

RESEARCH ARTICLE

EFFECTIVENES OF ORGANIC AND INORGANIC FERTILIZER IN ENHANCING GROWTH OF *Ipomoea aquatica* (WATER SPINACH) IN TWO DIFFERENT TYPES OF SOIL

Ameelya Farzana Jamaludin^a, Nur Shuhada Tajudin^{a*}, Rozilawati Shahari^a, Che Nurul Aini Che Amri^a, Mazidah Zulkifli^a, Mayzaitul Azwa Jamaludin^b

^a Department of Plant Science, Kulliyah of Science, International Islamic University Malaysia (IIUM), Kuantan 25200, Pahang, Malaysia.

^b Laboratory of Food Safety and Food Integrity, Institute of Tropical Agriculture and Food Security, Universiti Putra Malaysia, 43400, UPM Serdang, Selangor.

*Corresponding Author Email: nurshuhada@iium.edu.my

This is an open access article distributed under the Creative Commons Attribution License CC BY 4.0, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

ARTICLE DETAILS

Article History:

Received 25 April 2021

Accepted 29 May 2021

Available online 30 June 2021

ABSTRACT

Planting a crop with high productivity and quality while ensuring the continuity of good soil quality and environmental sustainability is important. With the changes of climate and extensive anthropogenic activities, soil had become undesirable for crops planting. However, various measures can be done to improve this such as applying suitable types of fertilizer and soil amendments besides monitoring the quality of soil continuously. Fertilizer application in a way is helpful in providing essential nutrients needed by the plant while soil organic amendment able to improve its quality through biotic and physical changes. In this study, different combination of treatments was applied in two different types of soil to observe its effect on morphological growth of water spinach (*Ipomoea aquatica*), soil pH, and total organic carbon (TOC) in soil. Field experiment was conducted at Glasshouse Nursery Complex (GNC), International University Malaysia for five weeks. Combination of treatments consist of control (T1), biochar (T2), chicken manure (T3), combination of biochar and chicken manure (T4), and combination of biochar, chicken manure, and NPK fertilizer (T5). Two types of soil that were used in this study which are normal topsoil and oxisols type of soils. Results showed that the T5 were observed to have the highest average of plant grown in both normal top soil and oxisols soil. The pH of both soils treated with biochar and organic manure increased compared to control which reflect a positive effect towards nutrient availability for plant. Total organic carbon content also showed an increased trend with soil amendment and fertilizer applications. Hence, in overall growth of *Ipomoea aquatica* improved with application of fertilizer and organic amendments.

KEYWORDS

Biochar, Chicken Manure, Soil Chemical Properties and Oxisols

1. INTRODUCTION

Nowadays, the increment of population worldwide has led to the enhancement of agricultural productivity in limited land resources. This is to ensure the food supply and energy for global population (Ostadi, 2020). Not only that, plant also serve as a major livestock's sustenance by providing many different nutrients (Hazra, 2016). In order to keep up with the demand, crop production need to be increased. For crop to have a high productivity or yield, quality and types of soils including its physical and chemical characteristics need to be considered. The soil must provide an optimum environment for plants to strive and produce the expected yield. Different types of soil have different properties that allow nutrient or water to be taken up by crop plant (Sung et al., 2017). Soils has high variability according spatial and temporal changes. Malaysia itself has diverse types of soils, where over 500 soil series had been recognized.

Different topography and parent materials or rocks affects the types of soil as these are the factor in developing soils (Sung et al., 2017). Soils properties, along with climate affects the types of plant or crops that will grow in certain region. This is because of the soils' properties that evolve from several factors govern the plant's ability to takes up nutrients and water (Sung et al., 2017).

In comparison to oxisols, plant could be deficient in nutrients due to its characteristics that have low nutrients needed for plant (Buol and Eswaran, 1999). Oxisols are soils that constitutes of oxic horizon. It has the upper boundary within 150 cm of the mineral surface (Buol and Eswaran, 1999). This type of soils has low amount of essential nutrients needed for plant growth (Buol and Eswaran, 1999). Essential minerals such as potassium, phosphorus, calcium, and magnesium are likely to be in small amount. Not only that, oxisols also have low CEC (Buol and Eswaran,

Quick Response Code



Access this article online

Website:
www.trab.org.my

DOI:
10.26480/trab.01.2021.45.50

1999). Oxisols are also mentioned to have low activity clay that are made up of kaolinite and iron (Fe) and aluminium (Al) oxides as well as low in pH (Hartemink et al., 2020). However, this does not mean they are infertile. Instead, they need the help of fertilizer to be able for crop sustainability. Similar to what had been mentioned, oxisols, when managed properly, perennials crops can be planted with high productivity and sustainably (Beinroth et al., 1996). This type of soils also has good internal drainage due to high aggregate stability making them less prone to erosion when compared to other types of soil. Thus, soil degradation can be avoided when oxisols are supervised properly.

