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Effect of Biochar and Water Level on Increasing Availability and Water Use Efficiency for Maize in Vertisol from Jeneponto South Sulawesi

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Abstract—*This study aims to determine the effect of biochar and water level on improving water retention and water use efficiency of corn crops in vertisol. The soil sample was taken from Jeneponto south Sulawesi. This research used split-plot design. The main plot treatment is a soil amendment consisting of two factors ie without biochar and Biochar,sub plot treatment is a water used level consisting of 4 levels ie 100%, 90%, 80%, and 70% field capacity. Observed parameters include field capacity, permanent wilting point, available water, the crops water consumption, crop matter use efficiency, and water use efficiency. The results showed that biochar was able to increase water retention and water use efficiency at low water used level conditions.*

Keywords— Biochar, Water Level, Availability and Water Use, and Vertisol.

I. INTRODUCTION

Vertisol is one type of soil that is widely used for agricultural because it has a fairly good fertility rate, characterized by high cation exchange capacity, relatively basic saturation, high water holding capacity , with a neutral to alkaline pH ranging from 6-8.5, but water available low for plants (Deckers*et al.*, 2001; Prasetyo, 2007).

The high water-binding ability of Vertisol is due to the high clay content that may reaches more than 30% in all horizon with montmorillonite as its main mineral (FAO, 1990). May a montmorillonite is a clay mineral that has a very small in size so that the surface area clay becomes high. According to Foth (1998), the fine grain size of the clay affects the pore space and the adsorptive surface area, thereby increasing water storage capacity. The more surface area the more water and ions can be absorbed, 2: 1 clay mineral has surface area of 700-800 m2 g^{-1}(smectite) and 57-152 m2g^{-1} (mica-smectiteinterstification), 1: 1 (kaolinite) 7-30 m2 g^{-1}, while allophane has surface area of 157 -484 m2 g^{-1} (Tan, 1998).

Hanafiah (2007) reported that groundwater content in the field capacity conditions (1/3 atm) in sand, silt, and clay were 15%, 40%, and 55%, respectively. In Vertisol high water content conditions are also followed by high moisture content at the condition of the permanent wilting point, so the high amount of water available does not guarantee adequate availability for the plant.

Efforts to improve soil properties of vertisol can be done by administering biochar (Gao Lu *et al.*, 2014; Shackley*et al.*, 2012; Atkinson *et al.* 2010; Van Zwietene*t al.*, 2010). Biochar significantly increases the amount of water available in vertisol (Gao Lu *et al.*, 2014; Fangfang and Lu, 2014; Ouyang*et al.*, 2013). One of the ingredients that can be used as a source of biochar is rice husk. Rice husk is an easy agricultural waste in research location and the surrounding area.

Soil improvement in Vertisol is expected to increase water availability for plants and avoid crops from drought. Drought conditions are responsible for 50% crop yield decline in the world (Wood, 2005). Plants with water shortages generally have smaller size compared to normal growing plants (Kurniasari*et al.*, 2010). Lack of water causes a very significant decrease in yield and even the cause of death in plants (Salisbury and Ross, 1992).

Research on the utilization of biochar to improve physical properties and water availability has been widely used (Asai*et al.*, 2009; Atkinson *et al.*, 2010; Chan *et al.*, 2007, 2008; Glaser *et al.*, 2002; Laird *et al.*, 2010; Liu *et al.*, 2012; Major *et al.*, 2010). Based on literature searches, previous studies have studied more appropriate doses of biochar to improve soil properties (Jacek*et al.*, 2017, Pandian*et al.*,2016, Scilowska*et al.*, 2015, Fangfang and Lu, 2014; Gao Lu *et al.*, 2014). So far, further research on how biochar response in improving water availability in various soil moisture conditions has not been done. Based on the above

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description, this study is deemed necessary to determine the effect of soil biochar and moisture level on improving water retention and water used efficiency in vertisol.

