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Effect of Charcoal and Seedling Depth on Soil Properties and Melon Yield Components (*Cucumis melo*) in Poro, Côte d'Ivoire

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The combined effect of charcoal amendment and seeding depth was tested on soil properties and yield components of melon (*Cucumis melo*) at the botanical garden of the Peleforo Gon Coulibaly University of Korhogo. With the exception of the control plot, 6 kg of charcoal were applied by hand on ridges of 2.25 m2 in the first 10 cm of soil one month before sowing. The seeds were sown manually at 0.5 cm (control depth); 3 cm; 7 cm and 9 cm deep. The results showed that the application of charcoal significantly increased germination rate (($P< 0.002$), growth ($P < 0.0001$) and fruit yield ($p = 0.0001$). The combined effect of charcoal input and sowing depth was noticeable from the 47th day after sowing ($P = 0.0001$), the greatest values having been observed at a depth of 9 cm Correlated to the growth of the plants, the best fruit yields were obtained from the depths 9 cm with an average of 4 fruits per plant.

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1. INTRODUCTION

Biochar takes its name from the term “bio” in reference to organic residues and “char” for charcoal. In the context of uses in soils and porous media, they are called charcoal [1]. Charcoal is obtained from a thermal decomposition of carbon-rich materials such as grasses, wood, and various agricultural and forestry residues [2]. This material first appeared in South America as charcoal used for agricultural practices by the inhabitants of the amazon incorporated large amounts of charcoal into the soil to improve the yields of their crops [3]. Charcoal is of interest to agricultural and environmental authorities not only because it permits recycling waste containing carbon, but also because of its physico-bio-chemical properties which influence those of the soil to which they are applied [1]. Its advantages in agronomy have been described by [4]. For these authors, an increase in soil organic matter, a greater cation exchange capacity (CEC) and an increase in yields of up to 200% are achieved compared to soils without amendment. In addition, it influences soil water dynamics [1].

In dry environments such as the transitional tropical climate prevailing in northern Côte d'Ivoire, the amount of water in the top soil layer is often limited at the optimum time for sowing. As a result, unless sowing is delayed until the next rains, crop stands may become poorly established, resulting in low yields. However, delaying sowing beyond the optimal time can also lead to yield reductions [5]. Increasing seedling depths can improve crop establishment due to higher soil water content in the seed zone, leading to better germination and seedling emergence [6]. At the same time, deep sowing can have adverse effects on seedling emergence [7,8] and subsequently on the grain yields of cultivars not adapted to these conditions [9,10].

Faced with the rainfall recession, the soils present constraints linked to acidity and to a strong desaturation in exchangeable cations (Ca, Mg, K, Na). This results in a drastic reduction in their productivity [11]. To improve production, farmers tend to use chemical fertilizers. Despite their applications, agricultural production drops considerably after one cropping season due to the leaching of minerals [12]. Moreover, the expensive cost of chemical fertilizers does not lighten the task of farmers who are generally on low and uncertain incomes.

The present study aims at evaluating the combined effects of charcoal amendment of sandy-loamy soils and seeding depth on the components of melon yield under dry tropical conditions in the Poro region, Côte d'Ivoire.

2. MATERIALS AND METHODS

2.1 Plant Material

The CAPORAL variety of Melon (*Cucumis melo*) constituted the plant material of the study. It is a variety that has good vegetative growth and fruits of good taste, fragrant, of good conservation and adapted to transport. This variety has a minimum germination rate of 85% with a purity of 99% and an earliness of 85 days between direct sowing and the first harvest.

2.2 Presentation of the Study Area

This study was carried out on the site of the botanical garden of the University of Péléforo Gon Coulibaly, Korhogo. This city is located in northern Côte d'Ivoire between on the one hand, 8º30' and 10º25' of north latitude and, on the other hand, 5º15' and 6º20' of west longitude, with an average altitude of 325 m above sea level (Fig. 1).

The climate of the Poro region is of a dry tropical type with two seasons: one dry, from November to April and the other wet, from May to October. The rainfall regime is unimodal and centred on the months of August-September which accumulate almost half of the annual average height of precipitation equal to about 1200 mm [13]. The average temperature ranges between 24º and 33ºC. The hottest months with 36°C are February, March, and April, and the coolest months with 16°C are December and January [14]. The soils observed have a predominantly sandy-loamy clay texture with low humic impregnation [15].

2.3 Experimental Plot Preparations

The land was prepared in early September 2019 using a hoe. The experimental device was established on a rectangular plot 6.9 m wide and 10.5 m long, i.e., a total of 72.45 m^2 (Fig. 2). The plot has been subdivided into three rows of 15.75 m^2 10.5 m long and 1.5 m wide. This configuration therefore consisted of a block of 15.75 m^2 with 3 repetitions. Each row was divided into 05 experimental units with a dimension of 1.5 m X 1.5 m or 2.25 m^2, each unit corresponding to an evaluated depth.