Supplying crop plants with fertilizers also helps in accommodating higher plant yield. Fertilizers is an amendment that can be applied to plants to enhance plant growth and promotes its productivity. Fertilizers have been categorized into several classification according to its features, strength, and constituents. Organic fertilizer helps in increasing soil organic carbon while inorganic fertilizer could be effective in a short period of time. Thus, crop productivity could be increased. Nevertheless, implementing soil amendment on the right amount of nutrients guarantee the improvement of crop growth while intensive application of fertilizers can bring harms to the environment (Hazra, 2016). Water spinach (*Ipomoea aquatica*) has been chosen to different treatments of fertilizers. The physiological plant growth of applying different treatment are observed and analysed.

Biochar has been widely used due to its characteristics that able retain nutrients due to its numerous pores and higher surface charges (Liu, 2017). Recent research has shown that additions of biochar lowered the potential of nutrient losses from the agricultural lands. Other observed benefits such as stabilizing soil pH, improving CEC increased soil water retention and improving beneficial microbe populations and activities, Application of combined organic and inorganic fertilizers had been documented in giving benefits towards soils and plant crops (Hossain et

al., 2010; Yuan and Xu, 2011; Novak et al., 2009; Kolton et al., 2011). Combination of both type of fertilizers had improved the rate of soil organic carbon besides meet the demand of nutrients needed for sustaining crop yield (Li et al., 2017). Make use of only chemical fertilizer without organic manure or micronutrients fertilizers for years contribute to this problem secondary macronutrient and micronutrients deficiency. Therefore, implementing both fertilizer in a long term helps in alleviating this problem (Chand et al., 2006). Therefore, the study was conducted to observe the growth response of *Ipomoea aquatica* in two different types of soil which receive different combinations of organic and inorganic fertilizers. Besides, observation through the changes of soil pH and total organic carbon content were also done to understand its chemical properties.

2. MATERIALS AND METHODS

2.1 Field experiment

The study was conducted under a controlled condition (glasshouse) in IUM Kuantan Campus. The experiment was done by planting water spinach (*Ipomoea aquatica*) as plant sample on two different types of soil which are normal topsoil and oxisols soil. Topsoil was taken at GNC of IUM Kuantan while oxisols soil was sampled from Bukit Goh, Kuantan.

2.2 Soil treatment

Five treatments were applied to each type of soil. The treatments consisted of T1 (no fertilizer), T2 (500 g of biochar), T3 (300 g chicken manure), T4 (250 g of biochar and 150 g of chicken manure), and T5 (14 g of NPK, 150 g of chicken manure, and 250 g of biochar). All of the treatments were prepared a week before transplanting (as shown in Table 1).

Table 1: Treatments and its application timing

Type of soil	Categories	Treatment	Application timing
Top soil	T1	Control (no fertilizer)	-
	T2	Biochar	Mixed with soil a week before transplant
	T3	Chicken manure	Mixed with soil a week before transplant
	T4	Biochar + Chicken manure	Mixed with soil a week before transplant
	T5	Biochar + Chicken manure + NPK fertilizer	Only biochar and chicken manure were mixed a week before transplant. NPK was applied once a week after transplant
Oxisols	T1	Control (no fertilizer)	-
	T2	Biochar	Mixed with soil a week before transplant
	T3	Chicken manure	Mixed with soil a week before transplant
	T4	Biochar + Chicken manure	Mixed with soil a week before transplant
	T5	Biochar + Chicken manure + NPK fertilizer	Only biochar and chicken manure were mixed a week before transplant. NPK was applied once a week after transplant

2.3 Sowing and transplanting

Plant were sowed and let grown for 2 weeks before transplanted into each treatment prepared. The experimental study was based on a randomized complete block design (RCBD) with two replications.

3. MORPHOLOGICAL CHARACTERISTIC ANALYSIS

3.1 Length of plant

The length of water spinach was measured every week for 5 weeks. The measurement was taken from the base of first emerged leaves of the water spinach.