II. MATERIALS AND METHODS

The study was prepared based on a split-plot design with a completely randomized design baseline design. Where the main plot factor is the soil amandement (A) and the plot factor is the water content level (K).The main plot factor consists of A0: no soil enhancer, A1: Biochar. Sub plot factor is K1: 100% field capacity, K2: 90% field capacity, K3: 80% Field Capacity, and K4: 70% Field Capacity. there are 8 treatment combinations and repeated 3 times, so there are 24 units of an experimental block.

Media Planting Preparation

Media planting comes from the Punagaya village Bangkala district Jeneponto. The soil is described as the Vertisol soil developed from the limestone parent material. The soil is taken from a depth of 0-20 cm and then dried, mashed and sieved with a 2 mm diameter strainer. The soil is weighed as much as 12 kg and given the soil enhancer according to the treatment of biochar as much as 6 % of the total weight of the soil (Fangfang and Lu, 2014; Gao Lu *et al.*, 2014). Giving water is done by weighing the pot to know the amount of water that should be given according to the treatment. The initial soil properties can be seen in Table 1.

Tabel.1: Soil characteristics

No	Soil Parameters	
1.	pH (H20)	6,7
2.	Organic matter	4,6 %
3.	Organic Carbon	2,6 %
4.	CEC	22,5 cmolkg-^{1}
5.	Bulk Density	1,2 g cm^{-3}
6.	silt	1,55 %
7.	pasir	24,9 %
8.	clay	72,23 %
9.	Porosity	56.49 %
10.	Field Capacity	42 %
11.	Permanent Wilting Point	31 %

Bulk density analysis was done by gravimetric method. Porosity was determined based on weight value of particle type and weight by using gravimetric method as follows:

Porosity (% volume) = (1- BD (Bulk Density) / PD (Particle Density is 2.65) X 100% (1)

Where BD is bulk density and PD is partikel density use a value of 2.65 for mineral soil. Water retention analysis using Pressure method Plate apparatus at pF 2.54 and pF 4.2 (Capillarity and pF curve equations) (Richards and Fireman, 1943).Water use efficiency in this study used the amount of water given during plant growth (mm) and dry weight of the plant (g) harvested at 60 days old plants, by the formula:

$$WUE = \left(\frac{E_y}{E_t}\right) \times 100 \qquad (2)$$

Where WUE is water use efficiency (g.mm-1), EyThe Dry weight of the plant (g), Et is the plant water consumption (mm)

Statistical Analysis

The result were analyzed by using variance analysis and followed by LSD at 5% level using STAR (Statistical Tool for Agricultural Research).

III. RESULT AND DISCUSSION

Bulk Density and Soil Porosity

Statistical analysis showed no interaction between the treatments of soil amendment with the water level. Biochar is able to decrease bulk density and increase soil porosity significantly, whereas biochar treatment decreases bulk density from 0.897 to 0.775 gcm^{-3}and increases porosity from 66.13% to 70.72%. Biochar's ability to decrease bulk density and soil porosity was also reported by Jacek*et al.* (2017) in the HaplicPodzol research in which biochar 4,5 and 3 t.ha-1 significantly reduced bulk density after 2 years of application. Biochar 2.5 to 5 t.ha-1 was found to decrease bulk density from 1.41 to 1.3 g.cm^{-3} compared to the application of manure on Alfisol soil (Pandian*et al.*, 2016). Castellini*et al.* (2015) reported that biochar administration significantly balances the amount of liquid phase and gas in the soil and reduces the solid phase in the soil.

