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Effect of a Typical Organo-Mineral Fertilization and of the Green Carpet Cropping System with *Acacia Auriculoformis* Cunn Ex Benth and *Pennisetum Purpureum* K. Schum on the Growth and Yield of *Zea mays* L. in the Hinterlands of Kisangani, Tshopo (DRC)

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ABSTRACT

Faced with soil impoverishment due to the population explosion, a study was undertaken on maize cultivation at kilometer point 12 in the hinterlands of the city of Kisangani. The objective was to test, on degraded soil, the effect of a small amount of pig manure, integrated with the compost of hedge trimmings from the green carpet and enriched with increasing microdoses of NPK, on the growth and yield of maize grown in the Plates under Green Carpet (ATV) system. The experimental design was a split-plot, with the first factor being the production systems (ATV and CIB) and the second, the fertilisers. The results showed that organo-mineral fertilisation under ATV influenced the duration of the vegetative and reproductive phases in addition to yield. The organo-mineral fertilisers under ATV with composts resulted in a yield that was 1.2 times higher than that obtained with the control and the CIB. Also, the organo-mineral manures under ATV tended to shorten the crop cycle and promote better plant growth and development. The use of these fertilizers in maize cultivation could constitute an alternative to the drastic consequences of soil degradation.

Introduction

Population growth in many tropical regions has led to the overexploitation of land and the shortening of fallow periods, with the corollary of too little restitution of nutrients exported by the crops. This results in the degradation and decline of production potential, especially in tropical fertile soils that are confronted with increased anthropogenic pressure and farming systems that are highly destructive to the natural heritage (Igué et al., 2013; Maliki et al., 2017).

Overgrazing, deforestation, extension of cultivation to fragile soils and degradation of cultivated land are particularly accentuated by demographic pressure (Pyame, 2015; Roose, 2018; Ntamwira, 2021), resulting in drastically reduced agricultural income, human undernourishment, malnutrition and chronic rural poverty.

Maize (*Zea mays*) is a food crop, a cereal grown all over the world, mainly for its grains. In some regions, it is an incomparable source of carbohydrates, one of the essential nutrients required to maintain a living organism. It is considered to be the most widely grown cereal in the world (Pierre, 2016; Joanis, 2018) and, together with rice, forms the two most widely consumed cereals (PSRSA, 2011).

Despite the considerable importance of this crop and its increasing demand, maize productivity is still low. Thus, some producers continue to have yields of less than 0.5 t/ha, compared to potential yields of 3 to 5 t/ha, or even 10 t/ha, depending on whether or not they use mineral fertilisers (Azontondé et al, 2010). In addition to climatic hazards and pests, low maize productivity is largely due to declining soil fertility (Azontondé et al, 2009; Maliki et al, 2017). Indeed, 90% of the world's cultivated land shows degradation leading to a decline in productivity. This is due to the abandonment of the traditional mode of fertility restoration based on long fallows of 15 years for very short fallows of 2 to 5 years (Gaiser et al, 2011; Maliki et al, 2017).

Today, agroforestry is increasingly recommended as a strategy for sustainable management of agrosystems, especially in tropical areas threatened by uncontrolled deforestation. The concept of agroforestry is essentially based on the ability of woody soil improvers to restore soil fertility more rapidly through the removal of nutrients from the lower soil layers and their restitution through litter, but also through nitrogen fixation, in the case of the use of woody legumes (Torquebiau, 2007; Atangana et al, 2014; Yusufu, 2020).

However, several aspects of this important approach seem to have been overlooked and deserve more attention. These include the search for the optimal time for agroforestry systems to restore soil fertility, the recognition of the major role of organic matter on fertility and crop yields. Research is therefore needed to elucidate the main factors in the adoption of agroforestry by farmers in the tropics.

The problem underlying this research is the low and uncertain productivity of the slash-and-burn system, which maintains unproductive forest/mixed fallows that are

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unsuitable for agricultural mechanisation, agricultural-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 focus for the research, a research question is formulated below, followed by the related hypothesis and objective.

Given the crowding of herbaceous hedgerows in the ATV system and especially the shading of tall trees in dense plantations, will the effect on maize yield of composting agroforestry prunings under NPK input be comparable to that obtained under IPC?

