



International Journal of Research in Agronomy

E-ISSN: 2618-0618
P-ISSN: 2618-060X
© Agronomy
NAAS Rating (2026): 5.20
www.agronomyjournals.com
2026; 9(6): 1070-1075
Received: 11-03-2026
Accepted: 15-04-2026

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Evaluation of the effects of a mixture of biochar and cow manure on the stability of yields of maize associated with peanuts during two growing seasons in farmer field schools in Yaselia

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DOI: <https://www.doi.org/10.33545/2618060X.2026.v9.i6n.5825>

Abstract

The Yaselia Farmer Field School evaluated the effects of a mixture of biochar and cow manure on the yield stability of maize intercropped with groundnuts over two growing seasons, in a context of severe soil fertility degradation in the Democratic Republic of Congo (DRC). An even-numbered block design with two treatments (control and biochar + manure) and three replications was implemented. Amendments were applied before sowing, and crop management was uniform throughout the trial. The main agronomic parameters measured were emergence, growth (height), yield components (ear weight and structure, pod weight), and grain yields of maize (*Zea mays* L.) and groundnut (*Arachis hypogaea* L.), expressed in kg/ha after moisture correction.

The results showed that the biochar-manure mixture improved corn plant height, ear weight, number of rows per ear, and grain yield. Corn yield increased from 2614.78 kg/ha in the control to 3101.06 kg/ha in the biochar-manure treatment during season A, representing a gain of 486.28 kg/ha (approximately +18.6%). During season B, yield increased from 1616.48 kg/ha (T_0) to 2129.94 kg/ha (T_1), representing a gain of 513.46 kg/ha (approximately +31.8%). In absolute terms, the yield increase is therefore similar between the two seasons (approximately 500 kg/ha), but the relative gain is greater in season B. Treatment with biochar enriched with cow manure improved peanut performance, resulting in increased pod weight and seed yield. In season A, seed yield increased from 1536.49 kg/ha (control) to 3008.33 kg/ha (biochar-cow manure treatment), representing a gain of 1471.84 kg/ha (approximately 95.8%). In season B, it increased from 799.03 kg/ha (T_0) to 910.39 kg/ha (T_1), representing a gain of 111.36 kg/ha (approximately 13.9%). The use of the biochar-cow manure mixture is an important way to improve the productivity and resilience of local peasant farming systems, while also justifying further research to refine doses, assess interannual variability and document long-term economic and environmental impacts.

Keywords: Effects, Biochar, cow manure, stability, yields

Introduction

Soil fertility degradation remains a major limiting factor for agricultural productivity in sub-Saharan Africa, particularly in humid tropical zones where the intensification of agricultural practices is often accompanied by rapid soil depletion (Vanlauwe *et al.*, 2015) ^[12]. In the Democratic Republic of Congo, this situation is exacerbated by low mineral fertilizer inputs, land pressure, declining organic matter, and the repeated use of poor agricultural practices (FAO, 2020) ^[3]. In this context, finding local, sustainable, and economically accessible solutions is essential to improving food security and the resilience of smallholder farms.

Maize (*Zea mays* L.) is one of the main food crops in the DRC, thanks to its significant contribution to human and animal nutrition, while groundnut (*Arachis hypogaea* L.) plays an important role in dietary diversification, household income, and soil fertility due to its nitrogen-fixing capacity (Giller, 2001). Maize-groundnut intercropping is a common practice among African farmers, as it allows for better use of light, water, and nutrients, while reducing some of the risks associated with monoculture (Rusinamhodzi *et al.*, 2012) ^[10]. However, despite its advantages, this intercropping does not always guarantee stable yields, especially when soils are

poor and organic matter inputs remain insufficient.