Table.2: Bulk density and soil porosity

Treatments	Bulk Density (gcm^{-3})	Soil Porosity (%)
	Soil Amendment	
A0 (Control)	0.897 a	66.13 b
A1 (Biochar)	0.775 b	70.72 a
	Water Level	
K1 (100 % FC)	0.877 a	67.04 b
K2 (90 % FC)	0.867 a	67.30 b
K3 (80 % FC)	0.788 b	70.25 a
K4 (70 % FC)	0.818 ab	69.12 ab

Note : numbers followed by different letters are statistically different ($P<0.05$)

The treatment of moisture level showed that the K3 treatment (80% FC) gave the best result against the decrease of bulk density and porosity increase of 0.788 $g.cm^{-3}$ and 70.25%, which was significantly different with K1 treatment (0.877 g.cm-3 and 67.04 %) and K2 (0.867 $g.cm^{-3}$ and 67.30%) and differed from K4 treatment (0.818 g.cm-3 and 69.12%). The treatment of K1 (100% FC) and K2 (90% FC) caused the soil to become more humid and the air in the soil decreased, whereas on the soil K3 and K4 treatment were drier and the pore of soil was filled with air. In the condition of K3 and K4 is the development of plant roots to be better and affect the decrease of bulk density and increased porosity of the soil.

Water Retention

The results of the analysis of variance indicate that there is an interaction between the treatment of soil enhancer and moisture level to field capacity, permanent wilting point, and available water.

Field Capacity

Comparison of soil amendment factor (A) at various levels of water content (K) showed that treatment A0 (control) was significantly different from treatment A1 (Biochar) at high water content levels K1 (100%) and K2 (90%), how ever at water content of K3 (80%) and K4 (70%) there is no real difference between A0 (control) and A1 (Biochar).

The comparison of water content (K) factor at soil amendment level (A) shows the field capacity at the highest A0 (control) treatment achieved at K1 treatment (100%) of 0.597% followed by K2 treatment (90%) of 0.56% and significantly different with K3 (80%) and K4 (70%). In Treatment A1 (Biochar) there was no significant difference between the various levels of water content (Table 3).

Table.3: The effect of soil amendment an water level on field capacity

Treatments	Water Level			
	K1 (100 % FC)	K2 (90 % FC)	K3 (80 % FC)	K4 (70 % FC)
Soil Amendment				
A0 (Control)	0.597aA	0.560aA	0.433aB	0.493aB
A1 (Biochar)	0.480bA	0.430bA	0.450aA	0.446aA

Note : numbers followed by different letters are statistically different ($P<0.05$). Different small letters indicates the Comparison of A at each level of K. Different capital letters shows Comparison of K at each level of A.

Permanent Wilting Point

Comparison of factor A at level K showed that the treatment of A0 (control) and A1 (Biochar) was significantly different at levels of water K1 (100%), K2 (90%), K4 (70%) and not significantly different at K3 level (80 %).

The comparison of factor K at level A shows that there is no real difference of permanent wilting point on treatment A0 (control). At treatment A1 (Biochar), the highest wilting point reached at K1 (100%), but content was not significantly different with K3 treatment (80%) danK4 (70%), but significantly different from K2 treatment (90%)(Table 4).

Table.4: The effect of soil amendment an water level on permanent wilting point

Treatments	Water Level			
	K1 (100 % FC)	K2 (90 % FC)	K3 (80 % FC)	K4 (70 % FC)
Soil Amendment				
A0(Control)	0.370 aA	0.356 aB	0.293 aC	0.337 aB
A1(Biochar)	0.307 bA	0.263 bB	0.283 a AB	0.283 bAB

Note : numbers followed by different letters are statistically different (P<0.05). Different small letters indicates the Comparison of A at each level of K. Different capital letters shows Comparison of K at each level of A.

Water available

Comparison of A at level K shows a significant difference between A0 (control) and A1 (biochar) occurring at treatment K1 (100%) and K2 (90%) but not significantly different at K3 and K4.

Comparison of K at level A indicated that the highest available water A0 (control) was achieved at the treatment of K1 and K2 and was significantly different from the treatment of K3 and K4. While treatment A1 (Biochar) showed no significant difference in water available at various levels of water content (table 5).

Table.5: The effect of soil amendment and water level on water available

Treatments	Water Level			
	K1 (100 % FC)	K2 (90 % FC)	K3 (80 % FC)	K4 (70 % FC)
Soil Amendment				
A0(Control)	0.267 aA	0.203 aA	0.170 aB	0.157 aB
A1(Biochar)	0.173 bA	0.170 bA	0.167 aA	0.163 aA

Note : numbers followed by different letters are statistically different (P<0.05). Different small letters indicates the Comparison of A at each level of K. Different capital letters shows Comparison of K at each level of A.

