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CLIMATE AND SOIL CHARACTERIZATION IN IRRIGATION PLANNING FOR BELL PEPPER IN THE HUMID CLIMATE OF OMU-ARAN, NIGERIA

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ABSTRACT

This study shows the relationship between soil physicochemical properties and water use of Capsicum annuum L. (Bell pepper) grown in a hydraulic weighing lysimeter. A hydraulic weighing lysimeter made from PVC drum was designed, constructed and installed to study the crop water use of Bell pepper. Analyses were carried out to determine the physico-chemical properties of soil and crop water use of Bell pepper in humid savanna zone of Omu-Aran, Nigeria. The soil in the study area is a slightly alkaline and the soil micro and macro porosity at depth 0-15cm to be 0.194, 0.536, and 0.73 respectively with that of depth 15-30 cm to be 0.115, 0.425, and 0.54 respectively. Also, bulk density for the 0-15 cm depth was 0.714 g/cm^3 while that of 15-30cm was 1.261g/cm^3 indicating that sample for 15-30cm is more compacted. The results also revealed that the ETc of the bell pepper crop increases during the development and mid stages hence the crop water use is highest during the crop growth mid stage.

Keywords: crop water use, growth stages, soil properties, CROPWAT, Bell pepper.

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1. INTRODUCTION

Bell Pepper *(Capsicum annuum L.)* is the commonly known domesticated pepper species in the world. The crop is a native of tropical South America especially Brazil which is thought to be the native home of peppers [1-2]. The fruit usually has a sweeter flavor, when green fruit are allowed to turn yellow or red at full maturity depending on the species [3]. Bell pepper is a warm-season crop and grow best at temperatures between 18 and 30°C. They can tolerate different soil types although sandy soils warm faster in spring and are good for early planting. The soil should have a pH between 6 and 7. Peppers will not tolerate water saturated soil and should be planted in a well-draining soil or raised bed. Peppers should be planted in an area that receives full sun for most of the day (Plant Village).

Omu Aran is located in the North-central area of Nigeria and lies in the middle belt region of Nigeria. It is located in the guinea savanna and enjoys moderate dry and wet seasons, with heavier rains falling in the double maxima months of June and September. The derived guinea savanna grassland dominates the Northern parts of the state while some parts of Southern Kwara falls within the derived savanna zone of Nigeria. Consumptive use of water by a crop is a function of the growth stage of crop and reference evapotranspiration (ETo). Consumptive use of water by a particular crop is conventionally determined from the reference evapotranspiration, the requirement of a standard crop under the applicable climatic conditions, and a crop factor relating to the growth stage of that particular crop A detailed knowledge of crop evapotranspiration from the period of crop emergence to maturity is essential for proper irrigation scheduling, efficient use of water resources optimal allocation of water to crops and for the decision making in agriculture [4].

There are no experimental water use estimates for bell pepper and other arable crops grown in the study area. Several authors have provided guidelines for crop water requirement in other places but not in the study area. Also, lysimetric experiment has been adopted in other places but none has been developed for water requirement estimation in the study area. Bell pepper cultivation is largely restricted to the rainy season in (sub-Sahara Africa) when precipitation is adequate. The insufficient knowledge of the evapotranspiration and crop growth factor during off seasons and limited water supply prevents farmers from raising Bell pepper. Pepper has a total growing period of 170 days with the initial stage of 30 days, the crop development stage of 40 days, and the mid-season stage of 70 days while the late season stage of 30 days [5]. The Crop factors (Kc) for the initial stage was found to be 0.35, the crop development stage as 0.70 and the mid-season stage as 1.05 while the late season stage is 0.90 from the same study in Abeokuta, South Western Nigeria.

The Kc values presented by [6] are typical values expected for average Kc under a standard climatic condition. The single (time-averaged) crop coefficients, Kc, and mean maximum plant heights for non-stressed, well-managed crops in sub humid climates (RHmin ≈ 45%, u2 ≈ 2 m/s) for use with the FAO Penman-Monteith ETo. Lysimeter (evapotranspiration) method provides the only direct measurement of ET and is frequently used to study climatic effects on ET and to evaluate estimating procedures. Lysimeters are set up to measure water balances; water adds, water retained by the soil, and water lost through sources of evapotranspiration and deep percolation [7].

In the crop coefficient approach the crop evapotranspiration, ETc, is calculated by multiplying the reference crop evapotranspiration, ETo, by a crop coefficient, Kc:

$$ETc = Kc\ ETo \tag{1}$$

Where: ETc crop evapotranspiration [mm d^{-1}],

Kc crop coefficient [dimensionless],

ETo reference crop evapotranspiration [mm d^{-1}].