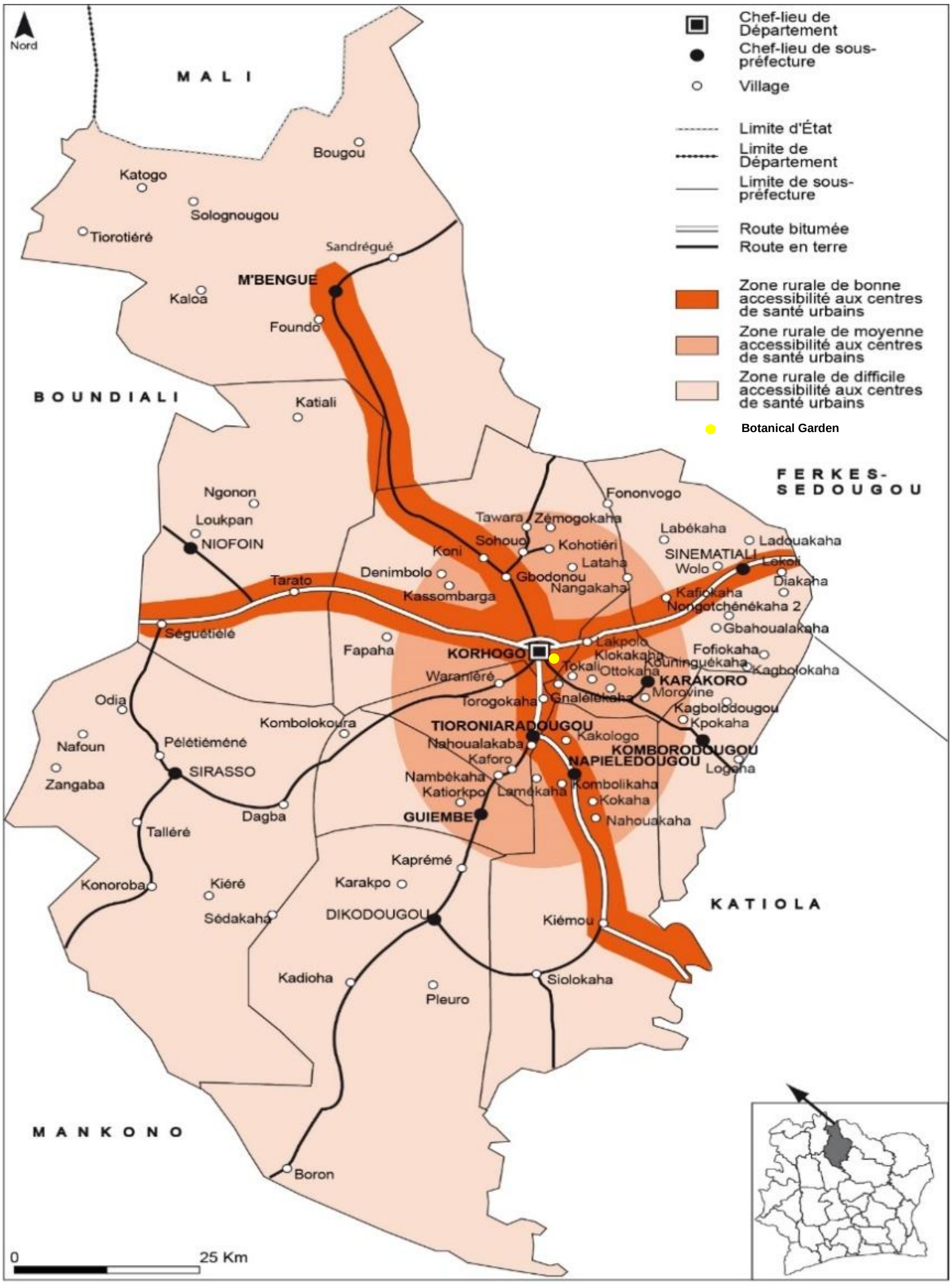

Fig. 1. Map of the Poro region

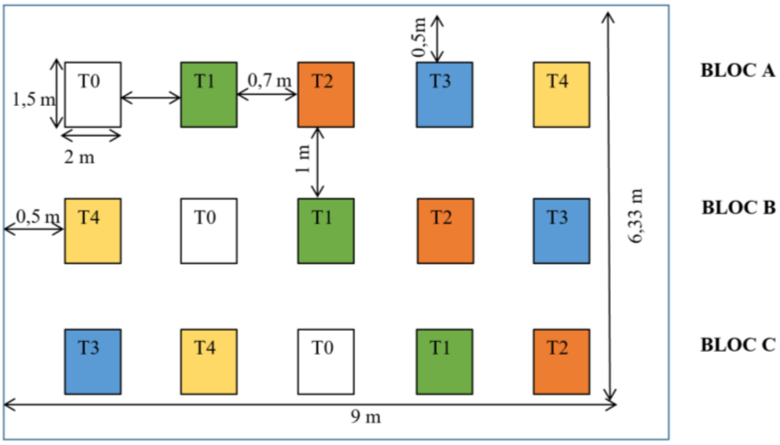

Fig. 2. Experimental apparatus

Sowing was carried out during early November, 2019. The method chosen was sowing in pockets. It consisted in making several holes with a dibber and 3 seeds were placed there at depths as follows:

