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VALORIZATION OF AGRICULTURAL RESIDUES IN BIOCHAR FOR A SUSTAINABLE VEGETABLE PRODUCTION: CASE OF AMARANTH (AMARANTHUS HYBRIDUS) IN GLO-DJIGBÉ DISTRICT

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ABSTRACT

The aim of this research is to study the effect of biochar, an organic fertilizer on the physiological parameters of growth (height, number of leaves) and yield (weight) of amaranth cultivation. To carry out this research, a completely randomized Fisher block device was fixed in an experimental station with 3 repetitions and 4 treatments. The R.3.0.0 software was used to analyze the data. The results showed that the corn stalk biochar has an average density of 0.26 g/cm3 and 0.32 g/cm3 for the peanut hull biochar. These types of biochar have mass yields of 25.61% and 26.75% respectively and average durations of 503' 48'' and 660' 27''. The treatments days after transplanting significantly influenced ($p < 0.05$) the physiological parameters (height and number of leaves) and the yield of the amaranth plants. The T2 treatment (75% corn stalk biochar and 25% groundnut fane biochar) performed best in plant height (21. 94 cm), number of leaves (14) and weight (3. 17 t/ha). The mixture of 75% of corn stalks biochar and 25% of biochar from peanut haulm can therefore contribute to a better yield of amaranth cultivation and ensure the sustainability of vegetable production.

Keywords: Glo-Djigbé, Biochar, Agricultural residues, amaranth.

1. INTRODUCTION

Market gardening is a very old practice in Benin. Its products play an important role in the human diet and constitute a very important source of income for producers. Despite the positive contributions, the production systems present high environmental and health risks. These latter are linked to the excessive and abusive use of chemical fertilizers and phytosanitary products, which are sources of soil, groundwater, surface water and air pollution (C. C. A. Ahouangninou p. 24). This is not without consequence on the health of market gardeners and consumers due to the presence of pollutants in crops. Traore et al. (2006) cited by G. Soro et al., 2019 p.14073 detected contamination of groundwater by organ phosphorus and organ chlorine pesticides in agricultural regions where pesticides are used in cocoa, coffee, rubber, banana and market gardening. Residues of active substances are detected in various vegetable products, sometimes in quantities exceeding the maximum residue limits (MRLs) set by the Codex Alimentarius or the European Union (Assogba-Komlan et al., 2007; Sæthre et al., 2011; Odhiambo et al., 2014) cited by C. C. A. Ahouangninou p. 24. The daily use of these products (vegetables, water, aquatic products) contaminated with pesticides is undoubtedly one of the main risk factors of intoxication for consumers (B. B. Yarou, 2017 p. 293). Skin irritation, headaches, cough, dizziness, respiratory disorders, fatigue, diarrhea, etc. are all symptoms of intoxication due to the use of these pesticides (Kanda et al., 2009; Ahouangninou et al., 2011; Son et al., 2017) quoted by B. B. Yarou, 2017 p. 292. Fertility management techniques practiced by farmers lead to rapid soil depletion (Yemefack et al., 2004) cited by B. L. A. Assavedo, 2021 p. 12. Protecting the environment and developing agricultural production are indissolubly tasks that require a coordinated demand on several funds (Dellere, 1993) A M. S. YEMADJE, 2015 p. 10. It is therefore crucial to adopt new attitudes in the future. The destructive farming practices currently used must give way to methods that increase production without destroying the natural systems on which agriculture depends. Thus, to meet the dual challenge of protecting the environment and satisfying food needs, it is necessary to promote sustainable organic agriculture based on the defense and restoration of soil fertility through the use of organic fertilizers. Compared to other organic fertilizers, biochar is a biofertilizer that has a positive impact on the environment through rational management of solid and liquid waste, its ability to improve the condition of soils that are naturally poor or acidic, or even degraded by intensive agriculture (Steiner et al., 2007) quoted by DH Tokpo, 2021 p. 9. Several publications have reported that the use of biochar can influence plant growth and yields and health status (Glaser et al. 2001; Glaser et al. 2002; Lehmann & Joseph 2009; Elad et al. 2010) cited by BMD Kanouo, 2017 p. 8. Its production can also be traditional, fast and cheaper (BLA Assavedo, 2021 p. 12). It is within this framework that the current article is entitled: "valorization of agricultural residues in biochar for a sustainable vegetable production: case of Amaranth (Amaranthus hybridus) in Glo-Djigbé district " in order to evaluate the effect of biochar on physiological growth parameters and the optimal dose for a better yield of the amaranth crop.