Among organic amendments capable of sustainably improving soil productivity, biochar is attracting increasing interest. Produced by biomass pyrolysis under low-oxygen conditions, it is recognized for its stability in the soil and its positive effects on several edaphic properties, including water retention capacity, nutrient availability, and soil biological activity (Lehmann and Joseph, 2015) [7]. Its use is particularly relevant in tropical agricultural systems where organic matter is rapidly mineralized and nutrient losses are significant. Furthermore, cow manure constitutes an abundant and readily available source of organic matter and fertilizing nutrients for farmers (Palm *et al.*, 2001) [9]. The incorporation of biochar and cow manure could produce a synergistic effect on soil fertility and the stability of agricultural yields. Indeed, several studies have demonstrated that biochar can reduce nutrient losses, improve the efficiency of organic fertilizer use, and prolong the availability of mineral elements in the soil, while manure rapidly provides plants with essential nutrients (Agegnehu *et al.*, 2017) [11] and contributes to the development of soil structure. This combination therefore appears as a promising option for family farms seeking low-cost technologies adapted to local conditions and capable of improving the sustainability of production systems.

In farmer field schools, which represent a participatory approach to extension and learning based on real-world experimentation,

the evaluation of these innovations becomes crucial. This method promotes the adoption of improved practices by farmers and strengthens local analytical and decision-making capacities (Davis *et al.*, 2012) [2]. In Yaselia, where soil and climatic conditions as well as farming practices can vary significantly from one season to the next, it becomes essential to identify strategies capable not only of increasing yields but also of stabilizing them over several growing seasons.

This study aimed to evaluate the effects of a biochar mixture loaded with cow manure on the yield stability of maize intercropped with peanuts over two growing seasons in the Yaselia farmer field schools. It analyzed the impact of this organic amendment on agricultural production over two seasons and determined the extent to which it can contribute to more resilient, sustainable agriculture better adapted to local communities.

Materials and methods

Study site

The study was conducted in Tshopo Province, Turumbu sector, Yelongo group, more specifically in the Yaselia farmer field school supported by the FORETS project (CIFOR-ICRAF) in the Yangambi landscape. The Yaselia CIFOR-ICRAF farmer field school is located in the Turumbu sector, Yelongo group, in the village of Yaselia in the Yangambi landscape (24°33'37.7"E, 0°46'05.4"N).

