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Efficiency of Legumes in Increasing Yam Yield under Sandy Ferrasol in the Forest Zone of Southwestern Côte d'Ivoire

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Abstract

The cropping system is based on traditional farming in rural areas. In this way, yields of some food crops like yam are very low considering their high need for nutrients. The nutrient-rich land is under high land pressure as it is occupied by cash crops such as oil palm and rubber at the expense of food crops and soil fertility is declining. The study was conducted in Grand-Lahou to assess the effect of organic matter provided by legumes in increasing yam yield. The randomized complete block design included four (4) treatments: *Arachis hypogaea* + yam association (T1), *Acacia mangium* + yam association (T2), Arachis + *Acacia mangium* + yam association (T3) and pure yam crop (T0). The parameters measured were: the soil nutrients content, the rate of mineralization of organic matter through the C/N ratio as well as the yield of yam through different techniques that allowed the objective of the study to be achieved. It was noted a slight improvement of nitrogen and organic carbon in all treatments with a higher value recorded in the T2 treatment. The C/N ratio decreased to 12 in all treatments compared to the control, which reflects a normal decomposition of the organic matter. Treatment T1 increased yam yield (8.4 t/ha) in contrast to treatments T2 (4.1 t/ha) and T3 (2.8 t/ha). Legume-based treatments T2 and T3 were associated with a significant decrease in yam yield, resulting in losses of −46.34% to −25.09%, while treatment T1 resulted in a gain of 28.57%. As a result, the treatments involving legumes contributed to normalizing the organic matter content of the soil. The simultaneous association of these two legumes led to a decrease in yam production, contrary to the treatment associating only groundnut.

Keywords

Legumes, Organic Matter, Yam Yield, Côte d'Ivoire

1. Introduction

In Sub-Saharan African countries, agriculture is characterized by low productivity. This reality is explained on the one hand, by the natural poverty of soils, and on the other hand, by the strong demographic pressure exerted on cultivable land [1] [2]. According to [2], 20% of soils in the tropical area are already degraded. These degraded lands constitute threats to the food security of populations. It is, therefore, necessary to find efficient alternative solutions according to agroecological zone, allowing to improve and maintain the fertility of degraded tropical soils. This includes the use of tree legumes, and nitrogen-fixing plants (legumes), either in association with crops or as fallow land improvement. Indeed, tree legumes fix atmospheric nitrogen and have proven to be effective in ensuring sustainable protection, improving soil fertility and increasing agricultural production [3]. In addition to fixing atmospheric nitrogen and maintaining soil fertility, legumes have other benefits: protection of soils against erosion; improvement of soil microclimate and physical characteristics; contribution to better management of species biodiversity; reduction of weed pressure; and improvement of soil water reserves [4]. Several studies have shown that tree legumes can restore the soil by managing organic matter. Indeed, in the Ivorian coastal zone, coconut palm/*Acacia auriculaeformis* and *Acacia mangium* associations [5] [6] [7] [8] have increased organic matter levels by improving the production of coconut plantations (doubled without nitrogen fertilization). But few studies have associated a tree legume and food to improve the fertility of degraded soils and increase crop yields in Côte d'Ivoire. This study was initiated in the region of Grand-Lahou, where soil fertility is under severe stress with the development of cash crops (oil palm, rubber) to the detriment of food crops. However, in a context where the Ivorian policy has placed emphasis on the development of food crop production, producers of Grand-Lahou region cultivate on islands without fallowing and these soils become poor in organic matter. In the absence of fertilization, yields are low, particularly for plants such as yam. This study is based on the principles of the agroecological system to improve soil fertility and its objective is to assess the effect of organic matter provided by legumes to increasingly sustain yam yields.

2. Materials and Methods

2.1. Materials

The study was conducted in N'Gorankro 1, a small village located in the northeast of Grand-Lahou region, around 10 km from the main town. The study site is located between latitudes 5˚15'0''N - 5˚30'33'0''N and longitudes 5˚0'W - 5˚15'W. The plant materials used for the study consisted of *Acacia mangium* (**Figure 1**), improved yam from International Institute of Tropical Agriculture (IITA, Ibadan, Nigeria) introduced in Côte d'Ivoire by Centre Suisse de Recherches Scientifiquesen Côte d'Ivoire (**Figure 2**) and local peanut (**Figure 3**).

Figure 1. *Acacia mangium.*

Figure 2. Improved yam tuber seed.

Figure 3. *Arachis hypogaea* (local peanut).