2.SITE, MATERIALS AND METHODS

2.1 Experimental site

This site is located in Glo-Djigbé district, one of the districts of the municipality of Abomey-Calavi. This district, located between 6°31' and 6°35' North latitude and 2° 15' and 2° 30' East longitude (Figure 1), has an area of approximately 100.79 km², or 0.09% of the national territory (INSAE 2012). It is characterized by a sub-equatorial climate marked by two rainy seasons and two dry seasons. The average annual rainfall is 1200 mm. This rainfall provides immense agricultural possibilities. But recently, climatic disturbances have led to an overlap of the two rainy seasons (Carder-Atlantique/MDR and FSA/MEN, 1995). The hygrometric state always remains high 60 to 80% with maxima at the time of heavy rainfall. The relief of Glo-Djigbé is very uneven and does not favor strong erosion. Overall, it presents a bar earth plateau, mostly degraded, but deep and easy to work. These soils have good physical characteristics that allow good amaranth development. They are very loose on the surface and well drained.

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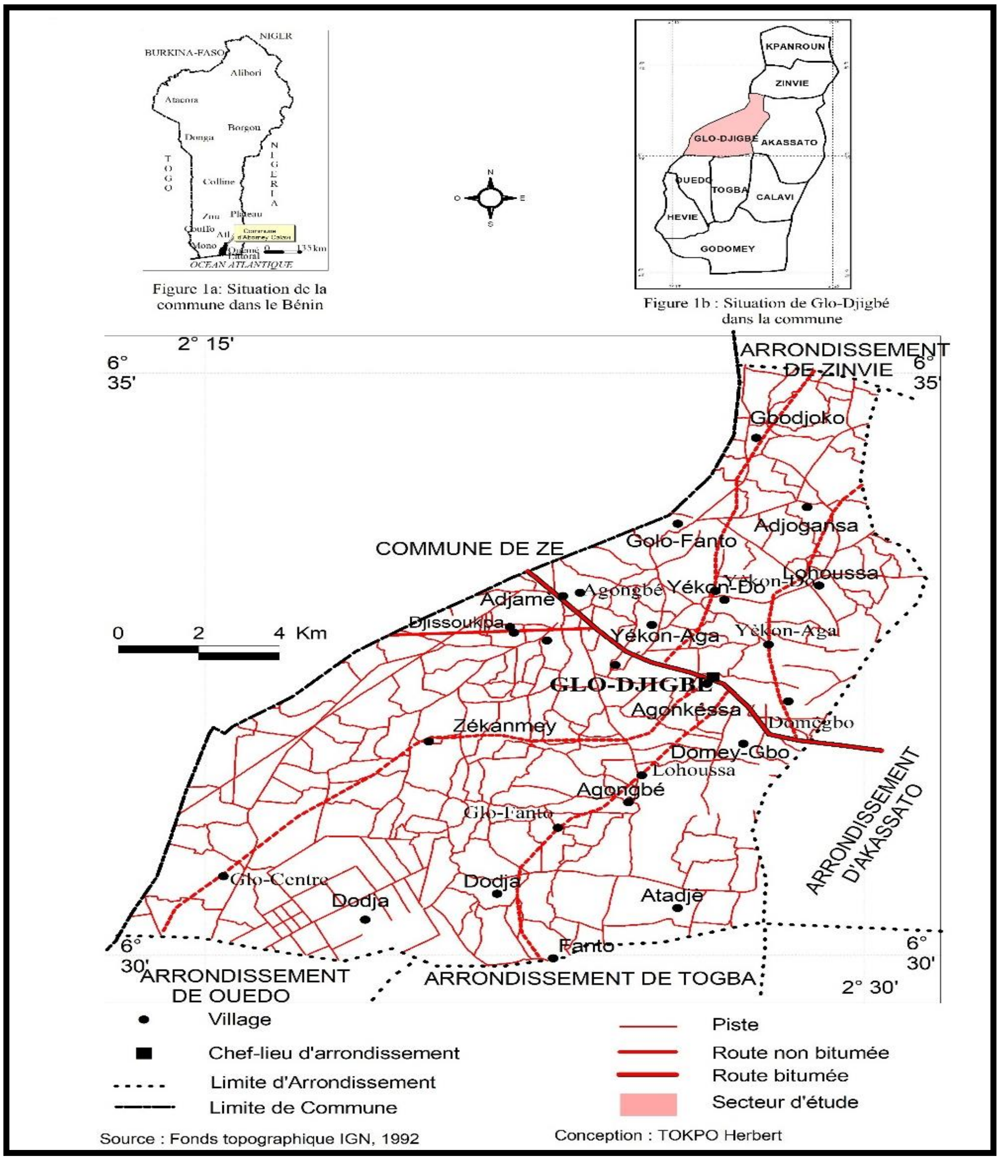