The result of statistic analysis for field capacity, permanent wilting point and water available on the comparison of soil enhancer (A) to water content level (K) showed that there was a significant difference between treatment A0 and A1 at water level K1 and K2, while on treatment K3 and K4 is not significantly different. This shows that at high levels of water content, A0 (control) treatment is able to bind water better than in treatment A1 (Biochar), but in low water content treatments, biochar is able to bind water better than control treatment. This result is in line with the Devereux et al. (2012) study which states that the addition of real biochar increases the water holding capacity when soil conditions dry out.

Comparison of moisture level (K) to the soil enhancer (A), indicating that the field capacity, permanent wilting point, and water available at the A0 treatment (control) decreased as water supply decreased. While in treatment A1 (Biochar) showed no real difference in field capacity, permanent wilting point, and water available at all levels of water content. The results of this study are in line with the results of the Fangfang and Shenggao (2014) study which stated that rice bran biochar on vertisol increases groundwater content in field capacity, permanent wilting point, and water available to plants.

The Crops Water Consumption

Table.6: Effect of Soil Amendment (A) and Water Level (K) on the Plant water Consumption

Treatments	Water consumption (mm)
Soil Amendment	
A0 (Kontrol)	125.49 b
A1 (Biochar)	163.43 a
Water Level	
K1 (100 % KL)	216.72 a
K2 (90 % KL)	146.04 b
K3 (80 % KL)	113.91 c
K4 (70 % KL)	101.18 c

Note :numbers followed by different letters are statistically different (P<0.05)

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The results of statistical analysis showed no interaction between treatment of soil amendment (A) with water level (K), but there was significant difference between the influence of soil amendment (A) and water content level (K), in which biochar administration increased the amount of water 163.43 mm in maize compared with A0 treatment (125.49 mm).

For the comparison of the treatment of moisture content, the largest amount of water consume by corn crops was achieved at K1 treatment (216.72 mm) followed by K2 (146.04 mm), K3 (113.91 mm), and K4 (101.18 mm) respectively. This is in line with Handayani (2004) study which states that the lower the moisture level of the soil during watering, the less water it will be. The reduced water the treatment responds to the plant by adjusting for water use during its growth phase. The plant responds to drought conditions in two ways by changing the distribution of new assimilates and regulating the level of stomatal opening to reduce the loss of water through transpiration (Mansfield and Atkinson, 1990).

The Dry weight of the plant

For the dry weight component of the plant, the statistical analysis shows that there is an interaction between the soil amandment (A) and the water content (K) level (Figure 2). For comparison A at level K, it was seen that treatment A1 (biochar) gave the highest yield and was significantly different from treatment A0 (control).

Comparison of water level (K) at soil amendment level (A) shows that the dry weight of the plant decreases in line with the decreasing amount of water administered both on treatment A0 (control) and A1 (Biochar). Maize is a very sensitive plant with soil moisture, where water is the limiting factor. The Khalili et al. (2014) study showed that the weight of plant biomass treated with drought stress significantly decreased compared to the control treatment. Previous research also proves that the decline in plant biomass is closely related to the decrease in soil moisture (Stone *et al.*, 2001, Osborne *et al.*, 2002).

Table.6: The effect of soil amendment and water level on dry weight

Treatments	Water Level			
	K1 (100 % FC)	K2 (90 % FC)	K3 (80 % FC)	K4 (70 % FC)
Soil Amendment				
A0(Control)	17.346 bA	15.355 bB	12.903 bC	6.489 bD
A1(Biochar)	76.823 aA	50.795 aB	46.940 bC	45.610 aD

Note : numbers followed by different letters are statistically different ($P<0.05$). Different small letters indicates the Comparison of A at each level of K. Different capital letters shows Comparison of K at each level of A.