3.2 Length of leaves

The length of the water spinach leaves was taken every week for 5 weeks. The measurement was taken from the 3 biggest leaves from petiole to the

apex of the water spinach leaves.

3.3 Number of stems

The number of water spinach stems was taken every week for 5 weeks. The stems were counted for every emerging stem on the water spinach branches.

3.4 Number of leaves

The number of the water spinach leaves was taken every week for 5 weeks. The leaves were counted for every emerging leaf on the water spinach branches.

3.5 Length of roots

The length of the water spinach roots was taken on week 5 after the plant was harvested. The measurement was taken on the longest root hair.

4. YIELD COMPONENT ANALYSIS

4.1 Fresh weight

The fresh weight of the water spinach was taken on week 5 after the plant was harvested. The measurement was taken with the help of measuring balance.

5. SOIL CHEMICAL ANALYSIS

5.1 Soil pH

Soil pH was determined by using the glass electrode by following the soil to calcium chloride ratio at 1:2.5.

5.2 Total of soil organic carbon content (TOC)

The percentage of total organic carbon was done by following the procedure of wet digestion method (Walkey and Black, 1934). 0.5 g of soil was digested with $K_2Cr_2O_7$, concentrated H_2SO_4 , and diluted with water. The sample was titrated with $FeSO_4$ solution with diphenylamine as indicator. The total organic carbon content was calculated by using formula below.

5.3 Statistical analysis

Data collected was subjected to two-way statistical analysis of variance (ANOVA) by using statistical analysis software. ANOVA was used to determine if one of the factors effects the result of plant parameter at $p < 0.05$ level of significant difference.

6. RESULTS AND DISCUSSION

6.1 Morphological characteristic of *Ipomoea aquatica*

The water spinach showed a positive growth effects responding to each different treatments of normal topsoil and oxisols soil. In topsoil, T2, T3, T4 and T5 showed higher growth compared to untreated water spinach (T1) which represents as control (Figure 1). Interestingly, dissimilar result was observed on oxisols, T3 showed similar growth compared T1 which did not receive any fertilizer. However, T3, T4 and T5 of normal top soil showed a significant higher fresh biomass compared to the same treatments in oxisols soil ($p < 0.05$).



Figure 1: Effects of treatments of on plant growth of water spinach after 5 weeks in topsoil (A) and oxisols (B). From left: T1, T2, T3, T4, and T5.

6.2 Length of plant

Figure 2 indicates length of plant after 5 weeks of study in topsoil. In terms of length of plant, T3 (85.01±32.01 cm) showed the highest average followed by T4, T5, T2 and T1 (36.15±1.91 cm) in topsoil. This result indicated that organic manure such as chicken manure has the ability to improve plant's height to the maximum. Plant height are proven to be improved when being applied with organic fertilizers (Ahmad et al., 2017). Organic fertilizers improved the availability of important macronutrients and other essential nutrients such as N, P, and K for the plant uptake. These nutrients play vital role in growth and development of plant (Ahmad et al., 2017). On the other hand, the addition of biochar to T4 and T5 helps in

efficiency of fertilizer, especially nitrogen fertilizer by retaining the nutrients in soil which enhance the soil fertility (Arif et al., 2017).

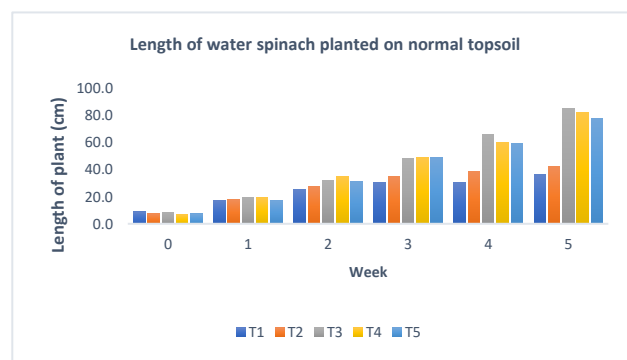


Figure 2: Effects of treatments on water spinach length in normal topsoil.