Figure 1: Geographical location of Glo-Djigbé district

2.2 Materials

- **Plant material**

The variety of amaranth (Amaranthus hybridus) used was delivered by authorized distributors. It is hybrid whose cycle varies between 8 to 10 weeks and is the most cultivated variety.

For the phytosanitary treatment, the aqueous neem extract was prepared from the fresh leaves. 1.5 kg of leaves were crushed with a soap fragment and the mixture was soaked in 1l of water for 24 hours. The next day, the mixture was filtered with a fine sieve to collect the extract. The resulting solution was diluted in water. For a treatment of an area of 84 m², 2.4 l was used (Gnago et al., 2006) for curative pest control.

- **Equipment used in the manufacture of fertilizer**

Several materials are used in the biochar manufacturing process. These are:
- raw materials (corn stalks and peanut haulms),
- the carbonizer which was used for the thermal decomposition of the raw material in an oxygen-poor environment,
- the mill which made it possible to reduce the char obtained after carbonization to powder,
- a container for mixing the char in order to obtain the biochar.

- **Equipment used for measurements**

These are: the 150 mm electronic caliper, the tape measure and the scale.

- **Fertilizer: Biochar**

2.3 Methods

- **Data collection techniques**
- **Documentary research**

The documentary research was carried out in libraries, documentation centers and research institutions whose activities are related to the subject of this research. It has made it possible to identify and exploit documents such as dissertations, theses, reports and scientific journals. These documents provided information on the study area and the topics related to biochar, phytosanitary treatments and amaranth cultivation.

- **Experimental device**

The experimental device used for this trial is a completely randomized Fisher block device set up in an experimental station with 3 repetitions and 4 treatments: (T0 = without biochar), (T1 = 50% corn stalk biochar + 50% biochar haulm peanut), (T2 = 75% corn stalk biochar + 25 peanut haulm biochar), (T3 = 25% corn stalk biochar + 75% peanut haulm biochar). The trial consists of a total of 12 plots. The dimensions of the plots are 7 m long and 1 m wide, i.e. 7 m². Aisles of 0.5 m were observed between plots and 1 m between blocks.

- **Cultural transactions**

The nursery lasted four weeks. Vigorous plants, reaching 3 to 4 leaf stage were transplanted. The relocating was carried out on the beds having received 7kg of biochar in various doses and watered twice a day for a week. The actual relocating activity was carried out in an afternoon on well-watered beds of 175 plants. Watering was done three times a day after transplanting and twice after the resumption of plants. The hoeing and weeding of the aisles were carried out on the 10th and 20th days after transplanting. The treatment is done two weeks after transplanting following the observation of the first pest attacks. Harvesting was done on the 21st day after transplanting. The harvesting principle consisted in uprooting the plants after watering the beds, rinsing the root system in order to take measurements. Three measurements were taken (one, two and three weeks after relocating at the rate of 15 plants randomly chosen in the middle of each bed). The growth and vegetative development parameters studied were: the stem height, the number of leaves and the yield.