T0 - sowing at 0.5 cm depth on control soil;
T1- sowing at 0.5 cm depth on soil enriched with charcoal;
T2- sowing at 3.0 cm depth on soil enriched with charcoal;
T3- sowing at 7.0 cm depth on soil enriched with charcoal;
T4 - sowing at 9.0 cm depth on soil enriched with charcoal.

Sowing was carried out at a spacing of 1.0 X 0.5 m. Earlier, with the exception of the control plot (T0), 6.0 kg of charcoal was applied manually to each elementary plot and mixed into the top 10 cm of soil during land preparation in September, 2019.

Fifteen days after germination, thinning was carried out to maintain 1 plant per pocket. The weeds were pulled out manually to avoid possible competition with the crop. Regular watering was done from sowing until the end of the study according to the need. The daily water needs have been estimated at 5 to 6 mm to ensure the growth and development of the plants [16]. No insect, pest or disease infestations was observed.

2.4 Plant Sampling and Soil Analysis

The germination rate, the stem height from the first to the fourth topping and the length of the branches from the second to the fourth topping were measured using a measuring tape. The plants were harvested in January 2020 and were counted and reported as fruit number per plant.

Soil samples were collected, before seeding and at the time of harvest, at 20 cm soil depth and soil physicochemical properties were analyzed in the soil laboratory of Institut National polytechnique Houphouët Boigny (INP-HB) in Yamoussoukro. A random samping at five different points of the plot to constitute a dry composite sample of 0.5 kg representative of the plot was followed. The results of soil analyzes were compared with threshold values, reference standards or results of previous work.

The granulometry in five fractions was carried out by the Robinson pipette method, according to the AFNOR NF X31-107 standardized method [17]. Soil texture classification was made following the USDA Texture Triangle [17]. The carbon and the total nitrogen were analyzed by the methods described in the international standard NF ISO 10694, for carbon, and NF ISO 13878, for nitrogen. The water and KCl pH were determined according to international standard NF ISO 10390. The cation exchange capacity was measured by the Metson method of the AFNOR NF X31-130 standard [18]. Element content of Ca^{2+}, Mg^{2+}, K^{+} and Na^{2+}, were determined by the fluoro-nitro-perchloric method. Total phosphorus and assimilable phosphorus were measured according to international standard NF ISO 11263 [17].

2.5 Statistical Analysis

The data collected were processed using two software. The EXCEL version 2013 spreadsheet was used to enter the data, to draw up the tables and graphs. The XLSTAT 2014 software made it possible to perform analyzes of variance (ANOVA) at the 5% probability threshold. Therefore, each time a variable is significant, the ANOVA is supplemented with a TURKEY test which makes it possible to classify the means.

3. RESULTS

3.1 Effect of Charcoal on the Physical and Chemical Characteristics of the Soil

The results of the soil particle size studied are presented in Table 1. The particle size test showed that the soils enriched with charcoal had a loamy texture with 7.5% clay, 41.28% sand and 49.88% silt while, the control soils had a sandy loam texture with 4.2% clay, 65.59% sand and 30% silt.

The pH of the both control soil and charcoal treated soil did not show any significant difference. However, there was a numerical difference with 6.8 for the control soil and 7.2 for the treated soil. It, therefore, appears that these two types of soil have a relatively neutral pH, as the values are close to 7 (6.6 ‹ pH › 7.4).

The contents of soil exchangeable bases were higher in the charcoal treated plots compared to the control (Table 2). The addition of charcoal increased the rate of these bases except that of Na+ (0.2 cmol/kg). The content of exchangeable bases in the treated soil is of the order of 8.60 cmol/kg for (Ca^{2}+), 1.41 cmol/kg for (Mg^{2}+) and 0.56 cmol/kg for (K^{2}+) against 0.56 cmol/kg for (Ca^{2}+), 0.51 cmol/kg for (Mg^{2}+) and 0.16cmol/kg for (K+) on the control plot. As regards the cation exchange capacity (CEC), it was in the order of 13.6 cmol/kg in the soil amended with charcoal and very low at 2 cmol/kg in the control soil.

The analysis results showed a highly significant difference in the assimilable phosphate content of the soil. It was 83 ppm for the charcoal-treated soil and 45 ppm for the control soil.

