indices in both production systems than *Zea mays* in the green carpet plate crop (4.1 tDM/ ha). This could be explained by the fact that *Pennisetum purpureum* had high weights of underground parts and a large number of roots in the ATV.

This is interesting for the improvement of the soil texture by increasing the pore size and thus favouring the penetration of many roots. In contrast, *Zea mays* produces a large underground biomass with a limited number of roots in both production systems. However, this species would be more interesting for fodder production.

Conclusion

At the end of this research work, it was found that the ATV production system used with chemical fertilisers and composts yielded a large amount of both fodder biomass and soil restitution. The different treatments also contributed to the improvement of the fertility of the treated soils. Thus, it appears that treatment T2 (compost with NPK 17- 17- 17) raises the fertile potential of the soil by increasing the organic matter produced by the different biomasses. The biomasses produced also contributed to the improvement of the soil's nutrient potential. The fallows are effective but less efficient than composts and chemical fertilisers associated with the ATV system. These results obtained on experimental plots, if confirmed on the farm, will make a low-cost but high agronomic value production system.

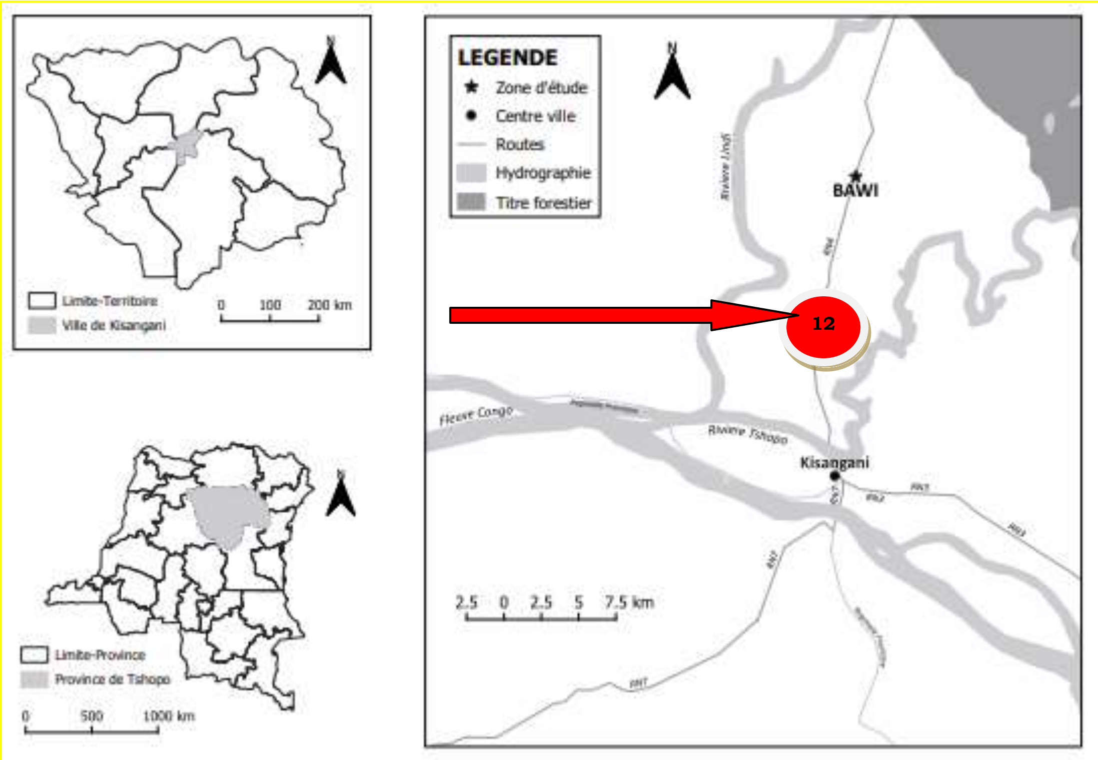