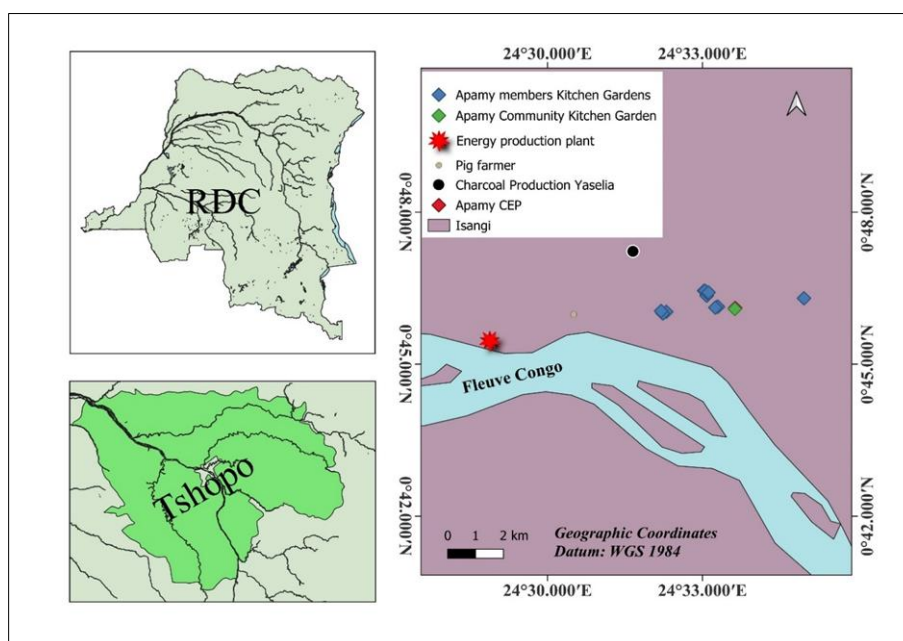


Fig 1: Map of the Yaselia peasant school field in the Yangambi landscape

Materials

Maize and peanut seeds were used to establish the maize-peanut intercropping system. They were essential for studying the effect of this intercropping system on soil production and resource use. Biochar was the primary soil amendment studied. Its use helped improve soil structure, retain water, and promote nutrient availability. Well-rotted cow manure was mixed with the biochar as an amendment to stimulate crop growth, provide nutrients, reduce soil acidity, and improve its organic matter content. Hoes, shovels, and picks were used for soil preparation and application of the biochar. A measuring tape was used to delineate plots, measure crop spacing, and plant height. An electronic scale was used to weigh the biochar, manure, seeds, and harvested crops, ensuring accurate measurements. Labels and identification diagrams were used to identify each experimental plot,

minimizing the risk of error and ensuring accurate monitoring throughout the study. Field notebooks and data collection forms were used to systematically record observations, measurements, and data throughout the research. Furthermore, the Global Positioning System (GPS) was used to precisely determine the geographic coordinates of the Yaselia study site and to support the accurate characterization and description of the study area.

Methodology

Experimental setup

The trial was set up at the Yaselia farmers' field school according to a paired block design. The study comprised two treatments and three replications. Each plot measured 4 x 6 m, for a total area of 24 m², and each treatment was replicated three times. This allowed for minimizing the effect of soil heterogeneity and

enabling statistical analysis of the results. The two treatments represented contrasting fertility management strategies: (i) a control (no inputs) and (ii) a soil amendment composed of loaded biochar. The amendments were applied uniformly to the designated plots before sowing to ensure consistent application of the treatments. The experiment included six plots amended with loaded biochar. This experimental design allowed for a direct comparison of crop and soil responses under conventional conditions (control and loaded biochar).

Preparation and application of organic amendments

In this study, two types of organic amendments were used: biochar derived from charcoal fines from charcoal production and well-decomposed cow manure. For each treated plot, 24 kg of biochar were mixed with 24 kg of cow manure, for a total of 48 kg of organic amendment per plot.

The mixture of biochar and cow manure was homogenized and then left to rest for five (5) days before application. This loading process allows for the absorption of nutrients from the manure by the biochar, the stabilization of organic matter, and microbial activation, thereby improving the agronomic effectiveness of the amendment after its incorporation into the soil. The experimental design comprised six (6) plots, each with an area of 24 m². Three (3) of these plots received loaded biochar (treatment), while the other three (3), without any application, served as controls. The amendments were spread manually on each plot that received loaded biochar, followed by light tillage to facilitate its incorporation into the experimental soil. This operation was carried out before sowing.

Vegetative parameters and yield components

Measurement of agronomic parameters

Agronomic parameters were measured on plants located in the center of each plot, excluding plants at the edges to avoid edge effects. Observations focused on emergence, plant height, number of ear rows, and grain yield, expressed in tonnes per hectare, after moisture correction. Observations were made every 7 days.

The collection rate is determined by the following formula:

$$\text{Lifting rate} = \frac{\text{Nombre de grains ayant levé par parcelle} \times 100}{\text{Nombre total de grains semés}}$$

The height of the plant

The height of the corn was measured at harvest to determine the final height of each target plant. Ten plants, randomly selected from the center of the field, were chosen per plot to be representative of that plot, according to the following rule: each selected hole must contain two live corn plants. For each selected hole, one plant is systematically chosen at random.

Number of rows of grains per ear (rows)

The number of rows of kernels per ear of corn was determined by direct observation of ears harvested at physiological maturity. Each ear was cleaned to clearly distinguish the rows of kernels, and then the number of longitudinal rows was counted manually along the entire length of the ear. This operation was repeated on a representative sample of ears for each treatment. The values obtained were then recorded and the average calculated to obtain a reliable estimate of the average number of rows per ear.