The organic matter content in the control soil was very low but, it was high in the soil amended with charcoal. The addition of charcoal varied the organic matter content of the soil, which remained low, increasing from 0.21% (control soil) to 1.34% (charcoal-treated soil).

The sodium content (Na+) was reduced from 0.2 to 0.16 on the treated soil. However, the charcoal improved the soil nitrogen rate (0.13%) against the control soil (0.03%). The results of the soil analysis revealed a highly significant difference (P=0.001) on the porosity of the soil. The porosity of the soil increased from 90.50% on the control soil to 30.40% on the charcoal amended soils. The low available carbon level in the control and biochar-amended soils increased from 0.12% on the control to 0.78% after charcoal incubation. The C/Nt ratio was low on both soils despite a significant difference (P=0.001). This ratio increased from 4 on the control soil to 6 after application of charcoal.

3.2 Effect of Charcoal and Depth on Germination Kinetics

The germination rate was significantly influenced by the addition of charcoal (p=0.002). It was 75±8% for soils enriched with charcoal while it was only 58.6±3.2% for the control.

Fig. 3 shows the evolution of the germination rate as a function of time for each seeding depth.

The germination started in 5^{th} day in all the treatments and continued for next couple of days. The highest germination rate is observed on 6^{th} day at depths of 0.5 cm, 3 cm and 7 cm.

3.3 Effect of Charcoal and Seedling Depth on Seedling Growth

Fig. 4 indicates that the sowing depth had a significant effect (P<0.0001) on the heights of the plants at the first topping (19 DAS). At this date, the heights varied between 5.5 cm and 7.5 cm. The highest values were recorded at depths of 0.5 cm for soils enriched with charcoal and control soils with plant heights of 7.5 cm. ower values (5.8 cm, 5.5 cm and 5.7 cm) were observed on soils enriched with charcoal at depths of 3 cm, 7 cm and 9 cm respectively.

Significant differences (P = 0.004) were observed for stem lengths on the 34th day after sowing, before the second pruning. The height of the plants varies from 13 cm to 16.5 cm. The highest values were observed for plants of depths of 0.5 cm and 9 cm, with an average length of 16.5 cm, followed by plants of depths of 7 cm and 15 cm, and plants of depths of 3 cm (14 cm). The controls obtained the smallest lengths (13cm) (Fig. 5).

The combined effect of the supply of charcoal and the seedling depth was particularly noticeable at the third and fourth pruning (Figs. 6 and 7). The analysis of variance showed significant differences for these two periods (P = 0.0001).

On the third topping (47th day after sowing), the stem heights were between 20 cm (T0) and 28 cm (T3 and T4). The sowing depths of 3 cm and 0.5 cm obtained the stem heights of lengths 25 cm and 24 cm, respectively.

On the fourth topping, i.e. 61 DAS, the heights of the stems reached between 25 cm (T0) and 37.5 cm (T4). These results showed that the stem heights are greater on the plots treated with charcoal compared to the control. The sowing depth of 7 cm made it possible to obtain 33.5 cm height while the depths of 3 cm and 0.5 cm gave only 29 and 28.5 cm tall plants, respectively. Control soils recorded 25 cm tall Stems.

3.4 Effect of Charcoal and Seedling Depth on Yield

It appears from the analysis of variance that charcoal and seeding depth have a highly significant effect (p = 0.001) on melon yield.

The yield of the plots varied between 1 fruit/plant and 4 fruits/plant (Fig. 8). Thus, plots treated with charcoal and sown at 9 cm deep were the best with 4 fruits/plants, followed by plots amended with charcoal and sown 3 cm deep. Finally, among the plots sown at 0.5 cm depth, the charcoal amendment made the difference allowing a yield of 2 fruits/plant against 1 fruit/plant.

Table 1. Results of soil particle size analysis studied

	Granulometry				
	Clay (%)	Fine silt (%)	Coarse silt (%)	Fine sand (%)	Coarse sand(%)
Charcoal enriched soil	7.5	22.08	27.8	29.56	11.72
Control soil	4.20	17.5	12.5	31.22	34.37
Resume	0.4	0.2	0.5	0.0	0.7

Table 2. Exchangeable cations and cation exchange capacity of the studied soils

	Absorbent complex (cmol.kg-1)				
	CEC	Ca2+	Mg2+	K+	Na+
Charcoal enriched soil	13.6	8.61	1.41	0.56	0.20
Control soil	2	0.56	0.51	0.06	0.16
Resume	1.1	1.2	0.7	1.1	0.2