2.2. Methods

2.2.1. Soil Preparation

The experimental plot was installed on a low slope (5%). The study was conducted on a strongly acidic sandy textured soil with a low organic matter content. The experimental set-up was installed after staking and ridge shaping. *Acacia mangium* was transplanted into holes after a nursery phase of 1 month. The distance between two *Acacia mangium* plants in the plot is 4 m and the distance between an *Acacia mangium* plant and a ridge line was 1.75 m. The yam seedlings were planted on ridges 12 m long and 0.50 m wide. No chemical fertilizer was applied. Between ridges, two cycles of peanuts were respectively sown per year in 2017, 2018 and 2019.

2.2.2. Experimental Set-Up

The experimental design used for the crop is the randomized complete block design with three treatments as follows:

- Treatment T0: plot without legume (control) + yam;
- Treatment T1: *Arachis hypogaea* + yam association;
- Treatment T2: *Acacia mangium* association (834 trees/ha) + yam;
- Treatment T3: *Arachis hypogaea* + *Acacia mangium* + yam association.

The size of the plots was 3600 m^2 (60 m × 60 m) split into three blocks. Each block is composed of four microplots whose sizes were 144 m^2 (12 m × 12 m). Soil samples were taken before setting the experimental and after the trial to measure changes in soil nutrients, organic matter (OM) and C/N ratio. Yam yields were determined during the three years of cultivation in all treatments in order to assess the most efficient treatment. Soil samples were collected at the feet of three central plants of the legumes in the elementary plot T0, T1, T2 and T3. The samples were taken using PVC tubes 20 cm long and 5 cm in diameter.

Analysis process

Determination of nitrogen was done by the Kjeldahl method and the Carbon (organic) was determined by the method of Walkley and Black.

3. Resultsand Discussion

3.1. Effect of Legumes on Total Nitrogen (N), Carbon (C) and C/N Ratio

The figures represent the values of total nitrogen (N), Carbon and C/N ratio by treatments during the experiment.

3.1.1. Effect of Legumes on Total Nitrogen (N)

Although there was a slight improvement over the nitrogen content of the control soil (T0), the total nitrogen contents were low; significant differences existed between treatments T1, T2 and T3. The highest value was recorded on T2 (**Figure 4**). The increase in nitrogen content in all crops compared to the baseline soil (T0) can be justified by the symbiotic fixation of atmospheric nitrogen. Indeed, legumes have the unique ability to establish a symbiosis with certain bacteria naturally present in the soil, which convert the air nitrogen (N2) present in their environment into an intermediate form, ammonia nitrogen (NH3), thanks to a specific bacterial enzyme, nitrogenase. The nitrogen thus reduced in the form of NH3 is then assimilated by the plant, to constitute its organic molecules, in particular proteins. The nitrogen fixed by legumes is drawn from an abundant resource: the nitrogenous substrate N2. This nitrogen, available in the ambient air, is fixed by the plants thanks to the energy resulting from plant photosynthesis. This natural symbiosis allows the plant to directly use the nitrogen in the surrounding air for its growth. The symbiosis is established within specific root outgrowths, called "nodosities", which host the symbiotic bacteria. The symbiosis is mutually beneficial: the bacteria provide the plant with the fixed N; in return, the plant provides the energy necessary for the synthesis of the nodules and their functioning [9]. The increase in N content could come from the fallout of plant debris especially from leaf fallout. The results proved the increase in nitrogen levels in the litter. The work of [10] helps to confirm our results; indeed for these authors, the previous legumes provided more nitrogen to the subsequent sorghum. The increase in nitrogen content after three years of cultivation may be due to the age of the crop. Most authors report that soils under *Acacia auriculiformis* stands are enriched in carbon and nitrogen. According to [11], it takes some time to observe an increase in nitrogen content because the nitrogen fixed by Acacia accumulates mainly in the biomass of the tree and therefore in the litter. Therefore, it is necessary to wait for the release of nutrients from the litter to take place before there is a significant increase in these elements in the soil. [12] found that Acacia trees are better at enriching the soil with nitrogen and organic matter than other local species.