Grain yield

Corn grain yield was chosen as the primary criterion for evaluating the agronomic performance of the studied system. This

parameter directly reflects crop productivity for the different experimental treatments. The harvested grains were dried, weighed, and expressed in kilograms per hectare to allow for consistent comparison between treatments. Measurements were taken using electronic balances and a standardized moisture content of 14%, corresponding to the standard for preserving corn grains. A sample of 100 grains per plot was weighed, placed in an oven for 72 hours, and then weighed again after drying to determine the dry weight of grains produced per plot.

The formula used is: Dry weight of grains =

$$\frac{\text{Poids frais à récolte de grains} \times \text{poids sec de 100 grains}}{\text{Poids à récolte de 100 grains}}$$

Peanut

The measurements focused on the weight of the pods and the seed yield per hectare.

All these variables have allowed us to appreciate the effect of treatments on the agronomic performance of the maize-peanut association and to link this performance to the changes observed in soil properties.

The weight of the pods

The weight of the peanut pods was determined after harvesting and drying to obtain more stable and reliable measurements. The harvested pods were first cleaned to remove debris, soil, and foreign matter that could influence the weighing. This step ensured that only the actual weight of the pods was recorded. After cleaning, the pods were weighed using an electronic balance. Pods from selected 10-foot plots were weighed, and the total weight of harvested pods was recorded to calculate the yield. The seeds were weighed after sun-drying for three days to determine their harvest weight. A 200g sample of seeds was placed in an oven for 72 hours and then weighed to determine the dry weight of seeds produced per plot.

Seed yield per hectare

Peanut seed yield was determined by dividing the quantity of shelled seeds obtained after harvest by the cultivated area of 24 m², expressed in kg/hectare. To this end, ten (10) peanut plants were randomly selected from each experimental unit to minimize bias related to plot heterogeneity. After harvest, the pods of the selected plants were separated and then shelled to extract the seeds. These seeds were then weighed using an electronic balance to determine their final mass. To standardize the measurements and eliminate the effect of variations in moisture content on yield, the harvested seeds were oven-dried for 72 hours until their mass stabilized. After drying, the seeds were weighed again to obtain their dry mass. Seed yield was then estimated from the ratio of the dry mass to the initial fresh mass of the seeds harvested from the ten sampled plants.

Dry mass of seeds

$$= \frac{\text{masse fraîche de graines à récolte} \times \text{masse sèche des graines}}{\text{masse fraîche de graines à récolte}}$$

Results and Discussion

Corn growth and yield parameters

Corn emergence rate

During season A, the corn emergence rate (Fig. 2) was 86% for the control (T₀) and 85.6% for the biochar-enriched treatment (T₁), a difference of 1%. During season B, this rate was 88.3% for the control and 90.3% for the treatment, representing a gain of 2 percentage points with the biochar-enriched treatment. These

differences between seasons and the contradictions between seasons show that the amendment has no effect on corn emergence. The comparative analysis of corn emergence rates between the two growing seasons and between treatments showed no statistically significant difference between the treatments ($p > 0.05$).

This is consistent with data from the literature, where the effects of biochar are primarily observed on growth, nutrition, and post-emergence yield rather than on germination capacity (Yeboah *et al.*, 2025) [14]. Favorable initial soil physicochemical conditions and appropriate sowing conditions likely promoted adequate germination and emergence in all treatments, resulting in the lack of a significant effect of the loaded biochar compared to the control during the early growth phase.