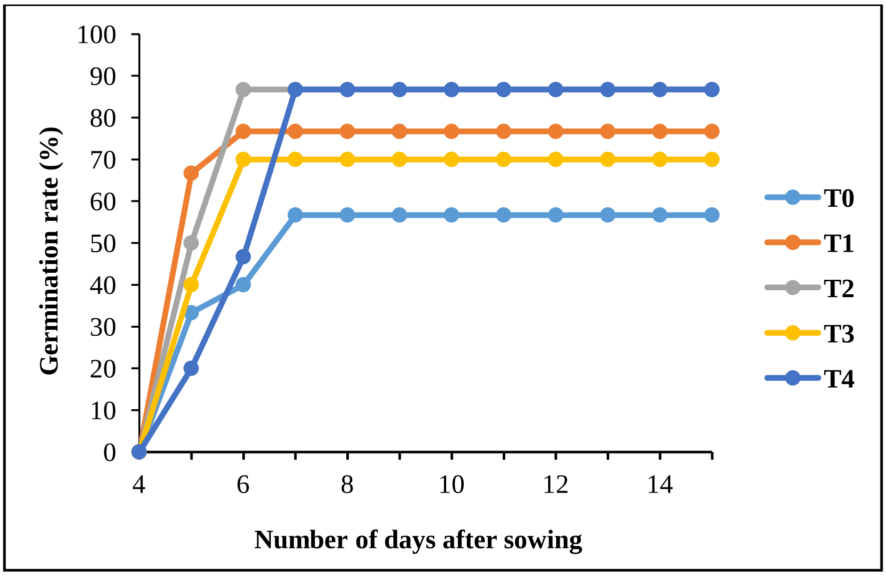

Fig. 3. Germination rate as a function of time

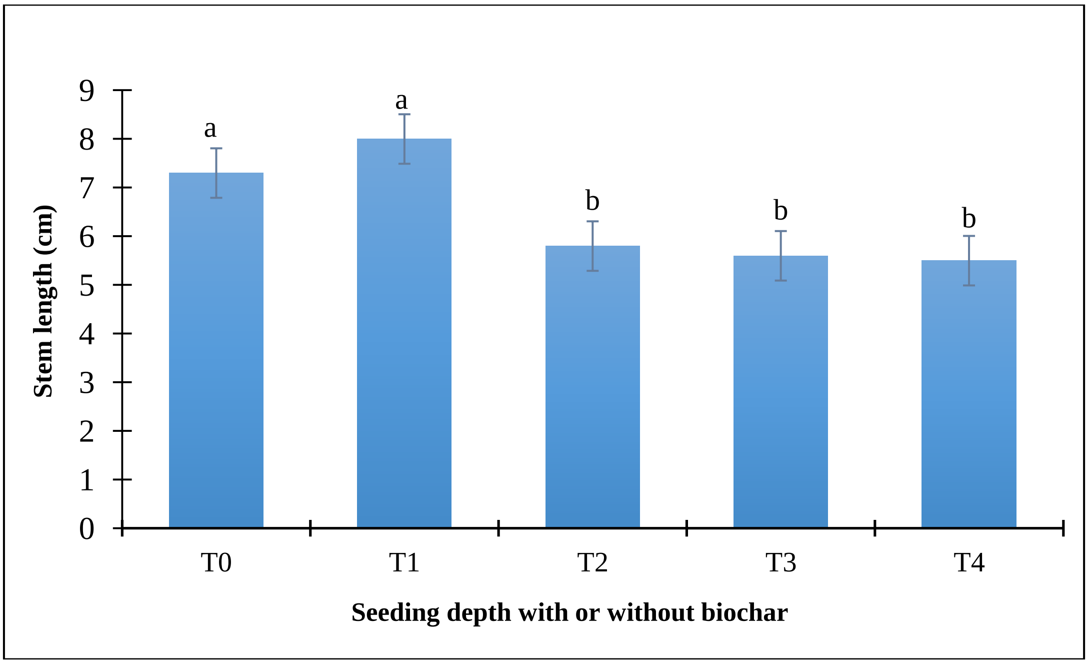

Fig. 4. Height of plants at first topping