- **Determination of the mass yield**

$$\mathbf{Rm = Mbp / Mmp \times 100}$$

with Mbp : Mass of biochar produced (kg) ;

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Mmp: Mass of raw material introduced (kg).

- **Determination of biochar density**

Several measurements were carried out to determine the density. Ten (10) measurements were carried out using a 2 liters container.

- **Data processing and analysis of results**

The data collected were subjected to analysis of variance at the 5% probability threshold using R. 3.0.0 software (R Core Team, 2020). The Ryan Joiner normality test and the equality of variances test were performed to test normality and equality of variances respectively. Plant height and leaf number data were analyzed using the general linear mixed-effect model with the fish family as the error distribution. For the yield data, an analysis of variance was performed to check the significance of the "Biochar Treatment" factors and the influence of their interaction on yield. The lmer function of the nlme packages (Pinheiro et al. 2017) made it possible to implement this model. Thus, graphical representations were performed in order to analyze the evolution of the height of the plants, number of leaves and the yield over time. The analysis of the results was descriptive, analytical and comparative.

3.RESULTS

3.1 Manufacturing process and basic physical characteristics of biochar products

- **Manufacturing process of the produced biochars**

The biochars were manufactured in a traditional way. Sheet I illustrates the manufacturing process.

Photo 1: Loading corn stalks into the carbonizer

Photo 2: Carbonozation of corn stalks in a low-oxygen environment

Photo 3 : Char obtained after carbonization

Photo 4: Biochar powder

Sheet I: Biochar production process
Shot: YEMADJE, September 2021

From the manufacturing process (sheet I), two types of biochars are produced. These are biochar from corn stalks (Photo 6) and that from peanut leaves (Photo 8).

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Photo 5: Corn stalks char after carbonisation

Photo 6: Biochar from corn stalks after milling

Photo 7: Char of groundnut husks after carbonisation

Photo 8 : Biochar of peanut hulls after milling

Sheet II: Different types of biochars produced
Shot: YEMADJE, September 2021

It results from sheet II that the biochar of groundnut tops is blacker than that of maize stalks. After grinding, it was also noted that the grain size of the char of peanut leaves is finer than that of corn stalks.

- **Basic physical characteristics of manufactured biochars**

The basic physical characteristics (mass yield, carbonization time and density) of the biochar types f produced are presented in Table I.

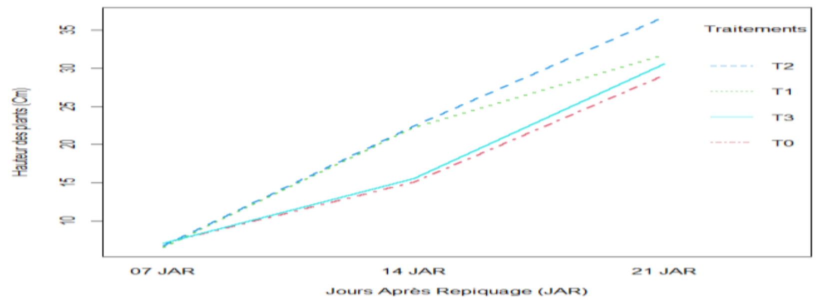
Table I: Basic physical characteristics of the biochars produced

Types of biochar / Caracteristics	Biochar peanut hulls	biochar corn stalks
Mass yield (%)	26,75	25,61
Charring times (min)	660' 27''	503' 48''
Density g/cm^3	0,32	0,26

The results in Table I show that all the elemental parameters (mass yield, charring times and density) of the groundnut husk biochar have higher values than the corn stalk biochar produced.