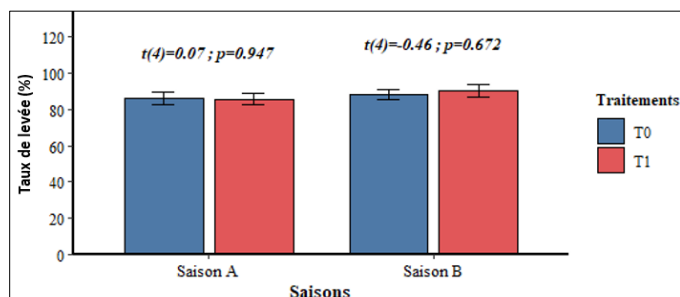


Fig 2: Corn emergence rate

Height of corn plants

During season A, the average height of the maize plants (Fig. 2) increased from 1.58 m in the control to 1.77 m in the biochar-loaded treatment, representing a gain of 0.19 m (approximately 12%). During season B, the height increased from 1.48 m (T_0) to 1.66 m (T_1), a gain of 0.18 m (approximately 12%). These results demonstrate a positive and stable effect of biochar-loaded maize on vegetative growth over two seasons. This increase in height is consistent with the improvement in fertility parameters observed during season A (slightly higher pH, increased P, Ca, Mg, and CEC) and with the yield gains. The comparative analysis showed a statistically significant difference between the treatments of the two growing seasons ($p < 0.05$).

Studies by Yeboah *et al.* (2025) [14], Gao *et al.* (2025) [4], and several review studies show that biochar, especially when combined with organic and mineral inputs, significantly improves the height, stem diameter, and biomass of maize plants, thanks to improved nutrient availability and soil structure (porosity, water retention). The approximately 12% increase observed here falls within the range of "moderate" effects reported in contexts with reasonable doses of biochar, thus confirming the agronomic consistency of the results.

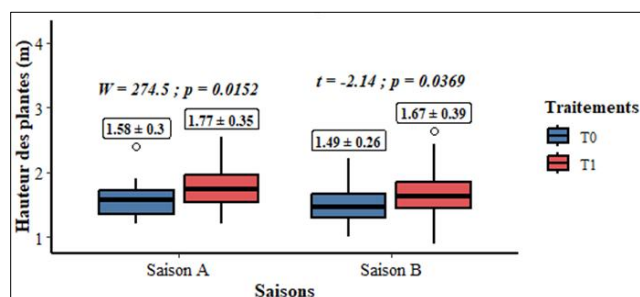


Fig 3: Height of corn plants

Weight of corn ears

The average weight of the corn ears (Fig. 4) increased during

season A, from 0.89 kg in the control to 1.09 kg in the biochar-loaded treatment, an increase of 0.20 kg ($\approx +22.5\%$). During season B, it increased from 0.98 kg (T_0) to 1.15 kg (T_1), an increase of 0.17 kg ($\approx +17.3\%$). The treatment significantly increased ear weight in both seasons, with the effect being slightly more pronounced in season A, which corresponds to the period when fertility parameters (P, Ca, Mg, CEC) were highest. The comparative analysis showed a statistically significant difference between the treatments applied in seasons A and B ($P < 0.05$). These results were consistent with the work of Uzoma *et al.* (2011) [11], which showed that biochar, especially when based on manure or combined with compost, increases ear length, the number of kernels per row, and the 1000-kernel weight, resulting in increased ear weight and yield. The 17–22% increase in ear weight observed in this study is therefore consistent with the literature (Cox *et al.*, 2020), while remaining lower than the very high effects reported in some very high-dose trials. It confirms that biochar-manure does indeed improve the components of maize yield.