Under conditions of low organo-mineral input, maize cultivation between *Pennisetum purpureum* and *Acacia auriculoformis* hedges (ATV system), pruned severely and composted by half, leads to a grain yield at least comparable to that under CIB.

The objective of this research is to test, on degraded soils, the effect of a small amount of pig manure, integrated with the compost of hedge prunings from the green carpet and enriched with increasing microdoses of NPK, on the growth and yield of maize grown in the ATV system.

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).

Collection of data on growth parameters and yield

To measure the growth rate and yield of maize, the following variables were used: crown diameter, plant height and grain yield.

The average collar diameter was obtained by indexing by the diagonal method, 5 plants on each of two randomly selected plots per treatment. Values were obtained (in mm) by caliper measurement and an average was obtained per treatment.

Plant height was also measured with a metric tape measure (in cm) from the crown to the stem apex.

The weight of the maize kernels harvested from each plot was determined, over the entire experimental set-up, using a 20-kilogram suspension scale with an accuracy of 50 g. The yield is calculated by the following formula:

$$\mathbf{R = (P \times 10{,}000\ m^2) / 25\ m^2} \qquad \mathbf{(1)}$$

Where R: yield in Kg/ha and P: average weight of grains (in kg) harvested on 25 m^2.

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

Statistical analysis

The data of the different variables (treatments) were entered in Excel, which also allowed the establishment of different graphs. The Past software 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

Effects of treatments on maize plant neck diameters (mm)

Figures 3 (A, B, C) below show the evolution of maize plant neck diameters as a function of treatments and number of days respectively the growth curve of average maize neck diameters in mm (0 Kg NPK), the growth curve of average maize neck diameters in mm (50 Kg NPK) and the growth curve of average maize neck diameters in mm (100 Kg NPK).

From these figures, it can be seen that plate cultivation under green carpet, compared to slash-and-burn cultivation, gives higher average diameters both in the zero treatment (F= 135. 6 and p = 8.79 E- 71), T1 (F= 184. 8 and p = 9.89 E- 82) and T2 (F= 480 and p = 5.46 E- 118). After taking neck diameters of the different samples in the different plots, it was found that the production system (ATV) had the highest average diameters in all treatments, while the lowest were recorded with the CIB system.

For all the treatments studied, the diameter at the crown increased from day 15 to day 60.

At 60 days after sowing, the neck diameters of maize plants in the organo-mineral fertiliser treatments showed statistically equivalent mean values (25 - 27 mm) and higher than those in the no fertiliser, T0 - CIB and T0 - ATV treatments (16 - 18 mm).

Effects of treatments on maize plant heights (cm)

Figures 4 (A, B, C) below show the evolution of the heights according to the treatments and the number of days respectively the growth curve in average heights of maize plants in cm (0 Kg of NPK), the growth curve in average heights of maize plants in cm (50 Kg of NPK) and the growth curve in average heights of maize plants in cm (100 Kg of NPK).

It is clear from these figures that slash-and-burn cultivation gives higher average heights for the zero treatment (F= 966. 8 and p = 5.38 E- 146), T1 (F= 4559 and p = 1.02 E- 209) and T2 (F= 5255 and p = 1.32 E- 215).

After the height measurement on day 15, it was found that the ATV production system had the highest average height while the lowest was recorded with the CIB production system. The height measurement 15 days later, on day 30, again revealed the same trend with the highest average height still being with the ATV system while the lowest was with the CIB system for all treatments. For the 3rd and 4th heights, we observed a rapid rise in growth with the ATV-T2 (113.3 - 164.7 cm) and CIB-T2 (102.3- 136.1 cm). CIB-T0 (88.6- 101.7 cm) and ATV-T0 (103.5- 115.9 cm) had the lowest average heights.

Effect of different fertility management practices on grain yield of maize

The effect of different fertility management practices on maize grain yields in the experimental site is presented in Figure 5 (A, B, C) below giving maize production per tonne per hectare (0 Kg NPK), maize production per tonne per hectare (50 Kg NPK) and maize production per tonne per hectare (100 Kg NPK) respectively.

From these figures it is clear that the green carpet paddy cultivation (GCP), compared to slash-and-burn cultivation (SBC), gives higher yields both in the zero treatment (0 Kg NPK), T1 (50 Kg NPK) and T2 (100 Kg NPK) (3.2 t/ha vs. 2.1t/ha; 5.2 t/ ha vs. 3.4 t/ ha and 5.9 t/ ha vs. 4.9 t/ ha, respectively). Maize grain weight varied from 3.5 kg (CIB-T0) to 17.5 kg (ATV- T2).