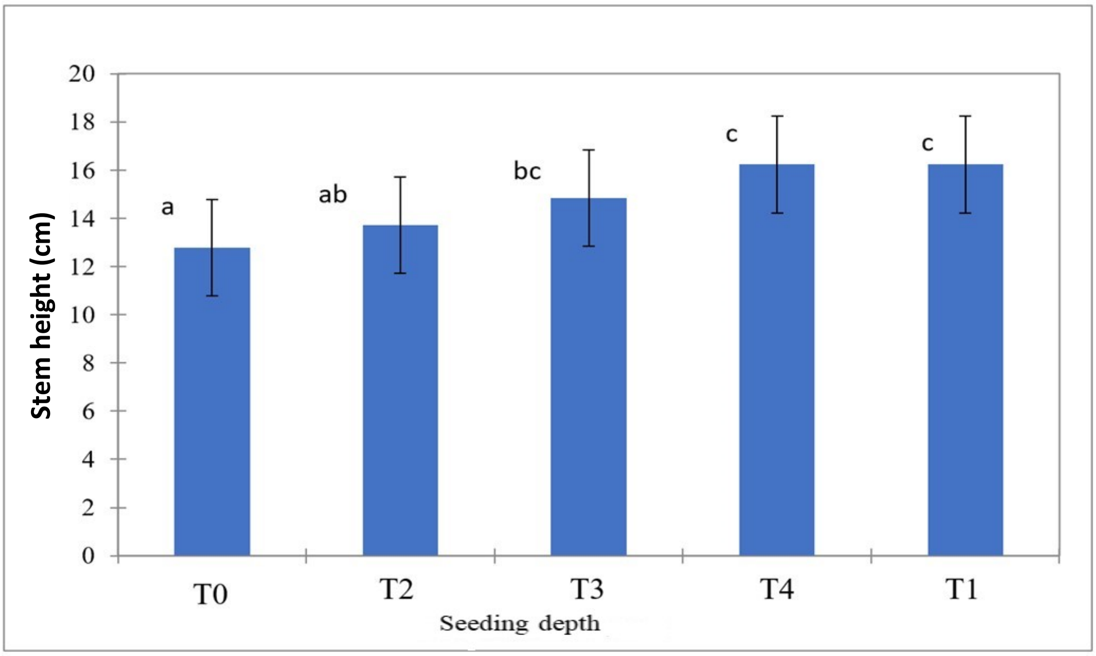

Fig. 5. Height of plants at second topping

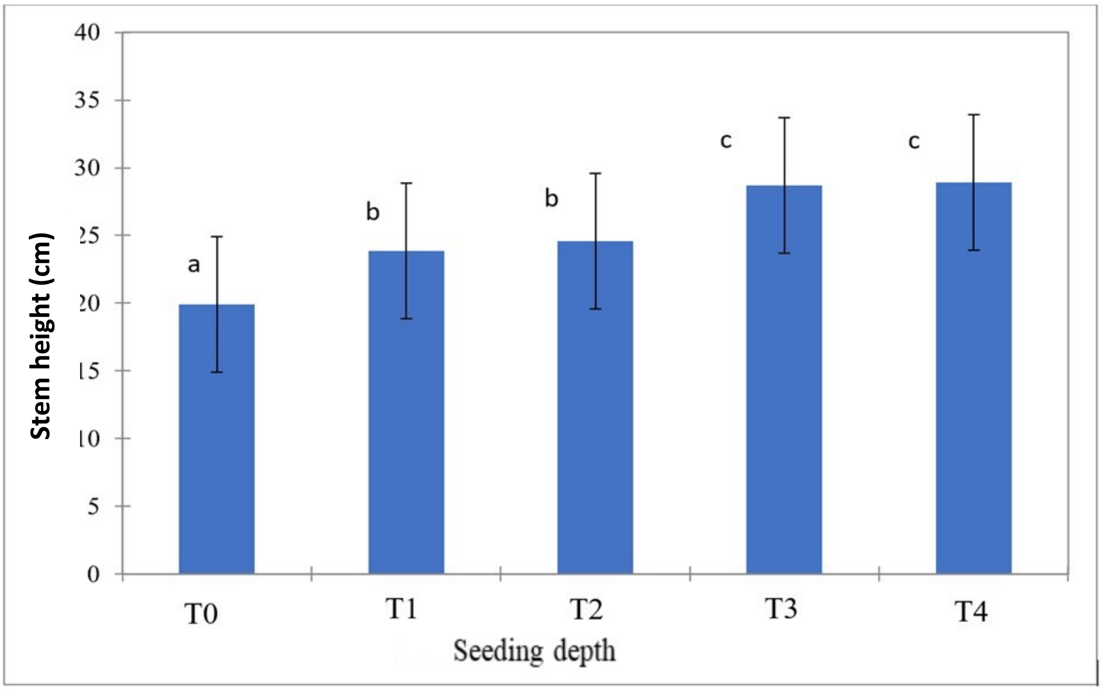

Fig. 6. Height of plants at third topping

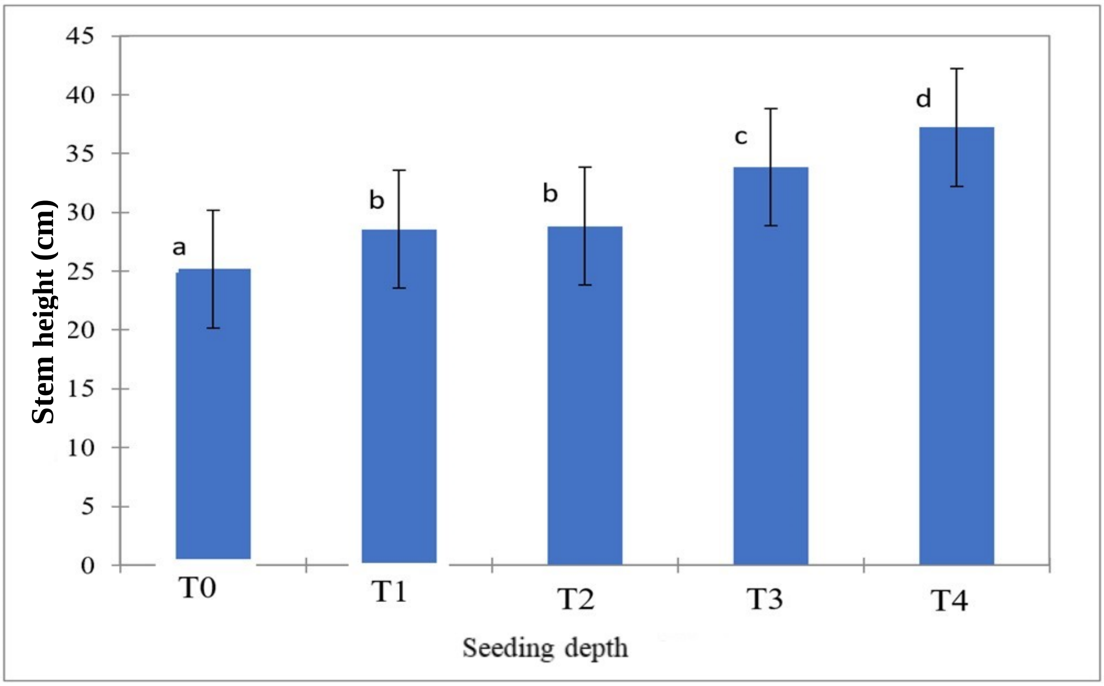