Water Use Efficiency

There is an interaction between the treatment of soil enhancer and the level of water content to the efficiency of water use in corn crops. The comparison of the median treatment of factor A at level K showed that treatment A1 (Biochar) gave the highest yield and was significantly different at different levels of water content than the A0 (control) treatment. Biochar's ability to increase the efficiency of plant water use caused biochar to increase the availability of plant nutrients, improve cation exchange capacity so as to improve crop growth and yield (Atkinson *et al.*, 2010; Mukherjee and Lal, 2013). This is in line with Yeboah's (2016) study which stated that 5 ton/ha biochar significantly increased corn yield by 2.5 ton H-1 compared to without biochar. Previous studies also suggest that Biochar can provide nutrients for plants, especially cations such as K, Ca and Mg (Danik***et al.,*** 2011) and ensure nutrient availability for plants (Zhang *et al.*, 2016).

Table.7: The effect of soil amendment and water level on water use efficiency

Treatments	Water Level			
	K1 (100 % FC)	K2 (90 % FC)	K3 (80 % FC)	K4 (70 % FC)
Soil Amendment				
A0(Control)	8.667 bC	11.420 bB	14.519 bA	9.197 bC
A1(Biochar)	33.999 a AB	32.350 aB	33.871 a AB	34.699 aA

Note : numbers followed by different letters are statistically different ($P<0.05$). Different small letters indicates the Comparison of A at each level of K. Different capital letters shows Comparison of K at each level of A.

For the treatment of water level (K) ratio at soil enhancer level (A) showed that the efficiency of water use in the K3 treatment gave the best result for corn corp on treatment A0 (control) and K4 level gave the best result of 36.69% for treatment A1 (Biochar) was significantly different from K2 treatment (32.35%) and was not significantly different with K1 and K3 treatment. The high efficiency of water usage at K3 level for treatment A0 (control) and K4 level on treatment A1 (Biochar) showed that under high humidity conditions (K1 and K2 levels) nutrient absorption did not run optimally, so that water content is appropriate for treatment A0 (Control) is at the level of K2 80% of the field capacity, under the condition of the moisture content the availability of nutrients decreases as the permanent wilting point increases. Provision of biochar is proven to increase the efficiency of water use at low levels of water content.

IV. CONCLUSION

1. Biochar is able to increase field capacity, reduce permanent wilting points and increase the amount of water available at all levels of water content.
2. Bbiochar feeding increases the amount of water consumption of the plant.
3. There is an interaction between the soil enhancer and the moisture content of the dry weight of the plant. The biochar treatment (A1) gave the best results compared to the treatment without biochar (A0). The dry weight of the plant decreases as the amount of water is decreased.
4. Biochar (A1) was able to increase the efficiency of water use compared to without biochar treatment (A0), and the highest result was obtained in combination of biochar treatment and lowest moisture content (K4).

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REFERENCES

[1] Asai, H., Samson, B. K., Stephan, H. M., Songyikhangsuthor, K., Homma, K., Kiyono, Y., Inoue, Y., Shiraiwa, T. &Horie, T. (2009). Biochar amendment techniques for upland rice production in Northern Laos 1. Soil physical properties, leaf SPAD and grain yield. Field Crops Research 111, 81–84.

[2] Atkinson, C.J., Fitzgerald, J., Hipps, N.A. (2010). Potensial mechanisms for achieving agricultura; benefits from biochar application to temperate soil : Review. Plant & Soil 337 : 1-18

[3] Castellini, M., Giglio, I., Niedda, M., Palumbo, A.D., Ventrella, D.(2015). Impact of biochar addition on physical and hydraulic properties of clay soil. Soil & Tillage Research 154 : 1-13.

[4] Chan, K. Y., Van Zwieten, L., Meszaros, I., Downie, A. & Joseph, S. (2007). Agronomic values of greenwastebiochar as a soil amendment. Australian Journal of Soil Research 45, 629–34.