2-2- Influence of treatments on stem height

The results on the influence of the different treatment rates on plant height are presented in figure 2.



T0: Treatment without biochar, T2: Treatment with 75% corn stalk biochar and 25% peanut haulm biochar,

T1: Treatment with 50% corn stalk biochar and 50% peanut haulm biochar,

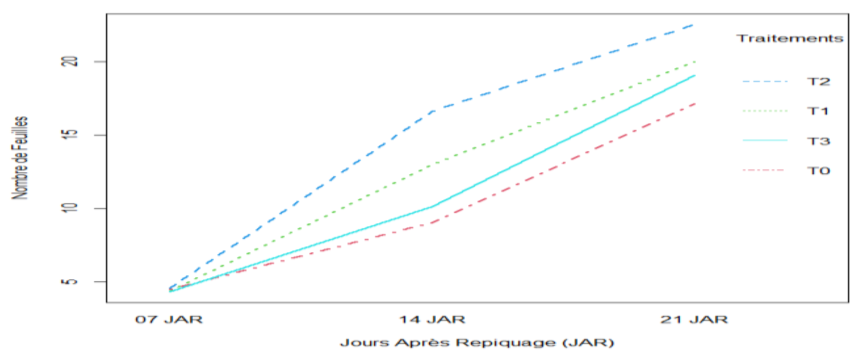
T3: Treatment with 25% corn stalk biochar and 75% peanut haulm biochar

Figure 2: Effect of different treatment rates on stem height

Figure 2 shows a gradual change in amaranth stalk height over time for all treatments and the control. The same pattern can be seen in treatments T3 (25% corn stalk biochar and 75% groundnut haulm biochar) and T0 (control) from day 7 to day 21 of growth. Treatments T2 (75% corn stalk biochar and 25% groundnut haulm biochar) and T1 (50% corn stalk biochar and 50% groundnut haulm biochar) also kept the same paces but this was until day 14 of growth when T1 tended to look like T0 and T3 until day 21 of growth. The statistical results showed that the treatments days after transplanting significantly influenced ($p < 0.05$) the stem height. Treatment T2 had the highest height of 21.94 cm followed respectively by treatment T1 with a height of 20.18 cm, treatment with a height of 17.64 cm and in last position T0 which has an average height of 17.12 cm.

2-3- Influence of treatments on the number of leaves

Figure 3 shows the growth of the leaves of amaranth plants compared to the different doses of treatments and the control over time.



T0 : Treatment without biochar, T2 : Treatment with 75% corn stalk biochar and 25% peanut haulm biochar,

T1 : Treatment with 50% corn stalk biochar and 50% peanut haulm biochar,

T3 : Treatment with 25% corn stalk biochar and 75% peanut haulm biochar

Figure 3: Evolution of the number of leaves per Amaranth plant over time

It results from figure 3 showing the leaf growth of amaranth plants in relation to the different doses of treatments and the control from day 7 to day 21, that treatments T3 (25% corn stalk biochar and 75% groundnut haulm biochar) and T0 (control) maintained the same growth rates

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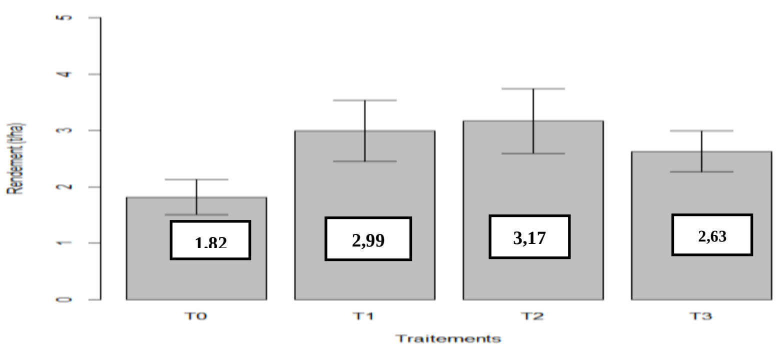
as those observed for height. However, those of T1 (50% corn stalk biochar and 50% groundnut haulm biochar) and T2 (75% corn stalk biochar and 25% groundnut haulm biochar) have changed their appearance. But there is still a continuous evolution of the number of leaves from the 7th day of growth until the 21st. However, the number of leaves found for the treatment (T2) is higher, with an average of 14 leaves, followed by the treatment (T1) with an average of 12 leaves and the treatment (T3) with an average of 11 leaves. The control gave the lowest values with an average of 10 leaves. The effect of the day-after-transplant treatment interaction is significant at the 5% level on the number of leaves per pigweed plant.