Most of the effects of the various weather conditions are incorporated into the ETo estimate. The Kc in Equation 1 predicts ETc under standard conditions. A weighing lysimeter provides a direct measure of the amount of water used in evaporation and transpiration by isolating and continuously monitoring a vegetated area in a field [8].

2. MATERIAL AND METHODS

2.1. The study Area

The Research was carried out at the Teaching and Research Farm of Landmark University, Omu-Aran. The Teaching and research farm lie in the humid plain agro-ecological region of Southern Guinea Savannah Nigeria. Omu-Aran is positioned on latitude 8° 8′00″ N and longitude 5°6′00″ E, on altitude of 564m above sea level. The climate is a tropical maritime with a lengthy rainy season. The area is characterized by moderate weather with an annual daily average Temperature range from 16°C – 32°C and yearly variation of ± 10°C to 20°C and average annual rainfall of 500 – 1500mm spread over 6-8 months of the year, subjected to modest variation of hot and cool as the season changes [9]. It lies in the region with peak rainfall in Kwara State as it is neighbored by the rainforest and the derived savanna in the North central (middle belt) of Nigeria. The location of OmuAran within kwara state is shown in figure 1. The area is partially gauged because the only automatic agro-meteorological station in Landmark University was installed in June 2014 and has a few years record of weather data.

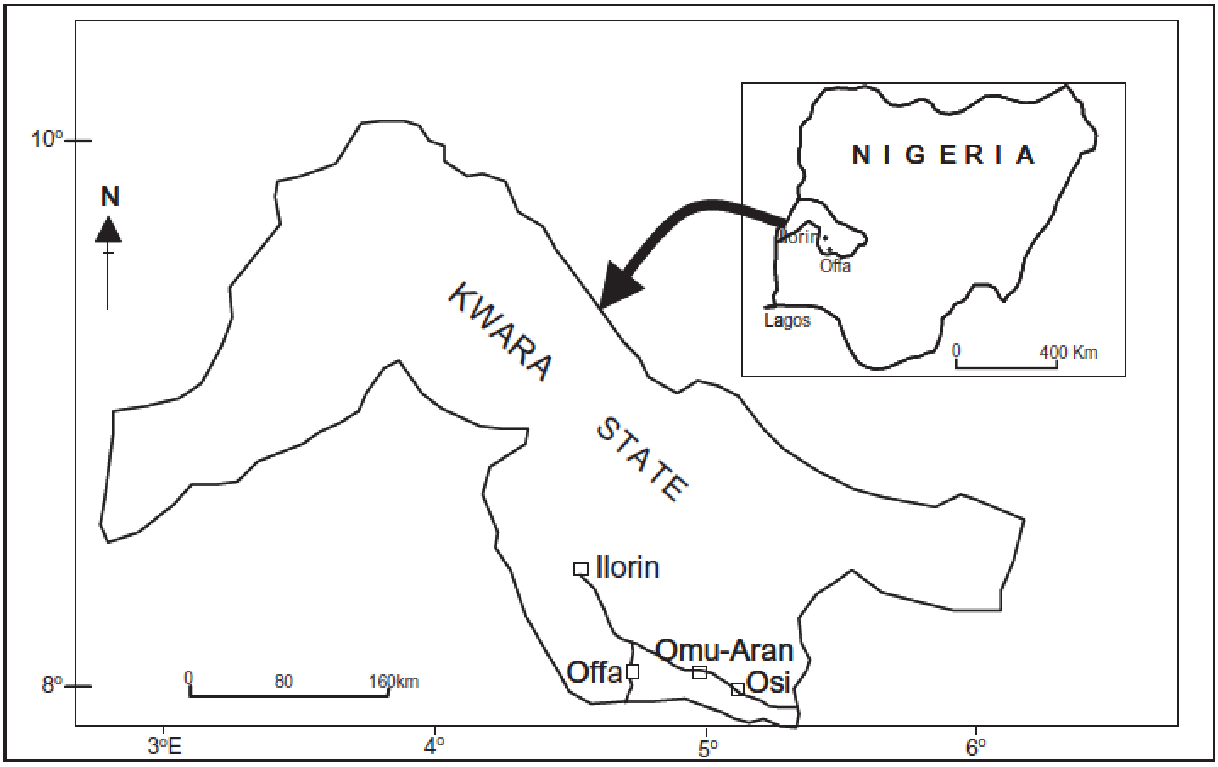

Figure 1 Map of Kwara State in North central Nigeria showing the location of Omu Aran. (Source: [10])