[5] Deenik, J.I., Diarra, A., Uehara, G., Campbell, S., Sumiyoshi, Y., Antal Jr., M.J. (2011). Charcoal ash and Volatile matter effects on soil properties and plant growth in an acid Ultisol. Soil Sci. 176 : 336-345.

[6] Deckers, J., Sparrgaren, O., Nachtergele, F. (2001). Vertisol :*Genesis, Properties and Soilscape Management for Suitable developtment*. FAO, Rome. Itali.20 pp. cropping systems. Soil Tillage Res. 43, 131–167.

[7] Devereux, R.C., Sturrock, C.J., Mooney, S.C. (2012). The effects of biochar on soil physical properties and winter wheat growth earth and environmental. Earth and Environmental Science Transactions of the Royal Society of Edinburgh. 103: 13–18

[8] Fangfang Sun and Shenggao Lu. (2014). Biochars improve aggregate stability, water retention, and pore-space properties of clayey soil. J. Plant Nutr. Soil Sci. 177 :26–33

[9] FAO. (1990). Soil Map The World,1 : 5.000.000. Vol.1,Legend (Legend Sheet and Memoir), Paris.

[10] Foth, H, D. (1998). Dasar-dasarIlmu Tanah.Gadjah Mada University Press.Yogyakarta.

[11] Hanafiah, K, A., (2007). *Dasar-dasarIlmu Tanah*.Rajawali Pers. Jakarta.

[12] Gao Lu, S., Zaffar, M, Dan-Ping Chen, Cheng-Feng Wu. (2014). Porosity and pore size distribution of Ultisols and correlations to soil iron oxides. Catena 123:79-87

[13] Handayani, H. (2004). Pengaruh Tingkat Kelembaban Tanah Sebagai Awal Pemberian Air Dan Tambahan Pencahayaan Terhadap Jumlahdan Efisiensi Pemberian Air serta Pertumbuhandan Hasil Bunga Krisan (DendranthemagrandifloraTzvelev) Kultivar Puma. Jurnal Fakultas Pertanian Universitas Padjadjaran. Bandung.

[14] Jacek, P., Tomaszewska, D., Olezezuk, P., Rozyla, K. (2017). Effect of biochar application on the physical properties of haplicpodzol. Soil and Tillagr Research 174 : 92-103

[15] Khalili1, M., Naghavi, M.R., Alireza PourAboughadareh, A.P., Rad, H.N. (2013). Effects of Drought Stress on Yield and Yield Components in Maize cultivars (Zea mays L.).International Journal of Agronomy and Plant Production. Vol., 4 (4), 809-812

[16] Kurniasari, A. M. Adisyahputra, R. Rosman. (2010). PengaruhKekeringanpada Tanah Bergaram

http://dx.doi.org/10.22161/ijeab/3.3.45 *ISSN: 2456-1878*

NaClterhadap Pertumbuhan Tanaman Nilam. Jurusan Biologi FMIPA UI. Jakarta.

[17] Laird, D., Fleming, P., Wang, B., Horton, R. &Karlen, D.(2010). Impact of biochar amendments on the quality of a typical Midwestern agriclutural soil.Geoderma 158, 443–49.

[18] Major, J., Steiner, C., Downie, A. & Lehmann, J. (2009). Biochar effects on nutrient leaching. In Lehmann, J. L. & Joseph, S. (eds) Biochar for Environmental management: Science and Technology, 271–88. London: Earthscan

[19] Mansfield, T.A. dan C.J. Atkinson. (1990). Stomatal Behavior in Water Stressed Plants. Dalam: Alscherdan Cumming (Eds). Stress Response in Plant adaptation and Acclimation Mechanisms. Wiley Liss Inc., New YorkMengel, K and Kirkby, E.A. 2001. Principles of plant Nutrition, 5th edition, Kluwer Academic Publisher, Dordrecht.