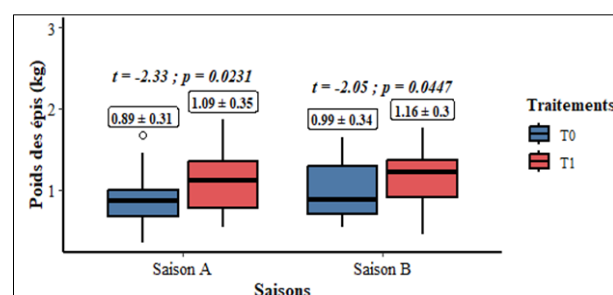


Fig 4: Weight of ears of corn

Number of rows of corn ears

During season A, the number of rows per ear of corn was eleven (11) for the control and Thirteen (13) rows were observed in the biochar-laden treatment, representing an increase of two (2) rows (approximately 18.2%). In season B, this number increased from ten (10) (T_0) to eleven (11) (T_1), representing an increase of one row ($\approx +10\%$). This increase in the number of rows of ears indicates an improvement in ear structure and grain count potential, which is a key component of yield. The statistical analysis showed a significant difference between the treatments amended with biochar laden with cow manure and the unamended control for season A. However, the analysis did not show any differences between the amended treatments and the unamended control for the season ($p = 0.05$).

The biochar-loaded soil improved P, K, Ca, and N nutrition, thus promoting better flowering, more efficient fertilization, and optimal grain formation (Uzoma *et al.*, 2011) [11]. The increase observed in season A compared to season B is consistent with the better nutrient availability and higher cation exchange capacity (CEC) observed in season A, confirming that ear structure is linked to soil fertility. Figure 5 shows the number of rows per ear.

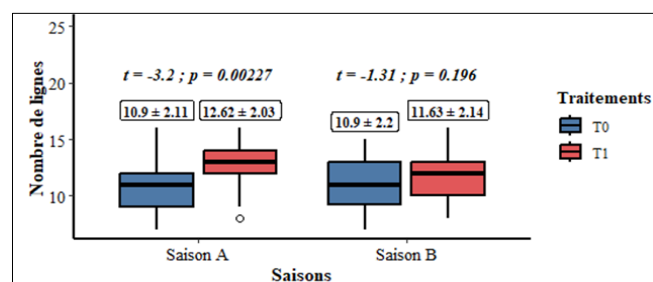


Fig 5: Number of rows of corn ears

Corn grain yield

Maize grain yield increased from 2614.78 kg/ha in the control to 3101.06 kg/ha in the biochar-loaded treatment during season A, representing a gain of 486.28 kg/ha ($\approx +18.6\%$) (Figure 6). During season B, it increased from 1616.48 kg/ha (T_0) to 2129.94 kg/ha (T_1), an increase of 513.46 kg/ha ($\approx +31.8\%$). The absolute yield increase was similar in both growing seasons, with an average gain of approximately 500 kg ha⁻¹. Despite this similarity, the proportional yield response was more pronounced in season B. Statistical analysis revealed slight differences between the treatments and the control from one season to the next; however, these variations were not significant at the significance level of $P = 0.05$.

These values fall within the range of yield increases reported for moderate doses of biochar combined with fertilizers. Yeboah *et al.* (2025) [14], for example, showed maize yield increases of 105–127% under a treatment integrating biochar, compost, and mineral fertilizer, while Gao *et al.* (2025) [4] and Kätterer *et al.* (2019) [5] reported increases of 10–50% depending on the amount and context. The 18–32% observed in this study indicates a positive agronomic response to the application of loaded biochar. Although the magnitude of this response is lower than that reported in other studies using higher doses of biochar and more integrated nutrient management systems, the results nevertheless demonstrate the potential of this amendment to improve crop productivity. Furthermore, the consistency of the improvements observed for key yield-related traits, such as ear weight, number of rows of grains per ear and plant height, as well as the increase in grain yield, provide strong evidence of the reliability and biological relevance of the measured treatment effect.