2-4- Influence of treatments on plant yield

The effect of different treatment doses on amaranth yield is shown in Figure 4.



T0 : Treatment without biochar, T2 : Traitement with 75% corn stalk biochar and 25% peanut haulm biochar,
T1 : Traitement with 50% corn stalk biochar and 50% peanut haulm biochar,
T3 : Traitement with 25% corn stalk biochar and 75% peanut haulm biochar

Figure 4: Effect of treatments on yield

The yield of amaranth varied between 1.82 t/ha and 3.17 t/ha (Figure 4). The analysis of this figure shows that the control (T0) amaranth plants have the lowest values with an average yield of 1.82 t/ha. The treatment T2 (75% corn stalk biochar and 25% peanut haulm biochar) had the highest yield (3.17 t/ha), followed by treatments T1 (50% corn stalk biochar and 50% peanut fodder biochar) and T3 (25% corn stalk biochar and 75% peanut fodder biochar) with average yields of 2.99 t/ha and 2.63 t/ha respectively. The analysis of variance at the 5% threshold showed that the difference between the treatments was significant.

4. DISCUSSION

4.1 Manufacturing process and basic physical characteristics of biochar products

The residues of corn stalks and peanut haulms underwent carbonization and milling of the char in order to obtain a biochar with a fine grain size. The manufacturing process adopted is artisanal. This carbonization process has already been tested in the UK (M. S. Dusabe 2014, p.16). It was chosen because it is simple, less expensive, accessible and easily used by market gardeners in particular and producers in general. This biochar production mechanism, which consists of the decomposition of the raw material through a high temperature in an oxygen-poor environment, was used by PERACOR, 2006 p. 9 and M. S. Dusabe 2014, p.17 in studies carried out respectively in Senegal and Burundi. The quality of the biochar and the yield of its production are influenced by the conditions of carbonization and the type of biomass used. (M.S. Dusabe 2014, p.17; T. Nandillon 2019 p. 34). Indeed, the results concerning the elementary physical characteristics (mass yield, carbonization time and density) of the biochars of corn stalks residues and peanut haulms give respectively mass yield values of 25.61% and 26.75%. %. The carbonization time is 503'48" for the corn stalks biochar and 660'27" for the peanut haulm biochar. The mass yield rates obtained are lower than those found by S. A. Onana Lebongo, i.e. rates varying between 29.4% and 42.42% with a duration between 65' and 123' (S. A. Onana Lebongo, 2011 p. 20). However, these rates are very close to that obtained by PERACOR, 2006 p. 9 or 24.3% for a duration of 234'. This difference can be explained by the nature of the raw materials used, the type of pyrolysis and the duration of combustion. As for the density, it is 0.26 g/cm3 for the biochar produced with corn stalks and 0.32 g/cm3 for that made from peanut haulms. These densities remain within the range of biochar density values (0.2 - 0.8g/cm3) according to S. A. Onana Lebongo 2011 p. 20. He mentioned in this research that biochar is suitable for agricultural use from a density standpoint. A. Downie, et al, p. 22, showed that the density of biochar depends on the nature of the biomass as well as the temperature at which it is produced. He also pointed out that adding a low-density biochar to the soil improves it in two ways: first, it reduces the mass density of the soil allowing plant roots to penetrate the soil for better development; then, it promotes high moisture retention.