2.2. Soil sample Collection and Analysis

2.2.1. Soil sample Collection.

Sixteen representative soil samples were collected from the site and immediately taken to the laboratory for analysis. These samples have all the characteristics of the soil on the farm. Land clearing and preparation had been carried out prior to soil sampling. The soil samples were taken to the soil science laboratory of Landmark University and the following analyses were carried out: textural class test, Percentage Nitrogen, exchangeable phosphorus, and extractable potassium, magnesium, Calcium, organic matter and cation exchange capacity (CEC). The soil particle size distribution was determined using the Bouyoucos hydrometer method [11]. Soil organic carbon on the plot was determined using method described by [12].

The exchangeable potassium (K^+) was extracted with HCl solution and their levels were determined by flame photometry. The cation exchange capacity (CEC) at pH 7.0 with ammonium acetate was determined following the procedure described by [11]. Another set of soil sample were taken using soil corers of diameter 5 cm and height 4 cm to an approximate depth of 45 cm at an interval of 15 cm i.e. 0 - 15, 15 - 30 and 30 – 45 cm in order to calculate the followings: Soil moisture content, bulk density (BD), total porosity, micro porosity and macro porosity. The soil which extended beyond each end of the sampler was trimmed to ensure that soil contains the entire volume of the cylinder. Thus, soil sample volume was confirmed to be equal to the volume of the sampler. The soil cores were transferred to the laboratory for analysis. The soil samples were transferred into the oven and dried at a temperature of 105^o C for complete 24 hours until samples reach constant weight. The weight of soil was recorded and bulk density was calculated using method described by [13]. The particle density was assumed to be 2.65 g/cm^3 since quartz is the predominant mineral in the sample [14] using equation 2.

$$\textbf{Bulk Density } (\rho) = \frac{weight\ of oven\ dreid\ soil}{volume\ of\ the\ soil} \tag{2}$$

Total porosity (% pore space) was estimated using the same soil samples collected for soil bulk density. Total porosity of the soil was calculated from bulk density assuming a particle density of 2.65 mg/m^3 following the method described by [15] using equation 3. Micro porosity and macro porosity were obtained using equation 4 and 5.

$$PT = \left[1 - \frac{DS}{DP}\right] \text{ x } 100\ \% \tag{3}$$

$$Mic = \left[\frac{Ww - Wd}{Vc}\right] \text{ x } 100\ \% \tag{4}$$

$$Mac = PT - Mic \tag{5}$$

Where:

PT= total porosity (%)

Mac = macro porosity (%)

Mic = micro porosity (%)

Ds = Bulk density (g cm^{-3})

Dp = Particle density (g cm^{-3})

Ww = Weight of fresh sample (g)

Wd =Weight of dried sample 105° (g)

vc = volume of the cylinder (cm^{-3}).

2.3. Climatic Data Acquisition

2.3.1. Reference Evapotranspiration Estimation

The microclimatological data were collected using the standard Campbell Scientific, Inc. The system collects and analyzed daily weather parameters at 6 seconds interval with 15-minutes outputs. The station collects data such as; potential evaporation, solar radiation, wind speed, air temperature, dew point temperature, relative humidity, precipitation, and barometric pressure. These parameters were used to estimate the reference evapotranspiration. ET_{o} using FAO- Penman Monteith model [6] given as in equation 6:

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T + 273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34 u_2)} \tag{6}$$

Where:

ETo= Reference evapotranspiration (mm day^{-1});

Rn = net radiation at the crop surface (MJ m^{-2}day^{-1});

G= soil heat flux density (MJ m^{-2} day^{-1}) = 0 for daily calculations of ET as G is small on daily basis;

T= mean daily air temperature at 2 m height (°C);

*u*2 =wind speed at 2 m height (ms^{-1});

es = saturation vapor pressure (kPa);

ea = actual vapor pressure (kPa);

(*es-ea*) = saturation vapor pressure deficit (kPa);

Δ= gradient of the saturated vapor pressure–temperature curve (kPa°C^{-1}), and the

γ= psychometric constant (kPa°C^{-1}).

The data generated by the weather station were used as input into the Crop Water Model (CROPWAT 8) in order to estimate the Reference evapotranspiration, crop evapotranspiration, net irrigation requirement, crop water requirement and irrigation schedule for maize.

2.4. The hydraulic weighing lysimeter

The lysimeter was made of a cylindrical PVC drum purchased locally. The drum was bisected to create a lysimeter tanks. It has a diameter of 600 mm and a circular cross-sectional area of 0.28 m^2. The lysimeter has a depth of 450mm with a wall thickness of 3mm. The lysimeter depth is appropriate as it permits normal root development as in [4]. The hydraulic weighing lysimeter set up is shown in figure 2.