[20] Mukherjee, A., and Lal, R. (2013). Biochar impacts on soil physical properties and greenhouse gas emission. Agronomy 3 : 313-339

[21] Orgutande, P.G., Abiodun, B.J., Ajayi, A.E., van de Giesen, N. (2008). Effect of charcoal production on soil physical properties in Ghana. Journal of Plant Nutrition & Soil Science 171: 591-596

[22] Osborne SL,Schepers JS, Francis DD, Schlemer M, R. (2002).Use of spectral radiance to estimate in-season biomass and grain yield in nitrogen and water-stressed corn. Crop Sci. 42: 165-171. and

[23] Ouyang, L., Wang, F., Tang, J., Yul, L., Zhang, R. (2013). Effects of biochar amendment on soil aggregates and hydraulic properties. Journal of Soil Science and Plant Nutrition 13 (4) : 991-1002

[24] Pandian, K., Gnasekaran, P., Subramaniayan, P., Chitraputhirapillai, S. (2016). Effect of biochar amendment on soil physical, chemical and biological properties and groundnut yield in rainfedalfisol of semi arid tropics. Agronomy and Soil science

[25] Prasetyo, B.H. (2007). *Perbedaan Sifat-Sifat Tanah Vertisol Dari Berbagai BahanInduk*. JurnalIlmu-Ilmu Pertanian Indonesia. Volume 9, No. 1, Halaman 20-31.

[26] Richards, L. A., and L. A. Fireman. (1943). Pressure plate apparatus for measuring moisture sorption and transmission by soils. Soil Sci. 56: 395-404.

[27] Salisbury, F.B. and C.W. Ross. (1992). Plant Physiology.4rd Ed. Wadsworth Publishing Company. California.

[28] Scislowska, M., Wlodarczykl, R., Kobyleckil, R., Bis, Z. (2015). Biochar to improve the quality and productivity of soils. Journal of Ecological Engineering Volume 16(3) : 31–35 .

[29] Shackley, S., Carter, S., Knowles, T., middelink, E., Haefele, S., Sohi, S., Cross, A., Haszeldine, S. (2012). Suistaninable gasification-biochar systems? A case of rice-husk gasification in Cambodia, Part 1 : Context, chemical propertises, environmental and health and safety issues, Energy Policy 42 : 49-58

[30] Sheng Gao Lu, Zaffar, M, Dan-Ping Chen, Cheng-Feng Wu. (2014). Porosity and pore size distribution of Ultisols and correlations to soil iron oxides. Catena 123:79-87

[31] Stone, P. (2001) The effects of heat stress on cereal yield and quality. In: Crop Responses and Adaptations to Temperature Stress (ed Basra AS), pp. 243–291. Food Products Press, Binghamton, NY, USA.

[32] Tan, K, H. (1982). *Dasar-dasar Kimia Tanah*.Gadjah Mada University Press. Yogyakarta

[33] Fru, B., & Angwafo, T. (2018). Effect of Biochar issued from Crop Wasteon the Yield of variety 8034 Cassava in the Humid-Forest Agroecological Zone, Cameroon. *International Journal of Horticulture, Agriculture and Food Science*, *2*(1), 13-27. doi: 10.22161/ijhaf.2.1.2

[34] Van Zwieten, I., Kimber, S., Morris S., Chan K.Y., Downie, A., Rust, J., Joseph, S., Cowie A. (2010). Effect of Biochar from slow pyrolisis of papermill waste on agronomic performance and soil fertility. Plant & Soil 327 : 235-246

[35] Wood, A.J. (2005). Eco-physiological adaptations to limited water environments. Dalam: Jenks MA, Hasegawa PM (ed) Plant Abiotic Stress. Blackwell Publishing Ltd, India. h 1-13.

[36] Yeboah, E., Asamoaha, G., Kofib, B., Abunyewac, A.A. (2016). Effect of biochar type and rate of application on maize yield indices and water use efficiency on an Ultisol in Ghana. Energy Procedia 93: 14 – 18

[37] Zhang, Y., Idowu, I., Brewer, C.E. (2016). Using Agricultural Residue biochar to improve soil quality of desert soil.Agricultur (6) : 1-11