4.2 Influence of treatments on average height and average number of leaves amaranth plants

The average height and average number of leaves of pigweed plants in the beds receiving different biochars (T1, T2 and T3) exceed those of the control beds (T0). The statistical results showed that the treatments of different biochars doses days after transplanting significantly influence ($p < 0.05$) both the average height and average number of leaves of amaranth plants. Treatment T2 presented the highest height of 21.94 cm, followed respectively by treatment T1 with a height of 20.18 cm and treatment T3 with a height of 17.64 cm. It should be noted that the treatments (T1, T2 and T3) have the same positive effects on the number of leaves. We can therefore deduce that the control beds are poor in nutrients while those having received the treatments are rich in nutrients which enrich the soil and promote good growth of amaranth plants in height and number of leaves. These findings approve those of R. M. Tshibingu, et al, 2017, p. 10575 who found that the soils of the control plots seem to reflect the low level of nutrient reserves in the soil. These authors pointed out that this could be the main cause of the poor height and leaf growth performance of the corn. M. A. S. Yêmadjè, 2015, p. 43 also made the same remarks. He noted that biochar addition to the soil stimulated the microorganisms that mineralized the organic matter and thus offered the amaranth crop the nutrients needed for its growth. The work carried out by Gaskin et al., (2008) as well as Prendergast-Millet et al., (2013) cited by M. A. S. Yêmadjè, 2015, p. 43, also reported that biochar is a direct source of nutrients. In other works, Gbadamosi (2006), Choudhary and Kumar (2013), Ognalaga et al (2014) quoted by M. Ognalaga, et al, 2015, p. 3851 also reported the improvement of soil structure following the addition of organic amendments. Our results also show that the treatments that receive a large proportion of the biochar from the corn stalks, i.e. ¾ and ¼ of the peanut haulms biochar (T2) give the best growth in height and number of leaves. It can then be concluded that the corn stalks biochar favored the height and leaf growth of the amaranth plants. This can be explained by the low density of biochar in corn stalks because, for A. Downie, et al, 2009, p. 22, this low density of biochar promotes high moisture retention and also reduces soil mass density which facilitates the penetration of plant roots into the soil for better development.

4.3 The influence of treatments on plant yield

The average weight yields of amaranth plants obtained under various doses of biochars show a significant effect at the 5% threshold between treatments. The results show a difference in gain of 1.17 t/ha, 1.35 t/ha and 0.81 t/ha respectively for treatments T1, T2 and T3 compared to the control (T0). It should be noted that the T2 treatment has the highest yield as reported in terms of height and leaf growth of amaranth plants. So this performance at the T2 treatment level can only be due to the significant contribution of biochar from corn stalks, which has physical properties that favor the rapid growth of amaranth plants and therefore their yield. These results are in line with those of M. A. S. Yêmadjè, 2015, p. 39, who found that the application of biochar increased the yield of amaranth and lettuce compared to the control and the combination of urea and poultry droppings. Magnan, 2006 cited by L. Tchaniley et al., 2020, p.15547 found that nitrogen being a constituent element of chlorophyll is a key factor in the growth and determination of plant yield.

5. CONCLUSION

The experimentation carried out during this research showed that the biochar treatments significantly influence the growth in height, the number of leaves and yield of amaranth plants at 5% threshold. However, the treatment T2 (corn stalks biochar, i.e. ¾ and ¼ of peanut haulm biochar) presents the best performance for the three parameters studied (growth in height, number of leaves and yield). It should be noted that the different doses of the two types of biochars (corn stalks and peanut haulms) could well be recommended either alone or associated with other organic fertilizers for amaranth cultivation. However, the dosage of the T2 treatment would be better indicated for this culture.

REFERENCES

1- PERACOD, 2006: Technical and economic scenario for the manufacture of Biochar from coal dust available in Saint Louis using the “Rotor Press” technology, Report, 5 p.

2- Sévérin Achille Onana Lebongo, 2011*, production of biochar from rice husk: from the study of the resource to the valorization of the product, Master II dissertation, Dakar, Cheikh Anta Diop University, 41p.