Figure 3 indicates length of plant after 5 weeks of study. From the ANNOVA analysis, the treatments showed a significant effect on the plant length planted in oxisols ($p < 0.05$). Treatment 5 had the highest average of plant length (59.54±2.67 cm) ($p < 0.05$) followed by T4 (42.26±0.41 cm), T2 (38.33±0.53 cm), T1 (34.54±4.01 cm), and T3 (32.60±12.94 cm). This trend is probably due to the combinations of both chemical and organic fertilizers, which enhance and boost the nutrient availability. The usage of biochar together with compost into acid soils have been mentioned to increase soils nutrient content. This is due to biochar or compost provides nutrients especially the macronutrients, by releasing it directly into the soils. Besides, the combination also helps in enhancing water-holding capacity of amended soils and thus, reduce nutrients leaching such as nitrate and phosphorus (Ventura et al., 2013). With the Addition of NPK inorganic fertilizer, the organic amendments helps in holding the nutrients more compare to treatments that did not receive any inorganic fertilizer.

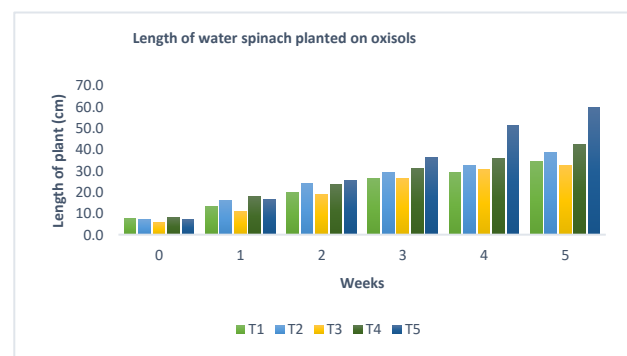


Figure 3: Effects of treatments on water spinach length in oxisols.

Treatment 3 was observed to have the lowest average of plant length compared to T1. This could be attributed to the quantity of the organic fertilizer that is insufficient for the plant growth. A study found that plant that are provided with higher amount of organic manure have higher yield compared to grown in lower amounts or synthetic fertilizer (Xu et al., 2003).

6.3 Number of stems

Water spinach in topsoil showed a significant effect to number of stems ($p < 0.05$). Treatment 5 had the highest number of stems, 91.25±8.13 ($p < 0.05$) followed by T3, T4, T2, and T1 which has the lowest number of stems, 12.63±3.71 (Figure 4). Similar result can be observed in oxisols types of soil, where T5 contributes the highest number of stems of water spinach while untreated T1 soils showed the least number of stems (Figure 5). This observation showed that the high amount of nutrients available for plant uptake in T5 could leads to increment in its vegetative growth. Zheng and Sharma (2020) found that biochar itself could increase the crop yield but when combined with fertilizers, the corn yield increased by 39% to 54%. Biochar are also said to help in reducing the inhibition of nitrification process thus, making nitrogen to be available for plant uptake.

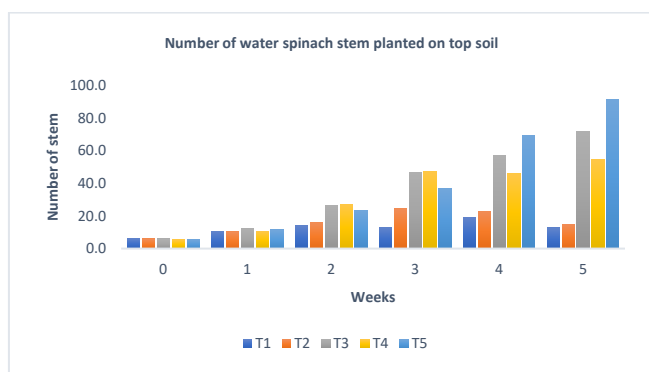


Figure 4: Effects of treatments on number of stems of water spinach in normal topsoil.

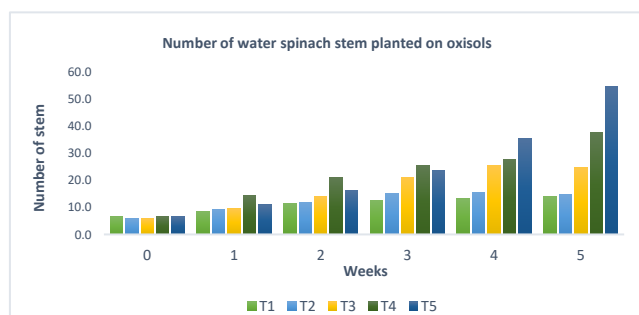


Figure 5: Effects of treatments on number of stems of water spinach in oxisols soil.