Fig. 7. Height of plants at third topping

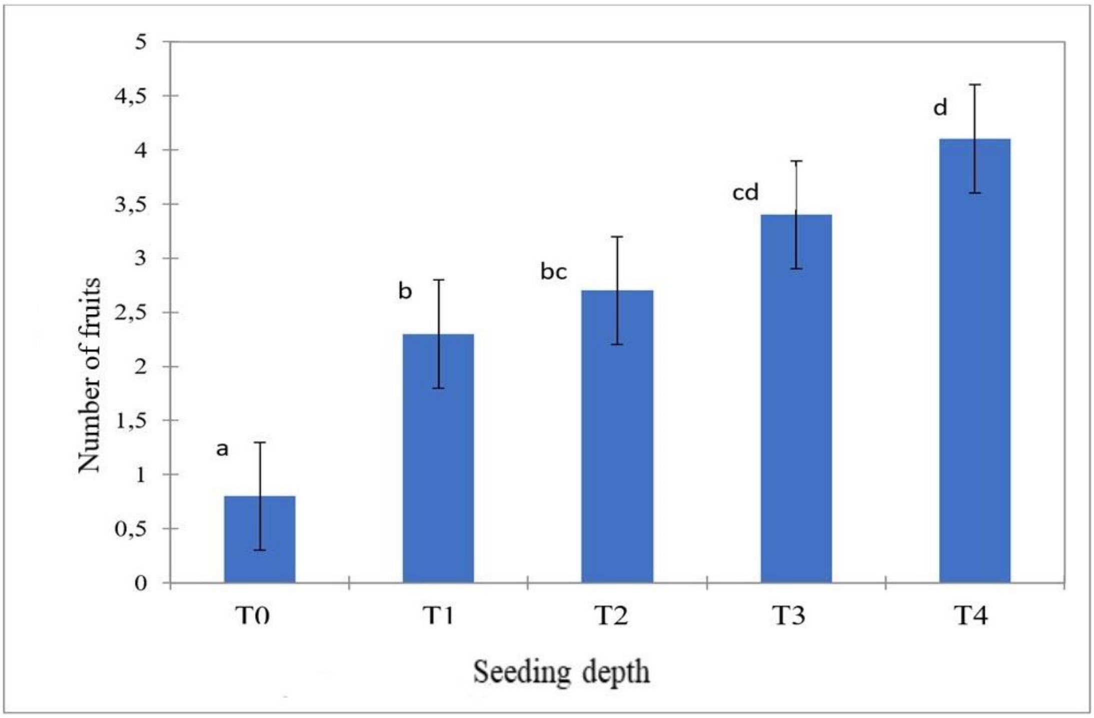

Fig. 8. Average number of fruits borne by the plants according to the substrate and the depths of sowing