3- Tchaniley Larounga, Ayisah Kwasi Dzola, DEWA Kassa Kodjo Akonta, 2020, Effect of the combination of organic and mineral fertilizers (NPK 15-15-15 and urea) on the yield of lettuce (Lactuca sativa L.) in the south du Togo, Journal of Applied Biosciences ISSN 1997-5902, 151: 15540 - 15549.

4- Tshibingu Remy Mukendi, Mukadi Théodore Tshilumba, Mpoyi Maurice, Ntatangolo Benjamin Mutamba, Musenge Dominique Kabongo, Tshibingu Meschack Ilunga, Kazadi Judith Ngoie, 2017, Evaluation of the productivity of maize (Zea mays L.) under organic and mineral amendments in the Lomami province, Democratic Republic of Congo, Journal of Applied Biosciences, ISSN 1997-5902, 109: 10571-10579

ISSN: 2456-8643

5- Yêmadjè Modeste Amour Sèflimi, 2015, Valorisation of agricultural residues and biomass in biochar for sustainable market gardening in the district of Abomey-Calavi, license dissertation, EPAC/UAC, 61 p.
6- Assavedo Bignon Luigi Aymar, 2021, Valorization of agricultural residues in biochar for sustainable market gardening: case of tomatoes in the district of Glo-djigbé, license dissertation, ENSET/UNSTIM, 79 p.
7- Tokpo Dèdomè Herbert, 2021, Valorisation of agricultural residues in biochar for sustainable market gardening: case of Amaranth (Amaranthus hybridus) in the district of Glo-Djigbé, license dissertation, ENSET/UNSTIM, 58 p.
8- Dusabe Marie Sandrine, 2014, Technical and financial feasibility study of the recovery of organic household waste, paper and cardboard for the manufacture of combustible briquettes in Bujumbura, Burundi, Master's thesis / International Institute of Engineering, 55 p.
9- Onana Lebongo Sévérin Achille, 2011, Production of biochar from rice husk: from the study of the resource to the valorization of the product, Master's thesis / International Institute of Water and Water Engineering environment, 41 p.
10- Nandillon Romain, 2019, Phytostabilization of the metallic elements of a vegetated mining technosol by the genus Salix assisted by Biochar, Earth Sciences. University of Orleans, 284 p.
11- Ahouangninou Claude Comlan Agbatan, 2013, Sustainability of market gardening in southern Benin: an essay on the ecosystem approach, Thesis dissertation, FLASH/UAC, 349p.
12- SORO Gbombele, Wahabi Saidy Amao, Adjiri Oi Adjiri, 2019, SORO Nagnin, Health and environmental risks related to the use of phytosanitary products in horticulture in Azaguié (South Côte d'Ivoire, Journal of Applied Biosciences ISSN 1997- 5902, 138: 14072–14081.
13- Yarou Boni Barthélémy, Silvie Pierre, Assogba Komlan Françoise, Mensah Armel, Alabi Taofic, Verheggen François, Francis Frédéric, 2017, Pesticide plants and protection of vegetable crops in West Africa (bibliographic summary), Biotechnol. Agron. Soc. About. 2017 21(4), 288-304.
14- Kanouo Boris Merlain Djousse, 2017, Production and use of biochar for the amendment of tropical leached red soils, Thesis dissertation / Laval University, 98
15- Ognalaga Maurice, Boussiengui-Boussiengui Gino, Oyanadigui Odjogui Pherla Ichida, 2015, Contribution to the restoration of soil fertility in the market gardening perimeter of IGAD DJAMITI (Franceville) by the reasoned contribution of organic and mineral amendmentsJournal of Animal &Plant Sciences, Vol.24, Issue 3: 3843-3853, http://www.m. elewa.org/ JAPS.
16- Downie Adriana, Crosky Alan, Munroe, 2009, Physical properties of biochar. An introduction. In: Lehmann, J. and Joseph, S. Eds., Biochar for Environmental Management: Science and Technology, Earthscan, London, pp.13-32.