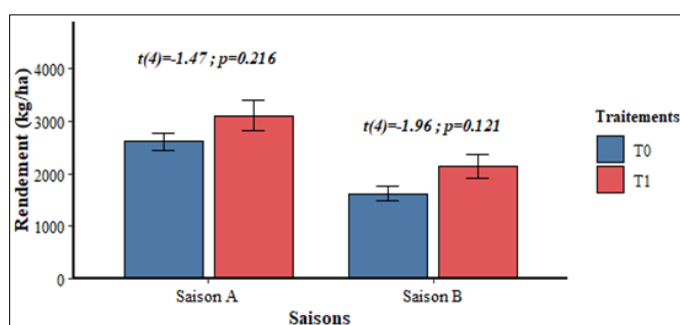


Fig 6: Corn grain yield

Peanut growth and yield parameters

Peanut emergence rate

Peanut emergence rate (Fig. 13) was 91% for the control and 94.33% for the biochar-manure treatment in season A, then 87.33% for the control and 84.66% for the treatment in season B. The increase from 91% to 94.33% in season A (approximately 3.7%) and the decrease from 87.33% to 84.66% in season B (approximately -3.1%) show that the effect of biochar-manure on peanut emergence rate is small and inconsistent. Overall, the amendment does not significantly alter the emergence rate of this crop. Comparative analysis showed no statistically significant differences between treatments ($P > 0.05$).

This result is consistent with the observations of Mendoza (2023) [8] and Zhang *et al.* (2016), who reported marked effects of biochar and biochar-compost on peanut growth, nutrition, and yield, but few systematic changes in emergence rates. Peanuts, due to their large, reserve-rich seeds, are less sensitive than other species to modest variations in soil physicochemical conditions at emergence. The main benefit of biochar-manure for this crop is therefore primarily seen after emergence, during pod formation

and filling.

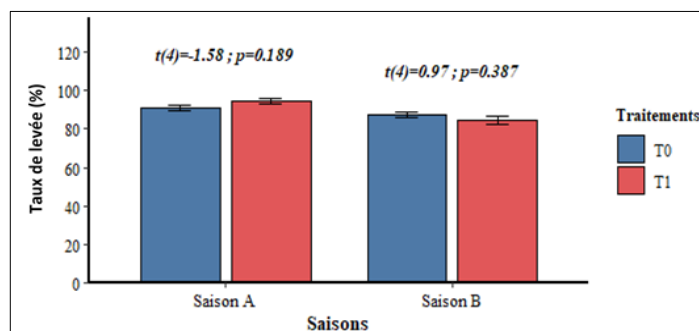


Fig 7: Peanut emergence rate

Weight of peanut pods

The weight of the peanut pods (Fig. 8) was 0.1820 kg in season A for the control and 0.31 kg for the treatment, representing a gain of 0.13 kg ($\approx +69.1\%$). In season B, it increased from 0.22 kg (T_0) to 0.32 kg (T_1), a gain of 0.10 kg ($\approx +47.6\%$). These increases show that biochar-manure significantly improved peanut pod production in both seasons, with a particularly marked effect in season A. The analysis revealed a significant difference between the treatment amended with biochar loaded with cow manure and the unamended control in season A ($P < 0.05$). In contrast, no difference was observed between the treatment and the control in season B.

The work of Mendoza (2023) [8] and Zhang *et al.* (2016) shows that biochar-based amendments (granulated biochar, biochar-compost) significantly increase soil organic matter content, phosphorus (P), potassium (K), calcium (C), and micronutrients, as well as pod weight and peanut seed yield. More recent studies (Wang *et al.*, 2025; Liu *et al.*, 2020) [13, 6] confirm this effect in saline or ferrallitic soils, highlighting an improvement in pH, nitrogen, phosphorus, potassium, and trace element availability, which promotes nodulation, symbiotic nitrogen fixation, and pod filling. In this study, the improvement in fertility parameters in season A (P, Ca, Mg, CEC) directly explains the 69.1% increase in pod weight, while the slightly weaker effect observed during season B (where these parameters deteriorate) remains significant, indicating a residual effect of the treatment.