In general, the results show that maize grain yield varied significantly among the management modes in each treatment. The highest yield was obtained in the green carpet plots followed by the organo-mineral fertiliser combination and the lowest by the slash and burn system.

The yield level achieved by the different maize treatments used in this trial ranged from 2.1 t/ha (CIB- T0) to 5.9 t/ha (ATV- T2). The results of the statistical analysis presented showed significant differences between the treatments (F= 14. 99 and p = 1.03 E- 06). According to the Tukey multiple comparison test performed in pairs, there was high significant difference between ATV-T_0 and CIB-T_0 (p = 0,03935), CIB-T_0 and ATV-T_1 (p = 0,0001698), CIB-T_0 and ATV-T_2 (p = 0,0001394), ATV –T1 and CIB-T_1 (p = 0,01636), CIB-T_1 and ATV-T_2 (p = 0,001315). The yields obtained could be higher if factors such as pests had not had direct impacts on the yield components. This property is of primary importance because, despite the export of above-ground biomass, the incorporated and well-distributed roots, especially on degraded soils, are both a net supply of nutrients and a reliable agent of root gallery development and structural stability for the subsequent crop.

Discussion

Growth parameters

The effects of the different fertilisers on growth parameters were remarkable. The plants that received the organic and mineral fertilisers showed a strong growth vigour in height as well as in diameter at the collar, in particular, those treated with the composts whatever the treatments. This finding highlights the availability of mineral elements in organic fertilisers for growth and development of field crops and as for maize through organo-mineral inputs (Muyayabantu et al, 2012; Siéné et al, 2020). Moreover, the results obtained in plants that received mineral fertiliser and composts could be explained by the primordial role that assimilable phosphorus released into the soil by this fertiliser plays in growth and development, as well as in plant metabolism and energy transport (Ouédraogo et al, 2014, Siéné et al, 2020). Thus, the low level of nutrient reserves observed during the analysis of soil samples from the control plots would explain the major cause of the poor height growth performance of maize observed on these plots.

The plants emitted their entire leaf just before the appearance of the male flower, regardless of the treatment. This result corroborates those obtained by Siéné et al (2018), who showed that in maize, leaf emission stops a few days before the appearance of the male panicle while the plant stem continues to grow. Similarly, according to Diatta (2007), water stress applied during the reproductive phase only affects grain yield, as there is no more leaf emission and the plant has reached its maximum number of leaves. In maize, senescence remains under the influence of reproductive functioning (Borras et al., 2003). Water stress can only accelerate leaf senescence. These observations corroborate the fact that composts promote good growth and development of maize. Our cultivation conditions would therefore have influenced maize productivity.

Maize grain yield

From the point of view of crop yield, organic manures and mineral fertilizer improved the yield values of the different treatments relative to the controls. According to Mulaji (2011), one of the promising ways to increase crop production in the farming community is to apply different types of organic matter and mineral fertilisers to the soil in order to increase the availability of nutrients in the soil for plants. Moreover, the yield obtained with maize plants fertilized with composts (ATV) and manures (CIB) respectively 4.8 t/ha and 3.5t/ha, lower than that found by Ntamwira (2021) respectively 5.6 t/ha and 4.1 t/ha, higher than that found by Siéné et al, 2020 with chicken droppings (2.8 t/ha) and (3.039 t/ha) and Gomgnimbou et al. (2019) with organic manure consisting of chicken droppings at a rate of 5 t/ha. The low yield of the control plants could be explained by the poor soil nutrient status coupled with the water deficit recorded during the reproductive phase. This water deficit alone can lead to a loss of 20 to 25 percent of the yield and up to 60 percent if the up to 60 percent if the stress occurs at the critical period (20 days before flowering and continues for 10 days after). During this period, maize mobilises 45 percent of its water requirements. The grain filling process is then slowed down or even blocked (Hiema, 2005). Indeed, according to Yang and Zhang (2006) and Aslani and Mehrvar (2012), late sowing of cereals under water deficit conditions and high temperatures during the grain filling phase leads to an increase in the proportion of small and immature grains.