6.4 Number of leaves

Figures 6 and 7 showed that T5 had significant highest number of water spinach leaves when planted in topsoil (89.63 ± 11.14) and oxisols (43.38 ± 0.88) respectively ($p < 0.05$). Whilst, T1 had the lowest average value of leaves. High vegetative growth in terms of leaf numbers was probably due to the high amount of nitrogen that is available in both topsoil and oxisols soil. Organic manure had been proven to improve vegetative growth under stress condition and contribute to high number of leaves per branch (Ahmad et al., 2017).

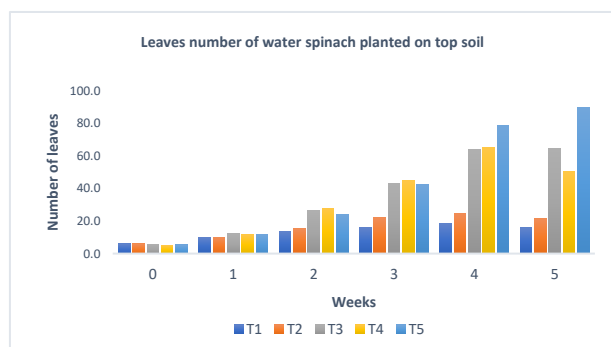


Figure 6: Effects of treatments on number of leaves of water spinach in normal topsoil.

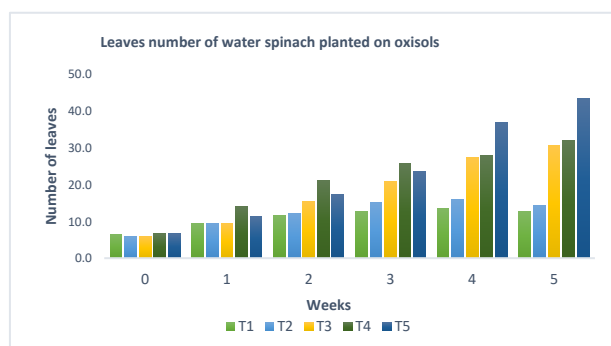


Figure 7: Effects of treatments on number of leaves of water spinach in oxisols soil.

6.5 Length of roots

Figure 8 showed the length of water spinach root after treated with different types of fertilizer for five weeks. From the graph, water spinach had the average of longest root hair in T4 in both topsoil and oxisols ($p < 0.05$). This suggest that combination of biochar together with organic manure helps in promoting the root growth throughout 5 weeks of treatment. A group researchers mentioned that biochar has a range of organic molecules such as butanolide and sesquiterpenes that may affect the germination of plant roots and growth of soil microbe respectively (Joseph et al., 2010). The T1, T2, T3 and T5 did not showed any significant difference in root length for both type of soil ($p > 0.05$).

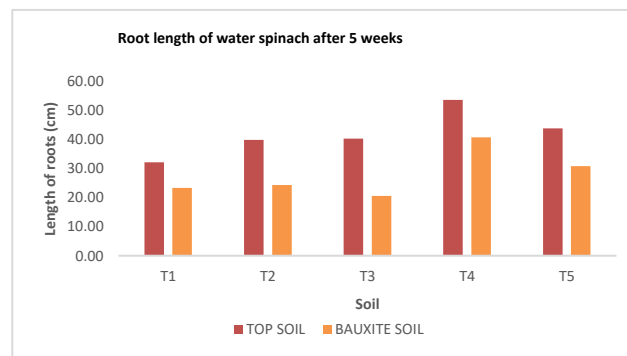


Figure 8: Effects of treatments on root length of water spinach in normal topsoil and oxisols soil.

6.6 Yield production

In normal topsoil treatment, T5 and T3 showed the same highest fresh yield with a value of $481.25 \pm 26.52g$, while the lowest yield ($81.25 \pm 8.84g$) was observed in T1 ($p < 0.05$). On the other hand, fresh weight of water spinach in T5 of oxisols had significantly the highest average of fresh yield with $237.50 \pm 0.00g$ ($p < 0.05$), while the lowest fresh yield was in T1. This suggested that application of combined fertilizers (NPK and chicken manure) along with biochar amendments significantly effect and improved the plant growth through its soil properties.