4. DISCUSSION

4.1 Effect of Charcoal on the Physico-Chemical Characteristics of the Soil

The results of the granulometric study show that the contribution of charcoal modified the texture and the porosity of the soils treated. The contribution of charcoal made it possible to raise a little more the content of clay and silt in the treated soil. This increase in clay and silt was accompanied by a decrease in the sand content. In addition, the pH was slightly increased to be in the neutral to slightly basic soil class. These results are similar to those [19,20] who consider that the particular physical properties of charcoal influence the texture, structure, porosity, pore size and distribution as well as the density of the soil in which it is incorporated. According to a study conducted on the effect of different rates of charcoal amendment (0%, 25%, 50%, 75% and 100% v/v) in sandy loam, the results showed an improvement in physical properties and soil hydraulics by adding charcoal [21]. Furthermore, [22,23] demonstrated that generally, the charcoal has a pH higher than neutrality, an excellent porosity as much at the level of the macropores as of the micropores and a low bulk density.

4.2 Effect of Charcoal and Seedling Depth on Melon Germination

Adding charcoal to the soil increased the germination rate. Sowing at 3 cm recorded high germination rates of 87%. The results also showed that melon seeds germinate better in a medium enriched with charcoal in Korhogo. These results are in contradiction with the work of Rogovska et al*.* [24] who showed that the contribution of charcoal to the soil has no effect on the germination rate of maize seeds in Nevada in the USA. Soil moisture and temperature must have been different due to seeding depth on sandy loam. This effect could suggest that the ideal seeding depth in the presence of charcoal would be 3 cm to obtain good seedling emergence. Indeed, water and temperature are determining factors for the germination of seeds. Both factors can, separately or together, affect the germination percentage and germination rate [25]. Guibert and Le Pichon, [26] reported that the temperature range of 13°C to 20°C is favourable for germination and emergence. This temperature optimum was observed for English oak by Suska et al. [27].

4.3 Effect of Charcoal and Seeding Depth on Seedling Growth

The results showed that the length of stems and branches was greater on the soils amended with charcoal compared to the control soil throughout this study. The increase in the size of the plants can be explained by the content of exchangeable bases raised at the level of the soils enriched with charcoal. Indeed, the study showed that the enrichment with charcoal made it possible to bring the contents of exchangeable bases closer to the intervals of the reference values for melon which are 10-20 $cmol.kg^{-1}$ for the CEC, 5-8$cmol.kg^{-1}$ for Ca^{2+}, 1.5-3.0 $cmol.kg^{-1}$ for Mg^{2+}, and 0.3-0.7 $cmol.kg^{-1}$ for Na^{2+}. In addition, the charcoal amendment resulted in an increase in K^{+}. This increase in cation concentrations favoured plant growth through better availability, as certain studies have shown [28-30]. Indeed, charcoal can have direct and indirect physical effects on plant growth by contributing to deeper root penetration and improved water and air availability in the root zone [31].

Concerning the effect of depth on the agronomic parameters, the results showed that on the 19th day, the sowing carried out at 0.5 cm obtained the longest plants. On the 47th and 61st day, the plants of the seedlings made at 7 cm and 9 cm had the longest stems. For the branches, the sowings carried out at 9 cm obtained the longest branches on the 47th day and on the 61st day. The beneficial effect of seeding depth on seedling growth can be attributed to good root development, as Duparque et al. [32] demonstrated. These authors believe that planting at a depth of 6 cm to 9 cm helps ensure adequate absorption, provides good moisture and good contact between roots and soil, promoting good growth. The weak growth of the plants observed at the level of the seedlings carried out between 0.5 cm and 3 cm could be due to a poverty of the soil in mineral elements linked to a low content of organic matter. This is in line with the work of Mandoli and Briggs [33] who showed that shallow sowing increased stress, which slowed root development, reduced stem diameter and length.

4.4 Effect of Charcoal and Seedling Depth on Yield

Fruit yields showed a significant difference between sowing depths on the one hand and an effect of charcoal on the other hand. Treatments that contain charcoal as a soil amendment gave the best yields. Charcoal-enriched soils were richer in P, K, Mg. The study showed that soils enriched with charcoal had a pH of 6.8. This value is included in the favourable pH zone for melon cultivation, varying between 6.5 and 7.5; acid soils below 5.6 should be avoided. This explains better plant growth on soils enriched with charcoal. Similar results have been obtained by several studies [34].

5. CONCLUSION

The use of charcoal in agriculture allows for better productivity and sustainability of production by improving the physico-chemical quality of the soil leading to the development of microbial flora and a reduction in the leaching of nutrients. The results under our experimental conditions show that the germination of seeds and the agronomic parameters of melon are influenced by the charcoal and the depth of sowing. The addition of charcoal to the soil in Korhogo promoted better mineral nutrition for the plants. The 3 cm seedling plants obtained a better germination rate. However, the plants of the 7 cm and 9 cm seedlings recorded the most important agronomic parameters.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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