Conclusion

The study conducted to test, on degraded soil, the effect of a small amount of pig manure, integrated with the compost of hedge trimmings from the green carpet and enriched with increasing microdoses of NPK, on the growth and yield of maize grown in the ATV system, gave promising results. It showed the impact of the organo-mineral fertilisers used on maize productivity. Regarding the duration of the vegetative and reproductive phases, organo-mineral fertilisers under ATV had a positive effect. The ATV production system was more affected by the different treatments during the reproductive phase compared to the IPC production system. The different organic and mineral fertilisers affected growth parameters and maize yield differently. Regarding plant growth parameters, the organo-mineral fertiliser under ATV clearly stood out from the others. It accelerated the growth of collar diameter and the height of the maize plants. The strong vegetative development caused by this manure resulted in rapid senescence of the leaves recorded from flowering to the end of the cycle. Organo-mineral fertilisation under ATV also showed a tendency to shorten the crop cycle. Yields under the ATV production system (4.8 t/ha) were higher than those under the CIB production system (3.5 t/ha), regardless of fertiliser. In addition, mineral fertilisers with manures (CIB) improved yields compared to the controls. The yields were 2.3 times higher than those of crops without manure. Mineral fertilisers with composts (ATV) were the most effective under our growing conditions. They gave a yield that was 1.9 times that obtained with the ATV control. Their use in maize cultivation could constitute an alternative to the drastic consequences of soil degradation.