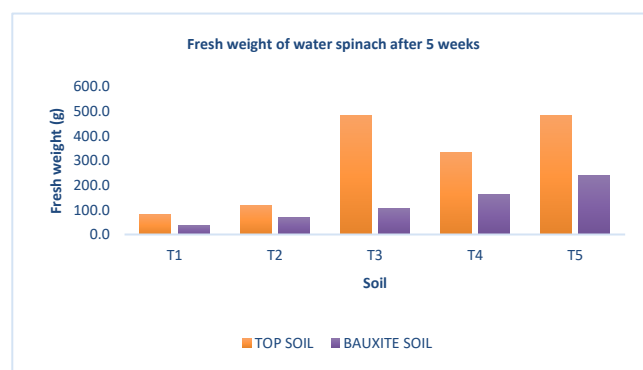


Figure 9: Effects of treatments on length of water spinach leaves in topsoil.

7. CHEMICAL CHARACTERISTIC OF SOIL

7.1 Soil pH

Table 2: Initial and final pH readings in topsoil and oxisols

pH reading in top soil					
Treatments	T1	T2	T3	T4	T5
Initial reading	4.96b	4.81b	5.25a	5.23a	5.15a
Final reading	3.48c	3.72c	4.23b	4.43a	4.49a
pH reading in bauxite soil					
Treatments	T1	T2	T3	T4	T5
Initial reading	4.66b	4.64b	6.43a	6.49a	6.40a
Final reading	4.50b	4.43b	4.65b	4.92a	4.93a

Table 2 showed the pH of soils before and after treated in both types of soil. Initially, the pH increased in T2, T3, T4 and T5 compared to T1 which had the lowest pH in normal top soil and oxisols soil. This is due to the application of organic amendments of biochar and chicken manure that leads to the increase of pH and soil nutrients content. Biochar has the ability to improve soil fertility and soil chemical property because of its characteristics. It has a high surface area, porous, and able to absorb soluble organic matter and inorganic nutrients. Biochar also comprised of ash, which is substantial with available nutrients especially cations (Adekiya et al., 2020). A group researcher also mentioned that biochar is able to elevate soil pH by releasing basic cations such as calcium (Ca), potassium (K), magnesium (Mg), and silicon (Si) (Phares et al., 2017).

These basic cations can form alkaline oxide or carbonates and reacts with H^+ and Al^{3+} and decrease exchangeable acidity thus, raise soil pH. Although, states that application of NPK fertilizer alone did not able to raise soil pH (Adekiya et al., 2020). Consequently, the elevation of initial soil pH in T5 are probably cause by the addition of biochar and organic fertilizers into the treatment. A study by also found that application of organic manures helps to increase the soil pH (Schulz and Glaser, 2012). However, in both type of soil, the pH were observed to be decreased after 5 weeks of applications. Treatment 5 had the highest value pf pH compared to other treatments with significant value compare to T1, T2 and T3 ($p < 0.05$) This is due to the production of organic acids by plants that had been released into the soil. Besides, the action of nutrient uptake into plant is countered by release extra H^+ ions into the soil solution especially if the nutrient is phosphorus (Toncea et al., 2015).

The increment of H^+ ions in soil solution could decrease the soil pH and making them acidic. Besides, overtime, decomposition process by soil microbes could lead to decrease in soil pH. At first, the soil pH raise because of the microbes in soil breaks down plant material to ammonium through a mineralization process. Then, the ammonium will be converted into nitrate through a process called nitrification. This process causes the pH to goes down and drop even more if the nitrate is lost to leaching (Mc Cauley et al., 2017). Furthermore, some study stated that addition of organic manures could result in drop of pH in alkaline soil (Yaduvanshi, 2003; Mahmood et al., 2017).

7.2 Total of organic carbon (TOC) in soil

Similar to soil pH, soil organic carbon is also one of indicators in measuring soil fertility and quality. The soil organic carbon influenced wide range of soil physical, chemical, and biological properties. It has been mentioned that changes in SOC could improve soil deterioration and fertility (Han et al., 2016). However, they are affected due to external factors. For example, reducing the usage of fertilizer especially nitrogen, could decrease the level of SOC. On the other hand, climate change could also affect soil carbon changes due to increasing temperature that could increase the rate of decomposition of organic matter (Bhagal et al., 2009).