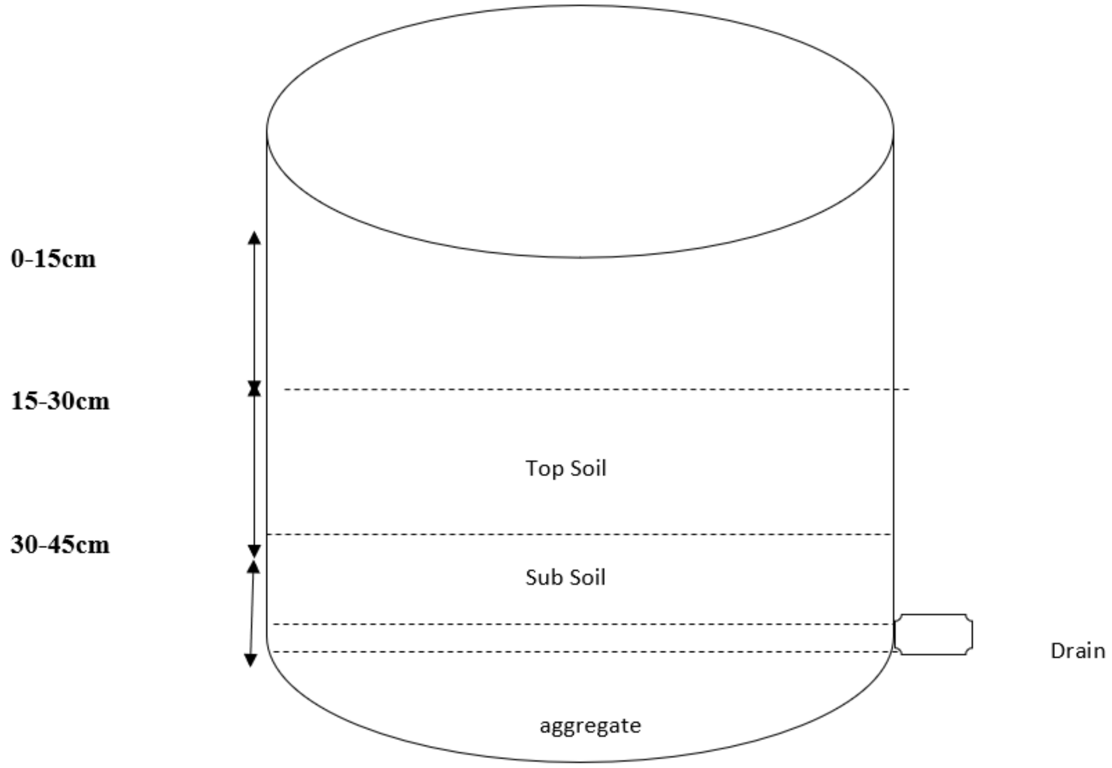

Figure 2 Soil profile within the Lysimeter.

2.4.1. Weighing Mechanism

The weighing mechanism for the lysimeter was made from a water filled tube (float) connected to a calibrated burette via a manometer. The changes in water level in the burette is taken as the ET for the day. The soil filled lysimeter tank rests on the water-filled automobile inner rubber tubes and this act as hydraulic load cells. The pressure generated by the weight on the tubes was measured using a water-filled open-end manometer as in [16].

2.4.2 Calibration of the hydraulic weighing lysimeter

A calibration routine was performed to ensure the proper functioning and accuracy of the hydraulic system after installation. The overall weight of the lysimeter tank was first determined by filling it with soils from the site and then a series of known weights were placed one at a time in the lysimeter, then the total cumulative lysimeter weight was recorded. The weights were then removed and the changes in water levels in the graduated glass tube was also recorded and tabulated against the known weight. Results of the lysimeter calibration was tabulated. The loading and unloading operations were repeated several times. A linear regression analysis was carried out in order to obtain a calibration factor for all variables in the relation. The linear regression equation was in the form shown in equation 7.

$$y = ax + b \tag{7}$$

Where: y is the measured output (mm),

x is the applied load (kg of water plus soil),

a is the calibration slope (mm/kg), and

b is the intercept (mm).

For each weight increase, the output readings were recorded. The average change in water level (mm) output was plotted against the weight increase in the lysimeter. After calibration, the lysimeter was tested by planting Bell pepper in it.