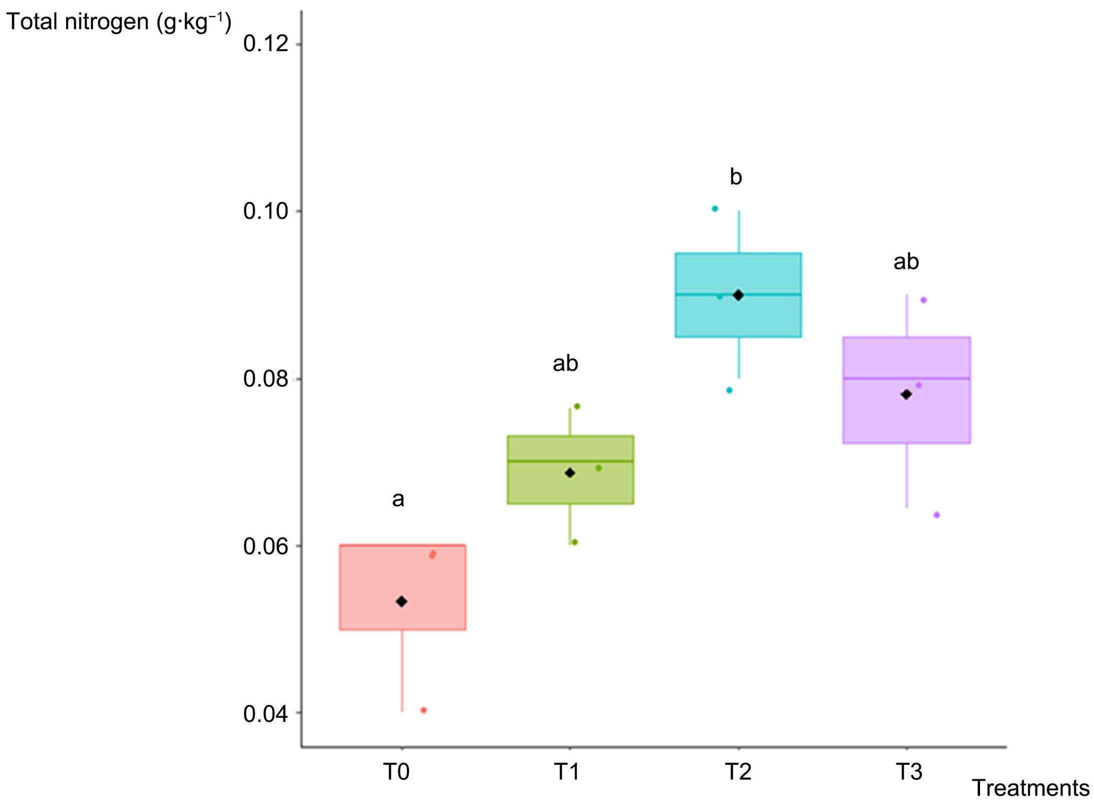

Figure 4. Distribution of total nitrogen content on 0 - 20 cm according to treatments.

3.1.2. Effect of Legumes on Carbon (C)

As for organic carbon, and therefore soil organic matter (SOM) content, it remains, itself, like the total nitrogen content, relatively low, especially for treatment T1. These low contents were not significantly different from the highest contents presented by treatment T2 (**Figure 5**). [13] and [14] found that organic carbon and nitrogen levels increased after 4 years, with a six-fold increase in organic carbon and nitrogen levels in a 17-year-old stand. [11] also notes the increase in soil carbon and nitrogen content after 7 to 9 years. This increase is not observed under younger trees.

[15] also concluded that fallows with *Acacia augustissima*, and in general, fallows with nitrogen-fixing trees, were able to increase soil carbon more significantly than non-nitrogen-fixing species, especially in the long term. The work of [16] showed that using Acacia to restore degraded soils following deforestation was a good idea, since in 13 years they were able to reach the same nitrogen and carbon levels as those present in soils under "natural" forest.

3.1.3. Effect of Legumes on C/N Ratio

The C/N ratio is of great agronomic interest; indeed, it conditions the process of mineralization of organic matter. In the case of this study, the C/N ratio decreased in all legume plots compared to the T0 treatment with a value between 9 and 12 (**Figure 6**). The C/N ratio is of great agronomic interest, as it conditions the mineralization process of organic matter, and also to the supply of nitrogen