Figure 1. Map of the location of the experimental site

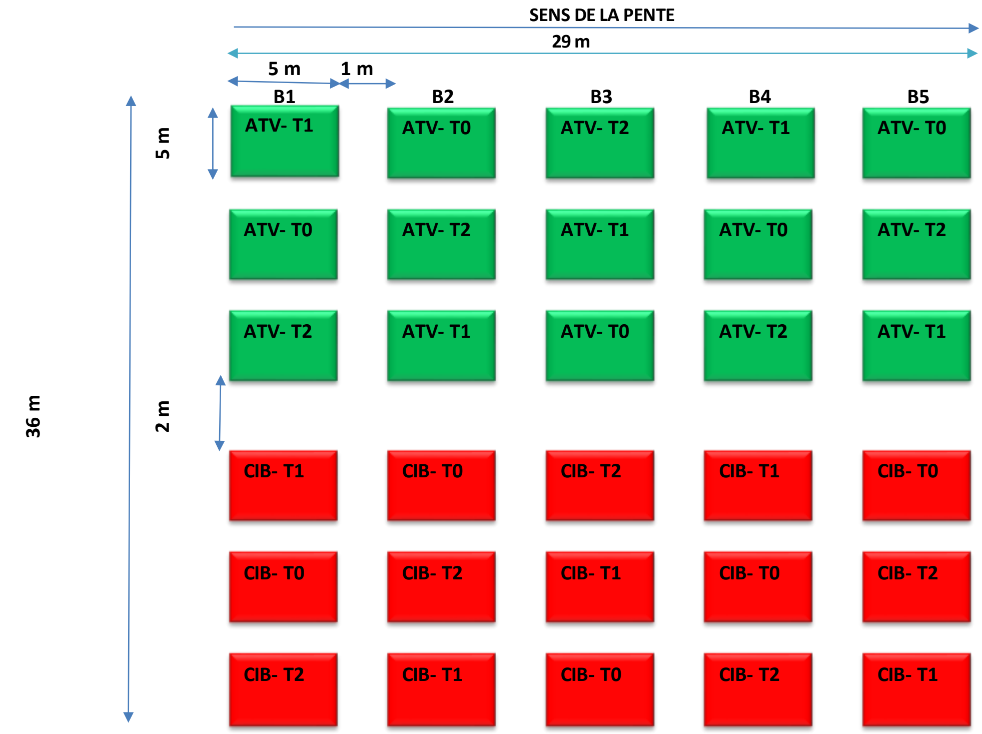

Figure 2. Experimental set-up

Legend

ATV-T0 = 0 kg of mineral fertilizer per hectare, but with a low dose of pig manure (5t/ha), with half of the *Pennisetum purpureum* biomass and *Acacia auriculoformis* litter removed from the field to be composted and then reapplied, with the other half forming the mulch in the ATV system;

ATV- T1 = 50 kg of NPK fertilizer per hectare, combined with compost made from manure (5t/ha) and green carpet prunings (half *Pennisetum purpureum* biomass + half *Acacia auriculoformis* litter), the other half forming the mulch in the ATV system;

ATV- T2 = 100 kg of NPK fertilizer per hectare combined with manure-based compost (5t/ha) and green carpet prunings (half *Pennisetum purpureum* biomass + half *Acacia auriculoformis* litter), the other half forming the mulch in the ATV system;

CIB-T0 = 0 kg of fertiliser per hectare, but with a low dose of pig manure (5t/ha), the herbaceous biomass from the clearing being burnt beforehand, providing fertilising ash;

CIB-T1 = 50 kg NPK fertilizer/ha combined with a low dose of pig manure (5t/ha), the herbaceous biomass from the clearing being burnt beforehand, providing fertilising ash;

CIB-T2 = 100 kg NPK fertiliser/ha combined with a low dose of pig manure (5t/ha), the grass biomass from the clearing being burnt beforehand, providing fertilising ash.
B1...B5 = Blocks