2.4.3. Development of Kc Curve

The single Crop coefficient (Kc) for the different growth – stages were calculated from the ratio of daily ETc and daily ETo. The daily Kc values were then plotted against the day after planting, the data generated by the weather station were used as input into the Crop Water Model (CROPWAT 8) in order to estimate the reference evapotranspiration, ETo as in [4]. The four growth stages based on the description of the signs of the growing stages proposed by [6] were noted and recorded.

3. RESULTS AND DISCUSSION

3.1. Calibration of the developed hydraulic weighing lysimeter.

The observed pattern for the reading shows that increase in cumulative weight causes an increase in level of water in the burette and value of readings on the burette. Burettes are usually graduated from zero ml at the top to the 50ml at the bottom, hence the negative slope value in the regression equation.

Figure 3 illustrates the simple regression between the changes in weight of the lysimeter and burette reading. A high linearity of data was observed, indicating a close relationship in the loading and unloading processes which occurred between the observed and measured values estimated in the lysimeters. The coefficient of determination was close to unity. The weight, W of the lysimeter tank at any time was determined from the level of water, H in the manometer glass tube using a relationship obtained as in equation 8:

$$W = -1.2235H + 75.294 \tag{8}$$

$$R^2 = 0.9824$$

where, W is weight of lysimeter in kg and H is height of water in the burette in ml