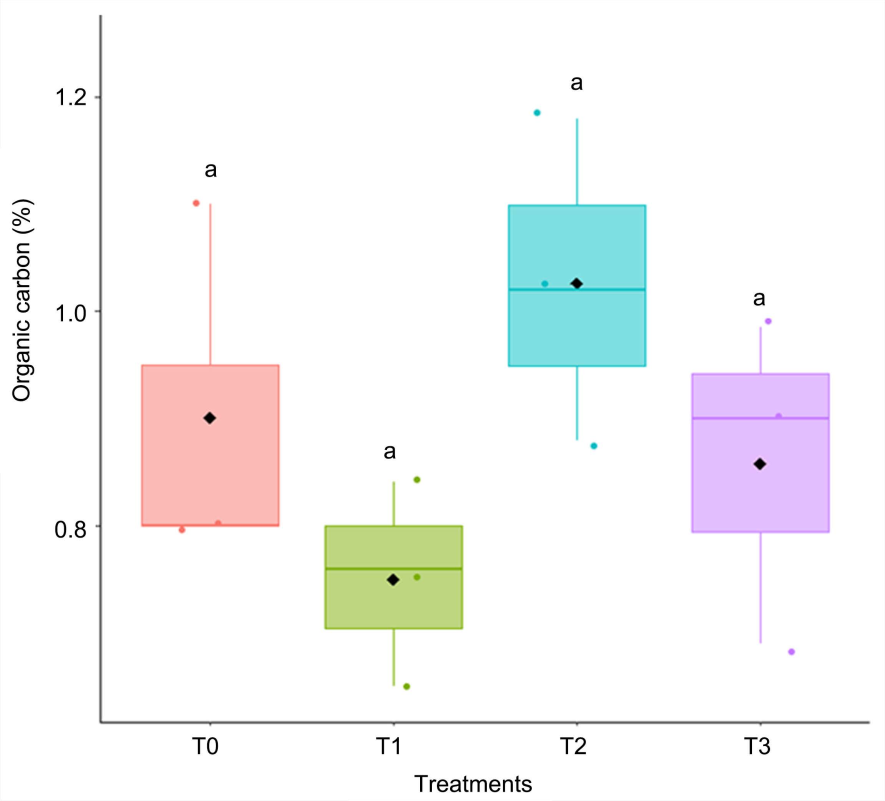

Figure 5. Distribution of organic carbon values on 0 - 20 cm according to treatments.

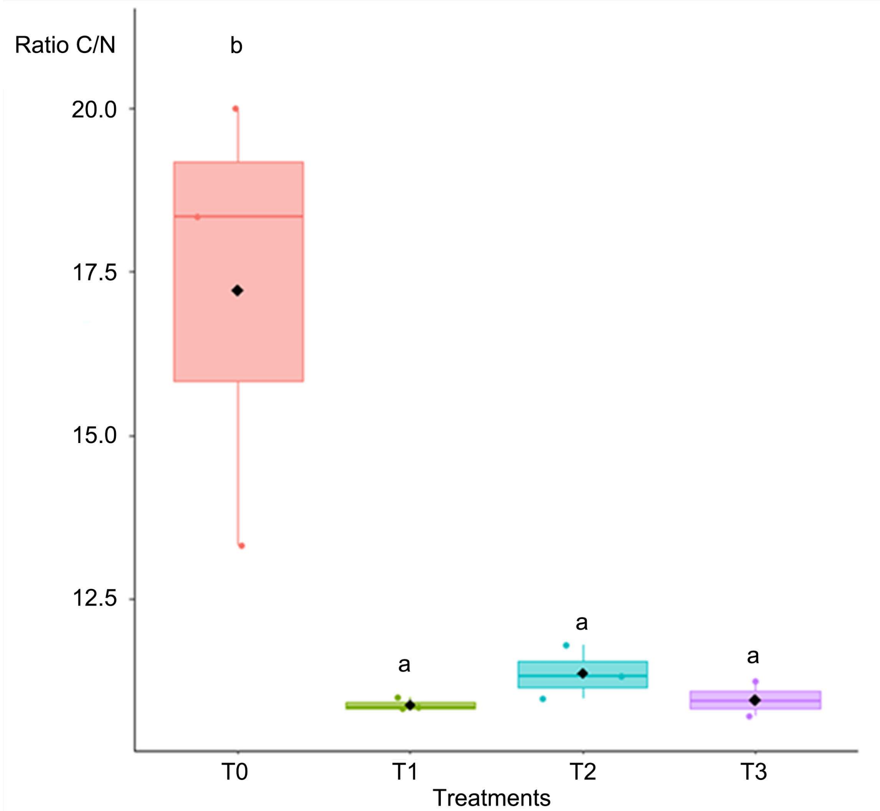

Figure 6. Distribution of C/N values on 0 - 20 cm according to treatments.

to plants. When C/N < 9, the mineralization of organic matter is rapid, which leads to a risk of N loss. When 9 < C/N < 12, it is said to be normal and when C/N > 12, mineralization is stopped and can only occur with an external supply of nitrogen. The results of the C/N ratio analysis indicated that the different treatments (A. hypogaea and A. mangium) improved the mineralization rate of SOM which showed normal C/N ratios (C/N < 12.5). This decrease observed in the different treatments could be due to stand age which is consistent with the work of [13] who had also found a decrease in C/N ratio with stand age.