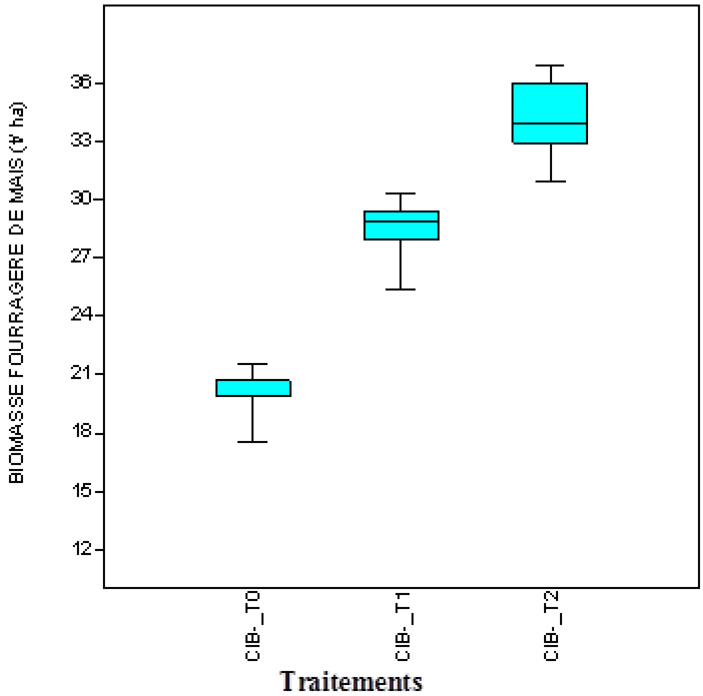

Figure 3. Forage biomass production from maize: fresh matter

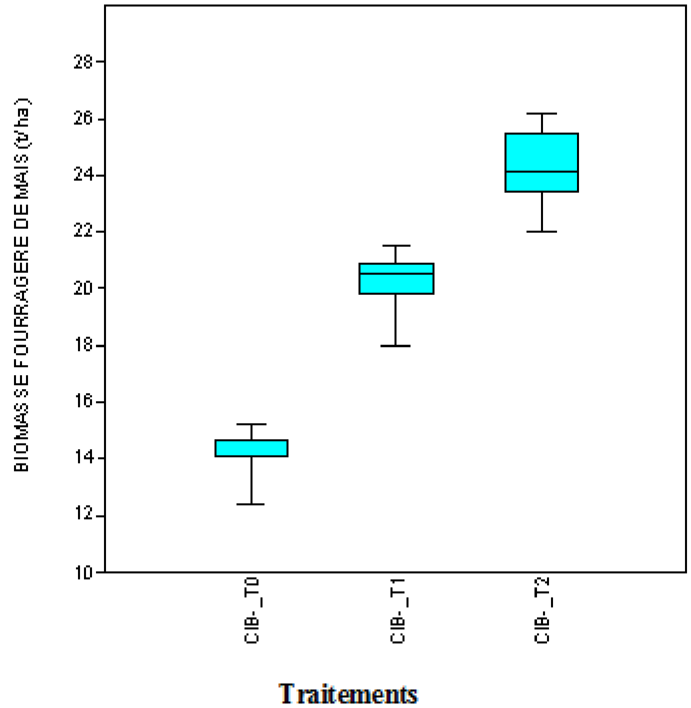

Figure 4. Production of maize fodder: dry matter

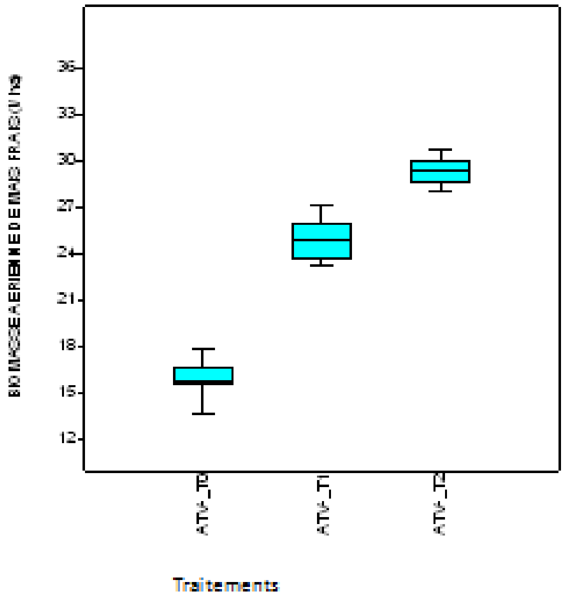

Figure 5. Production of maize forage biomass by ATV: fresh matter