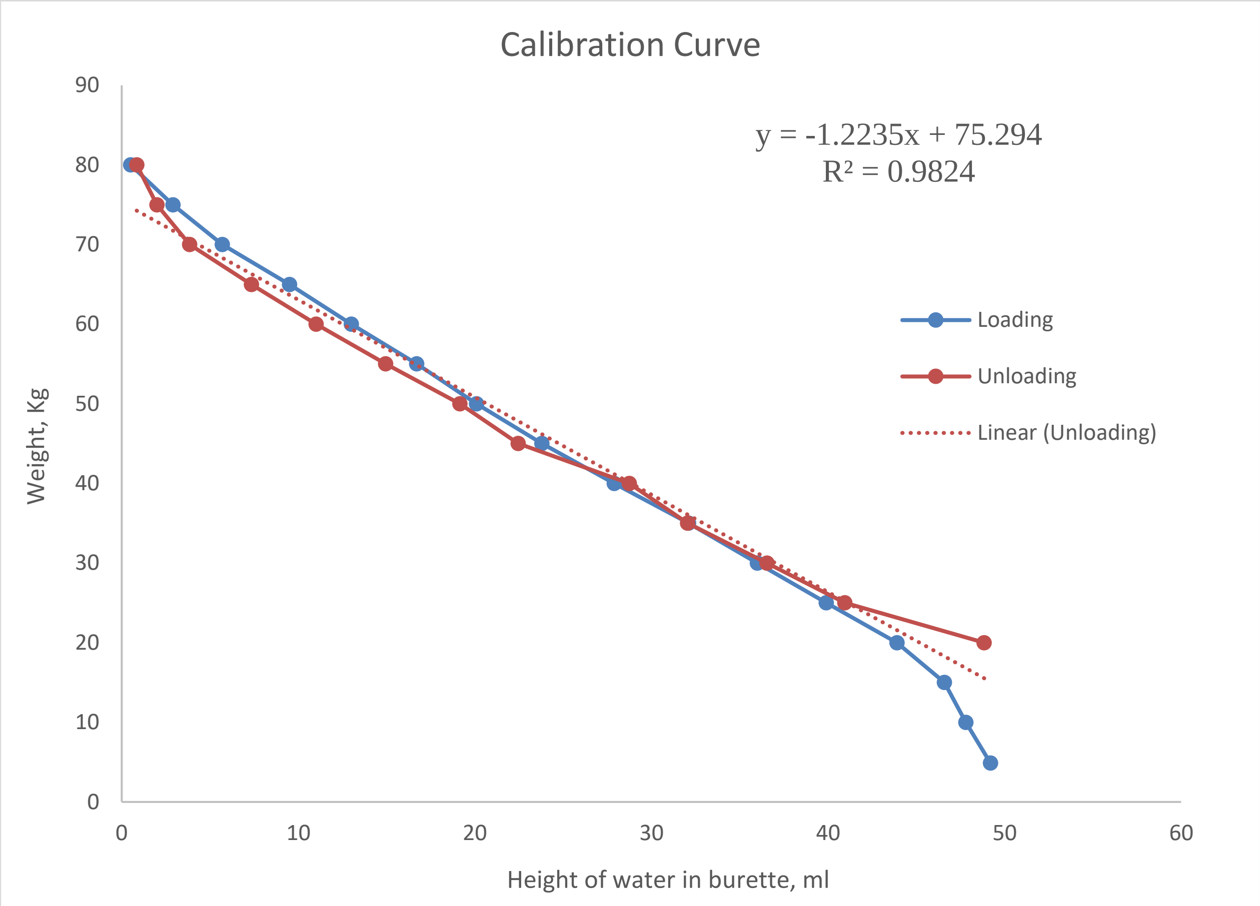

Figure 3 Lysimeter Calibration Curve

3.2. Climatic data observed in the study area.

The average monthly Reference Evapotranspiration in the study area is presented in Figure 4. It shows the graphical plotting of the monthly reference evapotranspiration of the research area based on data obtained from Campbell scientific weather station and fitted data into CROPWAT model 8. The highest values ET_o were observed at the dry season months (from October to April) while the wet months had the lowest ETo values. The mean monthly air and soil temperature variation; in the study area are presented in Figure 5 and 6. Soil temperature was noticeably higher than the ambient temperature throughout the 22 months with a mean temperature of 28.3^{o}C and 24.3 ^{o}C, respectively. This occurs as a result of low or zero vegetation cover particularly during the dry seasons to shelter the effect of direct solar radiation.

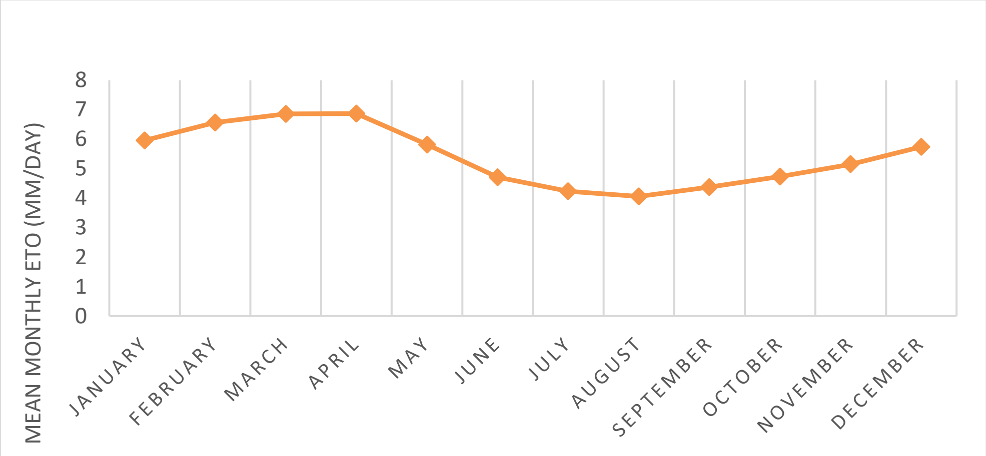

Figure 4 A Mean monthly ETo of the study area computed from CROPWAT.

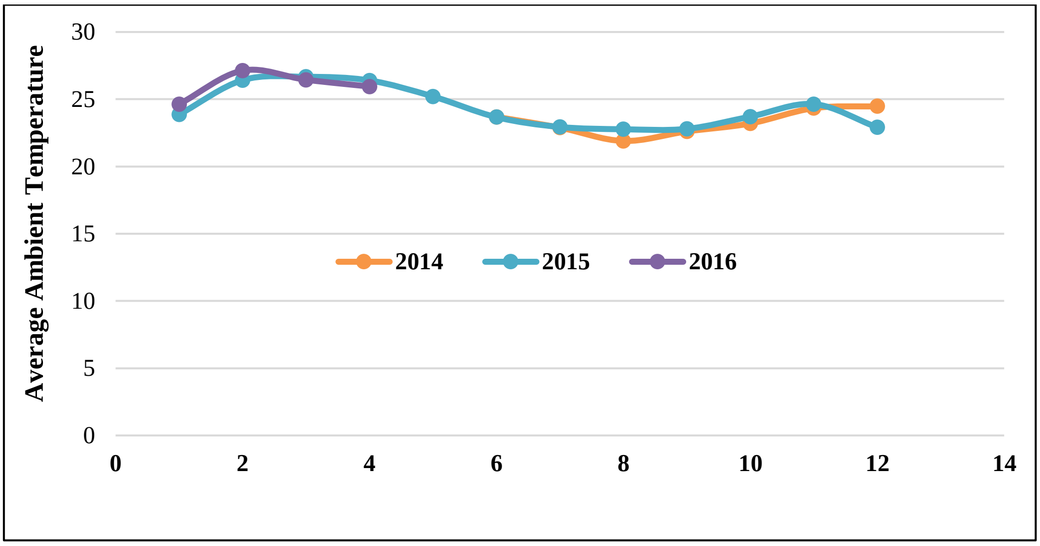

Figure 5 Mean Monthly temperature in the study area.