3.2. Effect of Legumes (*Acacia mangium* and *Arachis hypogea*) on Yam Yield during Three Cycles

Overall, the highest yield was recorded at the level of the plot combining groundnut with yam (T1) with an average of 8.4 t/ha compared to the T2 and T3 treatments. Nevertheless, this is not statically different from the control (without legume input) with a yam yield estimated on average at 6 t/ha (**Table 1**). The significant decrease in yield observed in treatments T2 and T3 could be due to the sedentary nature of the yam crop. Indeed, during the entire experiment, the ridges were made in the same place in the different treatments, which led to a decrease in available nutrients for the yam. Previous studies have shown that yam is a very demanding plant in terms of fertile soils [17]. [18] found the same results, when the prior exploitation of soils in successive crops (2 years) caused a decrease in soil nutrient levels that a single year of fallow was not sufficient to raise to an acceptable level. This overall low yield may be attributed to poor rainfall distribution. The trial was set up late and the rains stopped early, yet yam is water demanding in the first 5 months of cultivation [19]. The low yields obtained in treatments T2 and T3 could also be explained by the effect of *Acacia mangium* shading on the yam ridges, since by 12 months the overall average branch area occupied by *Acacia mangium* was 10.66 m^2. However, the distance between an *Acacia mangium* tree and a ridge was 1.75 m. It is likely that the densities used for the legumes (two rows of food legumes interspersed between two rows of yam ridges and two acacia rows 4m apart) are inappropriate for yam. Yield reductions in yams could be partly due to the soil slice of the ridges (0 - 40 cm). Indeed, the yams in the associated culture were sown on the 50 cm high ridges resulting from the turning of the soil in the 0 - 40 cm slice which is less rich in organic elements such as organic carbon (0.9%) and total nitrogen (0.6%).

3.3. Determination of Yam Yield Gains in the Different Treatments

The yield gains observed in the different treatments are presented in **Table 2**. Treatment T1 resulted in a gain of 28.57%, while treatments T2 and T3 showed losses of −46.34% and −25.09%, respectively, compared to the T0 control. The study observed in treatments T2 and T3. The yield losses recorded in the treatments associating *Acacia mangium* with yam and associating *Acacia mangium* + yam + groundnut show that the association is not profitable. This highlights the problem of planting density in *Acacia mangium.* The work of [7] also showed that the associations caused a decrease in the yields of yam and food legumes compared to pure crops. These losses were reportedly due to the planting density of *Acacia mangium*. This indicates that an appropriate distance of the trees from the associated crops must be adopted in order to benefit from the presence of the trees for the restoration of soil fertility.

Table 1. Yields of yam by treatment and year.

Treatment	Yield in year 2017 ($t{\cdot}ha^{-1}$)	Yield in year 2018 (t/ha)	Yield in 2019 ($t{\cdot}ha^{-1}$)	Average yield ($t{\cdot}ha^{-1}$)
T0	8 ± 0.08 a	6 ± 0.46 a	4 ± 0.02 b	6 ± 0.12 a
T1	10 ± 0.51 a	8.5 ± 0.63 a	6.7 ± 0.9 a	8.4 ±0.51 a
T2	7 ± 0.35 a	3 ± 0.37 b	2.5 ± 0.02 c	4.1 ±0.11 b
T3	6 ± 0.00 a	2 ± 0.00 b	0.5 ± 0.00 d	2.8 ±0.00 c
Pr > F	0.350	0.000	<0.0001	0.007

In the same column, the means followed by the same letter are not significantly different. T0: control treatment with no legume + yam input, T1: groundnut + yam input: *Acacia mangium* + yam input, T3: groundnut + *Acacia mangium* + yam input.

Table 2. Average values of yam yield gains (%) compared to the control.

Treatments	Averageyields (%)
T1	28.57 a
T2	−46.34 b
T3	−25.09 a
Pr > F	0.007

In the same column, the means followed by the same letter are not significantly different T0: control treatment with no legume + yam input, T1: groundnut + yam input: *Acacia mangium* + yam input, T3: groundnut + *Acacia mangium* + yam input.

4. Conclusion

The *Acacia mangium* + *Arachis hypogaea* + yam (T3) treatment improved soil pH by 0.83 units. High litter fall was observed in the *Acacia mangium* treatments. The legume system improved nitrogen levels and enhanced the soil mineralization process through litter recycling for sustainable soil fertility management. In this study, the treatments combining *Acacia mangium* with yam resulted in a decrease in yam production contrary to the treatments combining *Arachis hypogaea* with yam or an increase in yam production. In perspective, readjust distances between *Acacia mangium* and food crops for better productivity.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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