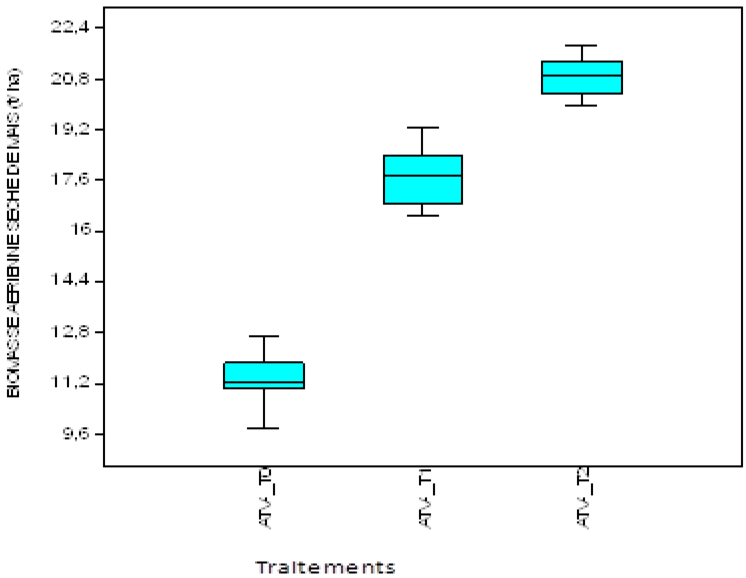

Figure 6. Forage biomass production from maize: dry matter (DM)

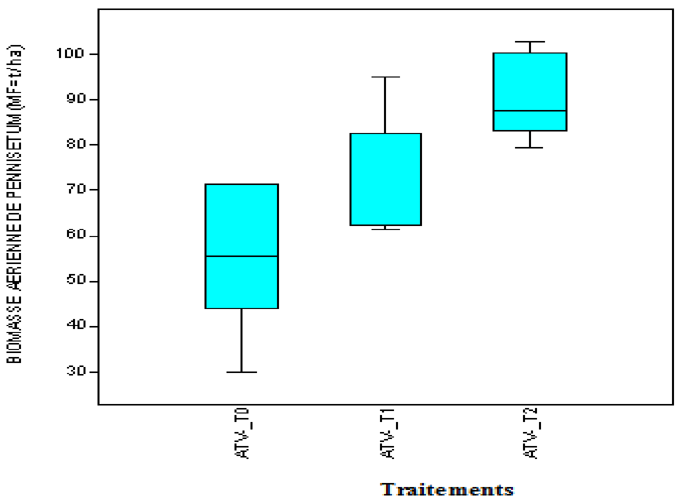

Figure 7. Production of *Pennisetum purpureum* forage biomass by ATV: fresh matter

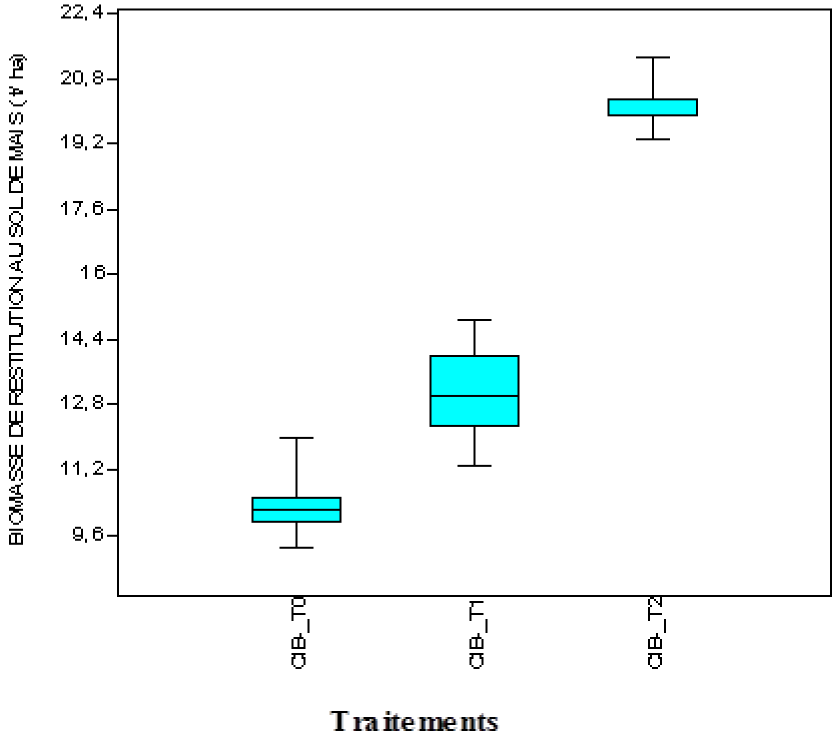

Figure 8. Production of maize soil biomass: fresh matter (CIB)