Table 3: Initial and final reading of total organic carbon (TOC) (%) in normal topsoil and oxisols

Total organic carbon (TOC) in normal topsoil					
Treatments	T1	T2	T3	T4	T5
Initial reading (%)	0.48c	0.96a	0.30d	0.66b	0.12e
Final reading (%)	0.33d	0.72b	0.42c	1.02a	0.96a
Total organic carbon (TOC) in oxisols					
Treatments	T1	T2	T3	T4	T5
Initial reading (%)	0.60c	1.44a	0.90b	0.78c	1.02b
Final reading (%)	0.72c	1.26a	1.02b	1.35a	1.50a

Application of biochar to any types of soil has the benefits of increasing soil carbon and organic matter status compared to synthetic fertilizers (Arif et al., 2017). This can be observed in the initial reading of both soils treated with biochar (T2). Treatment 2 showed a significantly highest reading of TOC with value of 0.96 and 1.44% in normal topsoil and oxisols soil, respectively ($p < 0.05$). However, after 5 weeks of treatment, T4 and T5 of both soils had a higher value compared to T1, T2 and T3. Treatment

1 showed the least content of TOC due to no presence of organic soil amendments.

8. CONCLUSION

The applications of biochar, chicken manure, and combination of chicken manure and NPK fertilizer along with biochar had been proved to have a significant effect on the growth of water spinach planted in both oxisols and normal topsoil compared to water spinach that did not receive any organic amendments (T1). For normal topsoil, T5 showed a significant effect on the growth of water spinach with a significant increase in the number of stems, number of leaves and its fresh yield. In oxisols soil, which characterized as an infertile soil with low pH value, applications of organic amendments had showed pH towards neutral in treatment 3, 4 and 5. Treatment 5 with a significant higher content of TOC ($p < 0.05$) showed the best treatment that can be used in treating oxisols soil for crop planting. A significant effect is found on the length of plants, number of stems, and number of leaves of the water spinach.

REFERENCES

- Adekiya, A.O., Agbade, T.M., Ejue, W.S., Aboyeji, C.M., Dunsin, O., Aremu, C.O., Adesola, O.O., 2020. Biochar, poultry manure and NPK fertilizer: Sole and combine application effects on soil properties and ginger (*Zingiber officinale* Roscoe) performance in a tropical Alfisol. *Open Agriculture*.
- Ahmad, T., Shah, S.T., Ullah, F., Ghafoor, F., Anwar, U., 2017. Effect of organic fertilizer on growth and yield of coriander. *International Journal of Agriculture and Environmental Research*, 3 (1), Pp. 116-120.
- Arif, M., Ilyas, M., Riaz, M., Ali, K., Shah, K., Haq, I.U., Fahad, S., 2017. Biochar improves phosphorus use efficiency of organic-inorganic fertilizers, maize-wheat productivity and soil quality in a low fertility alkaline soil. *Field Crops Research*, 214, Pp. 25-37.
- Beinroth, F.H., Eswaran, H., Palmieri, F., Reich, P.F., 1996. Properties, classification and management of oxisols. Washington, D.C.: USDA-National Resources Conservation Service.
- Bhagal, A., Nicholson, F.A., Chambers, B.J., 2009. Organic carbon additions: Effects on soil bio-physical and physico-chemical properties. *European Journal of Soil Science*, 60 (2), Pp. 276-286.
- Chand, S., Anwar, M., Patra, D.D., 2006. Influence of long-term application of organic and inorganic fertilizer to build up soil fertility and nutrient uptake in mint-mustard cropping sequence. *Communications in Soil Science and Plant Analysis*, 37 (1-2), Pp. 63-76.
- Fernández, F.G., Hoef, R.G., 2009. Managing Soil pH and Crop Nutrients. In 1154892010 867870130 E. D. Nafziger (Ed.), *Illinois Agronomy Handbook 24th ed.*, Pp. 91-112. Urbana, Illinois: University of Illinois.
- Han, S.H., An, J.Y., Hwang, J., Kim, S.B., Park, B.B., 2016. The effects of organic manure and chemical fertilizer on the growth and nutrient concentrations of yellow poplar (*Liriodendron tulipifera* Lin.) in a nursery system. *Forest Science and Technology*, 12 (3), Pp. 137-143.
- Hartemink, A.E., Zhang, Y., Bockheim, J.G., Curi, N., Silva, S.H., Grauer-Gray, J., Krasilnikov, P., 2020. Soil horizon variation: A review. *Advances in Agronomy*, 160 (1), Pp. 125-185.
- Hazra, G., 2016. Different types of eco-friendly fertilizers: An Overview. *Sustainability in Environment*, 1 (1), Pp. 54-70.
- Hossain, M.K., Strezov, V., Chan, K.Y., Nelson, P.F., 2010. Agronomic properties of wastewater sludge biochar and bioavailability of metals in production of cherry tomato (*Lycopersicon esculentum*). *Chemosphere*, 78, Pp. 1167-1171.
- Joseph, S.D., Camps-Arbestain, M., Lin, Y., Munroe, P., Chia, C.H., Hook, J., Amonette, J.E., 2010. An investigation into the reactions of biochar in soil. *Soil Research*, 48 (7), Pp. 501-515.
- Kolton, M., Harel, Y.M., Pasternak, Z., Graber, E.R., Elad, Y., Cytryn, E., 2011. Impact of biochar application to soil on the root-associated bacterial community structure of fully developed greenhouse pepper plants. *Appl. Environ. Microbiol.*, 77, Pp. 4924-4930.
- Li, H., Feng, W., He, X., Zhu, P., Gao, H., Sun, N., Xu, M., 2017. Chemical