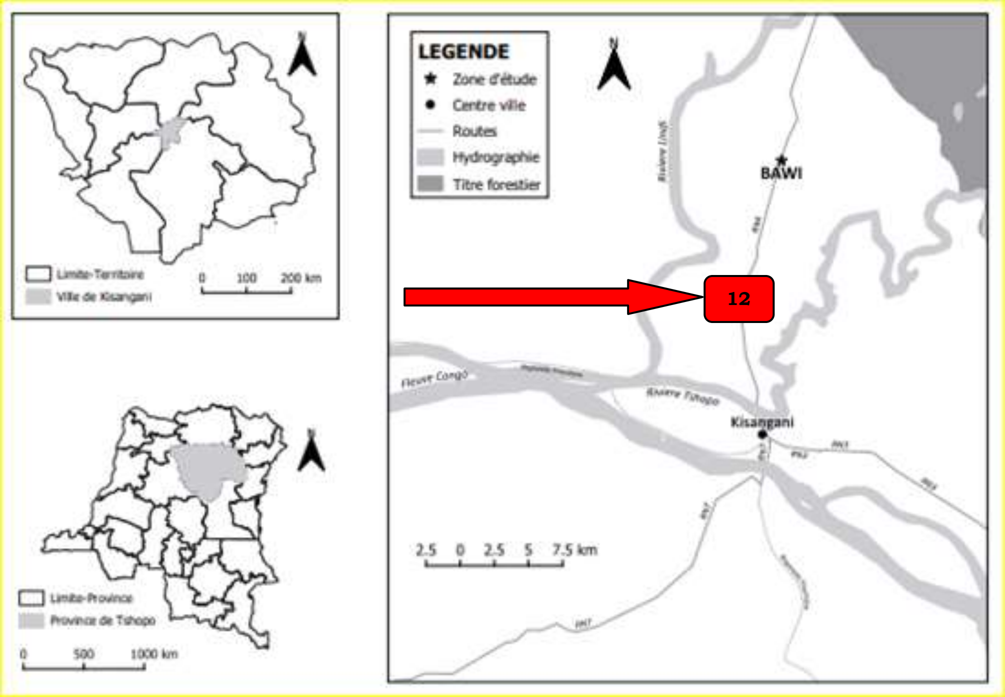

Figure 1. Map of the location of the experimental site

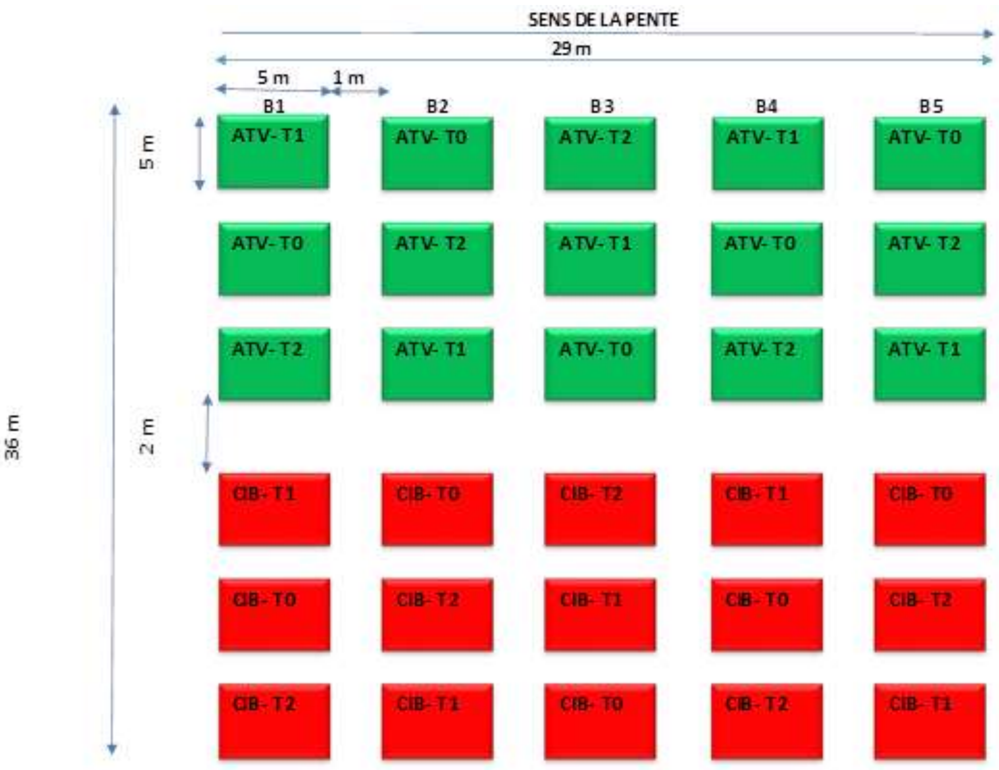

Figure 2. Experimental set-up

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

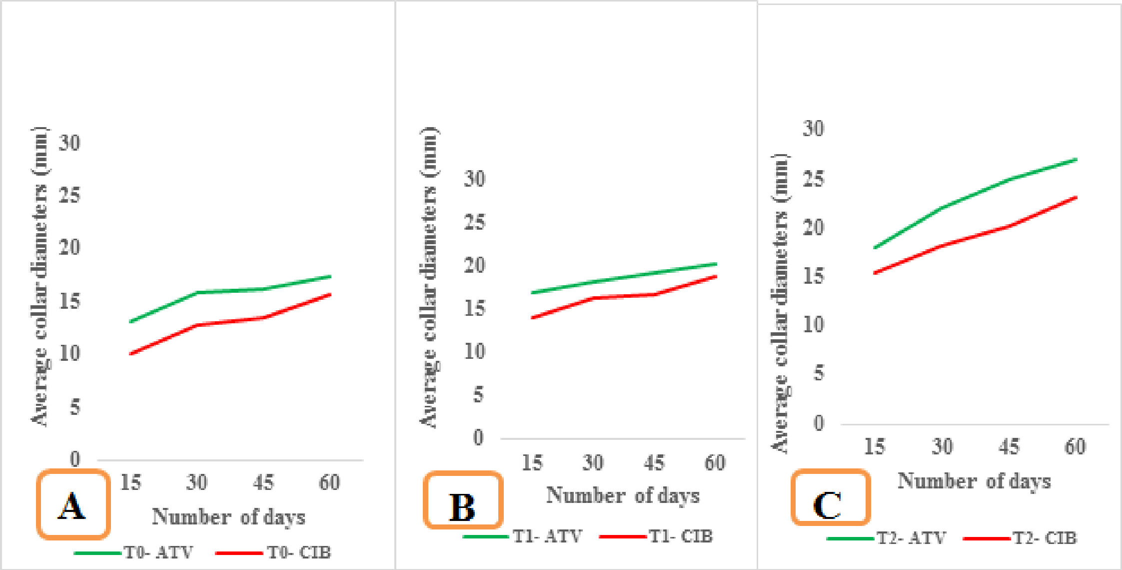

Figure 3. (A, B, C). Evolution of growth of average maize crown diameter (0 Kg NPK) (A), Evolution of growth of average maize crown diameter (50 Kg NPK) (B) and Evolution of growth of average maize crown diameter (100 Kg NPK) (C) in the maize experimental field contrasting green mat and slash-and-burn systems.