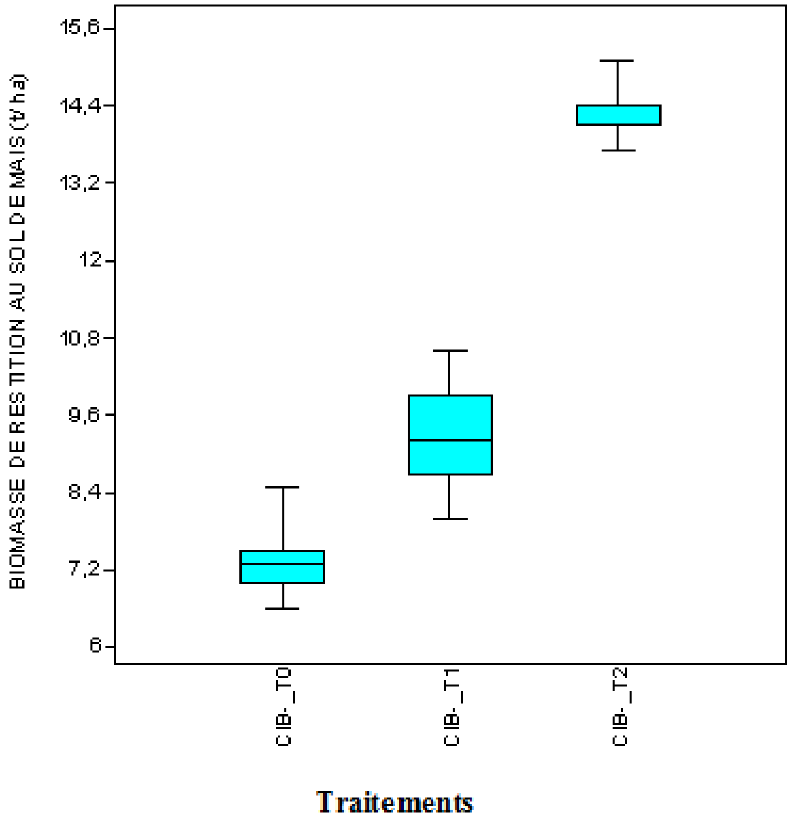

Figure 9. Maize soil biomass production: dry matter (DM)

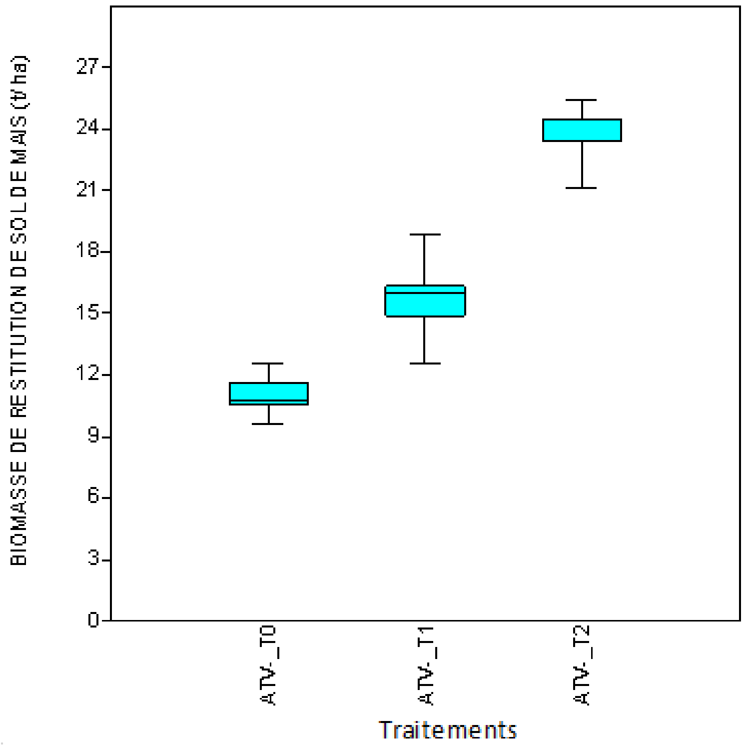

Figure 10. Maize soil biomass production: fresh matter (ATV)