- fertilizers could be completely replaced by manure to maintain high maize yield and soil organic carbon (SOC) when SOC reaches a threshold in the Northeast China Plain. *Journal of Integrative Agriculture*, 16 (4), Pp. 937-946.
- Liu, Z., He, T., Cao, T., Yang, T., Meng, J., Chen, W., 2017. Effects of biochar application on nitrogen leaching, ammonia volatilization and nitrogen use efficiency in two distinct soils. *J. Soil Sci. Plant Nutr.*, 17, Pp. 515-528.
- Novak, J.M., Lima, I., Xing, B., Gaskin, J.M., Steiner, C., Das, K.C., Ahmedna, A.M., Rehrah, D., Watts, D.W., Busscher, W.J., Schomberg, H., 2009. Characterization of designer biochar produced at different temperatures and their effects on a loamy sand. *Annal. Environ. Sci.*, 3, Pp. 195-206.
- Ostadi, A., Javanmard, A., Machiani, M.A., Morshedloo, M.R., Nouraein, M., Rasouli, F., Maggi, F., 2020. Effect of different fertilizer sources and harvesting time on the growth characteristics, nutrient uptakes, essential oil productivity and composition of *Mentha x piperita* L. *Industrial Crops and Products*, 148, Pp. 112290.
- Phares, C., Osei, B., Tagoe, S., 2017. Effects of biochar and poultry manure on the composition of phosphorus solubilizing fungi and soil available phosphorus concentration in an oxisol. *Journal of Agriculture and Ecology Research International*, 12 (2), Pp. 1-15.
- Sung, C.B., Ishak, C.F., Abdullah, R., Othman, R., Panhwar, Q.A., Aziz, M., 2017. Soil Properties (Physical, Chemical, Biological, Mechanical). In M. A. Ashraf, R. Othman, & C. F. Ishak (Eds.), *Soils of Malaysia* (1st ed., pp. 103-154). Boca Raton: Taylor & Francis.
- Thomas, G.W., 1996. Soil pH and Soil Acidity. In D. L. Sparks, A. L. Page, P. A. Helmke, R. H. Loeppert, P. N. Soltanpour, M. A. Tabatabai, et al. (Eds.), *Methods of Soil Analysis: Part 3 - Chemical Methods* (pp. 475-490). Madison, Wisconsin: Soil Science Society of America.
- Ventura, M., Sorrenti, G., Panzacchi, P., George, E., Tonon, G., 2013. Biochar reduces short-term nitrate leaching from A horizon in an Apple Orchard. *J. Environ. Qual.*, 42, Pp. 76-82.
- Xu, H.L., Wang, R., Xu, R.Y., Mridha, M.A., Goyal, S., 2003. Yield and quality of leafy vegetables grown with organic fertilizations. *Acta Horticulturae*, (627), Pp. 25-33.
- Yan, F., Schubert, S., Mengel, K., 1996. Soil pH changes during legume growth and application of plant material. *Biology and Fertility of Soils*, 23 (3), Pp. 236-242.
- Yuan, J.H., Xu, R.K., 2011. The amelioration effects of low temperature biochar generated from nine crop residues on an acidic Ultisol. *Soil Use Manage.*, 27, Pp. 110-115.
- Zheng, W., Sharma, B.K., 2020. Agronomic Effect of Combined Application of Biochar and Nitrogen Fertilizer: A Field Trial. In E. Meers, G. L. Velthof, E. Michels, & R. Rietra (Eds.), *Biorefinery of inorganics: Recovering mineral nutrients from biomass and organic waste*, Pp. 301-310. Hoboken, New Jersey: John Wiley & Sons.