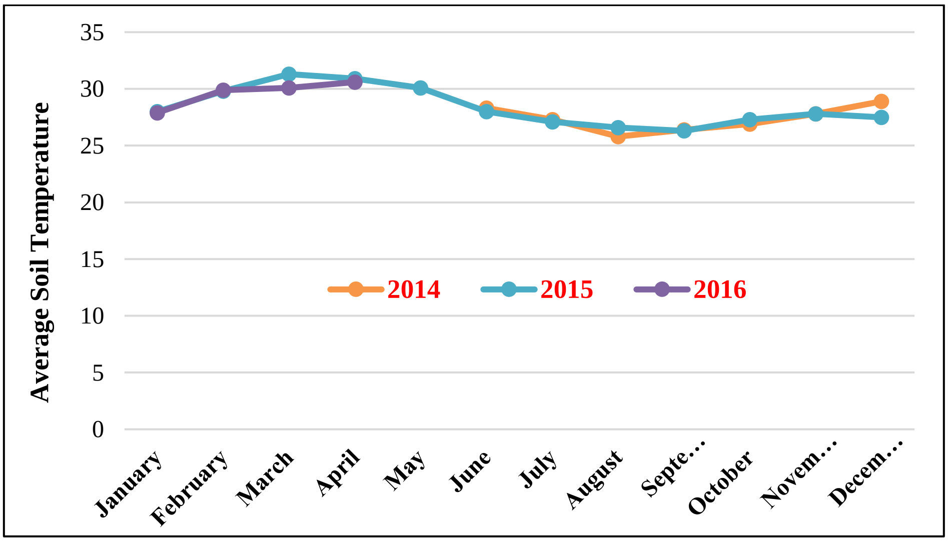

Figure 6 Mean Monthly soil temperature of the study area .

The highest air temperatures of 26.4ºC and 26.7ºC for February and March 2015; 27.1ºC and 26.45ºC for February and March 2016 were recorded. Furthermore, a pattern was observed that the temperature plummets as the rainy season approaches, and attains the lowest value in the wettest month of the year and thereafter increases little by little as the dry season approaches before attaining its peak value in the driest/hottest months (February, March). Conversely, the temperature of the harmattan period (December and January) is lower than that of other dry months. This is caused by the cool dry wind, which blows across this area from the Sahara Desert during the period. The relative humidity pattern was opposite to that observed for monthly temperature and the results are as shown in figure 7. It was noted that when the air temperature was at its peak the relative humidity was at the lowest

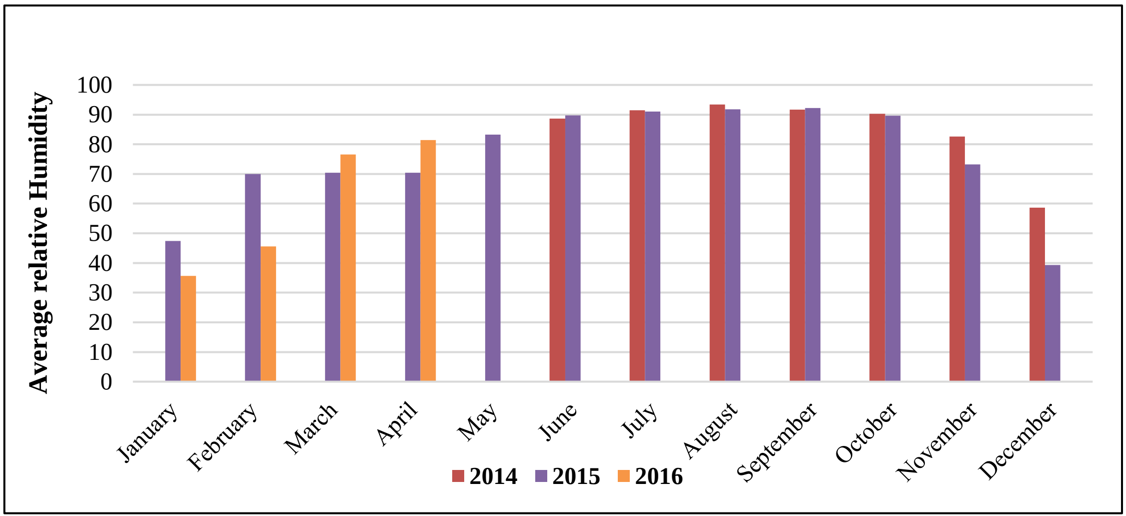

Figure 7 Relative humidity at the study area for mid2014-2016

The Precipitation increased gradually from March to August; and then begins to decline from the end of September, until it finally declines to zero in December as shown in figure 8. A sharp plunge is noted around end of July and early august which is caused by a phenomenon known as August break. After the break, the precipitation peaked at September and then decreases toward the end of the year due to the onset of dry season.