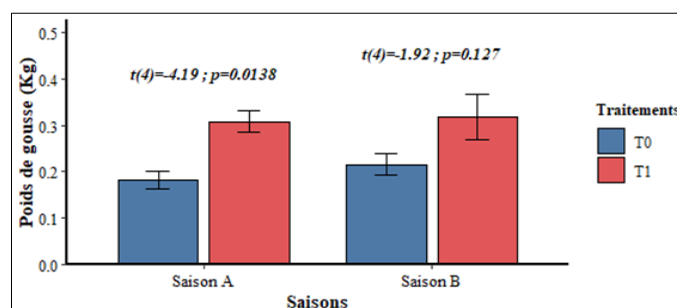


Fig 8: Weight of peanut pods

Peanut seed yield

Peanut seed yield (Fig. 9) increased during season A, rising from 1536.49 kg/ha for the control to 3008.33 kg/ha (biochar-cow manure treatment), representing a gain of 1471.84 kg/ha ($\approx +95.8\%$). During season B, it increased from 799.03 kg/ha (T_0) to 910.39 kg/ha (T_1), a gain of 111.36 kg/ha ($\approx +13.9\%$). Therefore, during season A, the biochar-manure treatment nearly doubled peanut seed yield, while during season B the effect, although positive, was significantly less pronounced. Comparative analysis

showed a significant difference between the treatment with biochar mixed with cow manure and the unamended control for season A ($P < 0.05$), while no statistically significant difference was observed between this same treatment for season B.

These results are consistent with the work of Mendoza (2023) [8], which showed a significant increase in peanut pod and seed yields under biochar and biochar-compost, and with that of Zhang *et al.* (2016), who reported yields of approximately 1900 kg/ha for seeds and over 3600 kg/ha for pods under biochar-compost. Wang *et al.* (2025) [13] also observed that biochar improved the physicochemical properties of rhizosphere soils and increased peanut biomass and yield in saline alkaline soils. In this study, the very strong response observed during season A is explained by a combination of factors: a slight increase in pH, enrichment in phosphorus (P), calcium (Ca), and magnesium (Mg), and an improvement in cation exchange capacity (CEC), all of which are favorable to nodulation, nitrogen fixation, and pod filling. The results of season B reflect the partial depletion of these same resources (P, K, Ca, Mg, CEC) and the lack of replenishment with amendments, confirming that the impact of biochar-cow manure on peanuts is highly dependent on soil fertility.

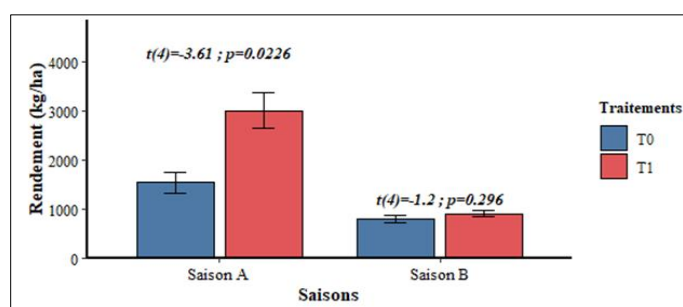


Fig 9: Peanut seed yield.

Conclusion

The application of a biochar-cow manure mixture in the maize-peanut intercropping system at Yaselia consistently improved vegetative growth and several components of maize yield, including plant height, ear weight, and the number of rows per ear, with increases of approximately 10 to 30% depending on the parameters and seasons. These positive effects, consistent with the observed improvement in certain fertility indicators (pH, P, Ca, Mg, CEC), resulted in an increase in maize grain yield of approximately 500 kg/ha over two seasons, although the differences were not always statistically significant at the 5% level.

In groundnuts, the amendment did not systematically alter the emergence rate, but it contributed to improved productivity through increased pod weight and seed yield, confirming that the effect of biochar-manure is primarily manifested after emergence, through soil nutrition and structure. Overall, the results show that the biochar-cow manure mixture represents a promising agroecological option for stabilizing and increasing yields in maize-groundnut systems in farmer field schools, while remaining compatible with the technical and economic resources of local producers. However, the moderate magnitude of the gains and the lack of statistical significance for some parameters indicate the need for further trials at multiple sites and seasons, with varying application rates and consideration of economic performance and long-term sustainability.

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