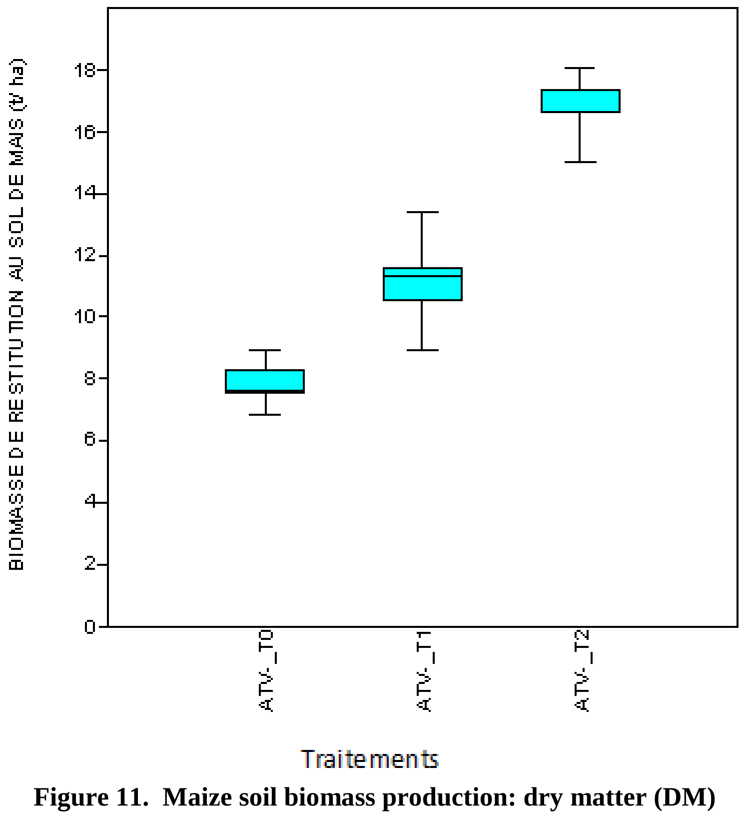

Figure 11. Maize soil biomass production: dry matter (DM)

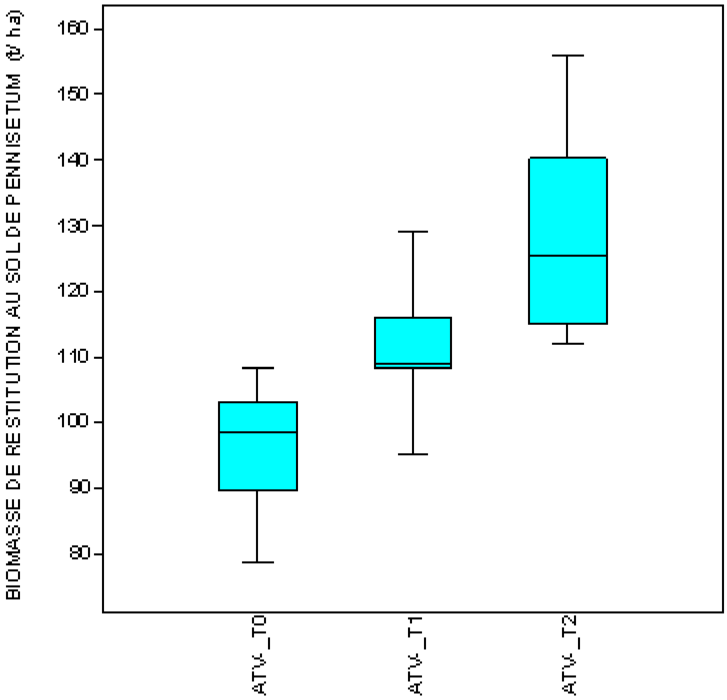

Figure 12. *Pennisetum purpureum* soil biomass production: dry matter (DM)

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