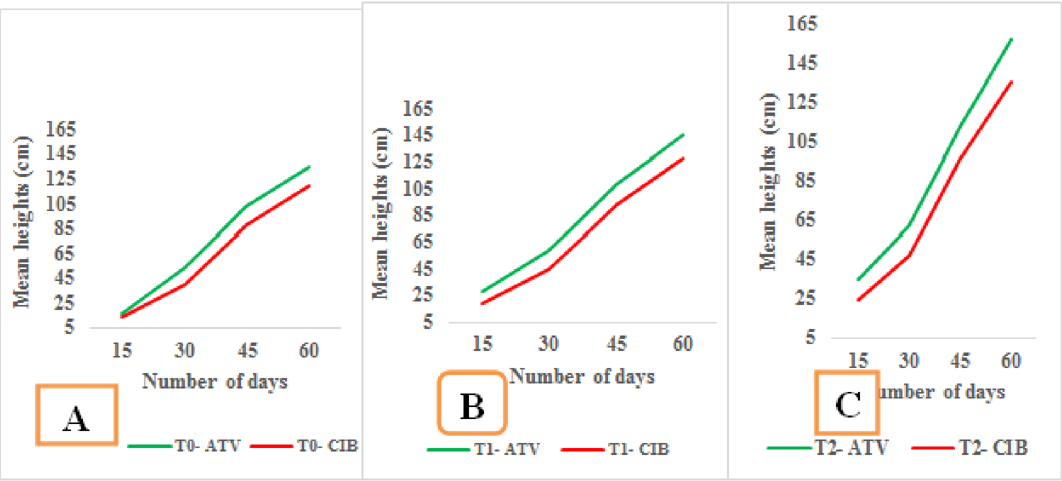

Figure 4. (A, B, C). Evolution of growth in mean height of maize plants (0 Kg of NPK) (A), Evolution of growth in mean height of maize plants (50 Kg of NPK) (B) and Evolution of growth in mean height of maize plants (100 Kg of NPK) (C) in the experimental maize field, contrasting the systems of cultivation under green mats and slash-and-burn cultivation

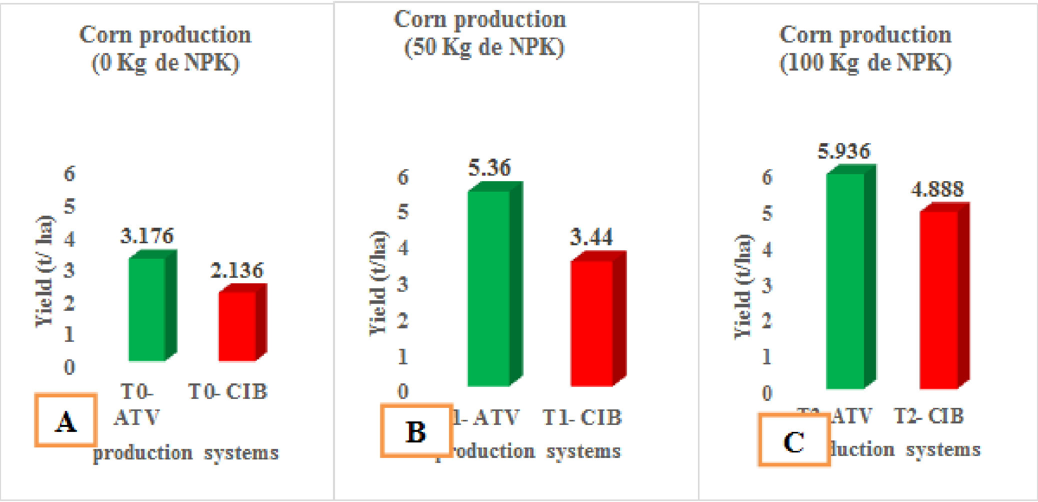

Figure 5. (A, B, C). Maize production per tonne per hectare (0 kg NPK) (A), maize production per tonne per hectare (50 kg NPK) (B) and maize production per tonne per hectare (100 kg NPK) (C) in the maize field experiment between green cover and slash and burn systems.

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