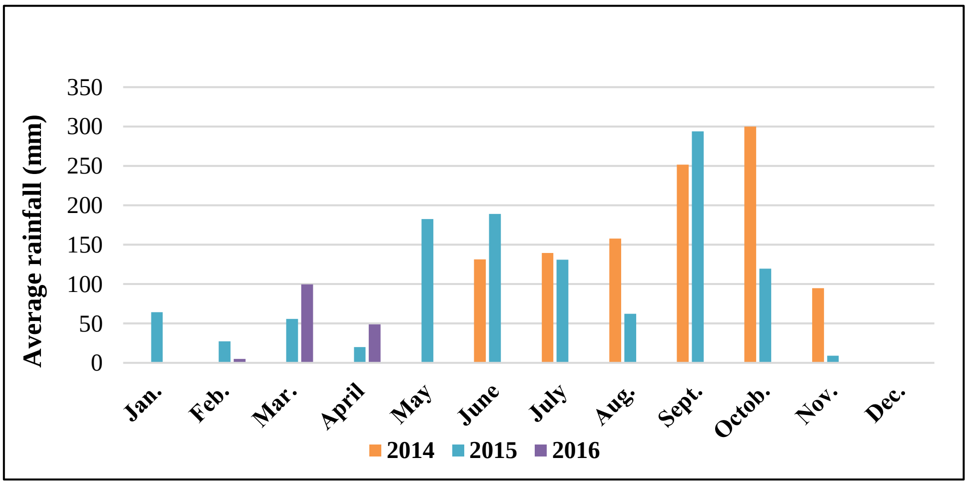

Figure 8 Monthly rainfall of the research area.

3.3. Soil physicochemical properties in the study area.

The soil samples at different depths are identically loamy sand, while the chemical properties of the soil are shown in Table 1.

Table 1 Physicochemical properties in the study area

Parameter	Depth (cm)	
	0-15	15-30
EC (dSm^{-1})	7.80	8.30
pH (H_2O)	5.80	5.70
N (%)	0.10	0.10
K ($mol\ kg^{-1}$)	0.88	1.22
Ca ($mol\ kg^{-1}$)	8.01	12.00
P (%)	8.67	12.00
Mg ($Mol\ Kg^{-1}$)	2.00	3.02

3.4. Moisture Content, Bulk density and volumetric moisture at Field capacity

The results of soil moisture content, bulk density and soil moisture volume at depths 0 - 15 cm and 15 - 30 cm of the experimental site are presented in Table 2. Higher moisture content was obtained at the 0 - 15 cm depth contrary to that of 15 – 30 cm depth during the time of test. The soil classification is loamy sand and it has the capacity to retain more moisture at field capacity [17]. The higher moisture content obtained at the 15-30cm depth caused by the onset of rainfall, which might not infiltrate deeply into soil as a result of long period of dryness and loss of moisture from the superficial layer of the soil. Loss of moisture from the surface of the soil will still be high even at early growth stages of crops because the water is located close to the soil surface and therefore evaporates very easily. The bulk density results reveal that soil compaction is higher at 15 – 30 cm depths, this causes increased bulk density. This is in accordance to the observation that compacted soils have higher bulk densities [15].

Table 2 Moisture content, bulk density and soil moisture volume of the research site

Depth	Sample No	Bulk Density (g/cm3)	Soil Moisture Content (%)	Volume of Soil Moisture Content at Field Capacity (cm^3/cm^3)
0-15	1	0.742	27.11	0.193
	2	0.686	27.24	0.194
	mean	0.714	27.18	0.194
15-30	1	1.314	9.11	0.114
	2	1.209	9.01	0.114
	mean	1.261	9.06	0.114

3.5. Determination of Effective Rainfall and Irrigation Requirement for Bell Pepper Using CROPWAT 8.0 Model.

During the first 10 days after planting, there was no rainfall hence the field was irrigated to a depth of 41.8 mm. Subsequently the field was irrigated less as rainfall continued to increase gradually until the 40th day when rainfall depth was 48.1mm, there was no need for supplementary irrigation at this point. After the 40th day, rainfall decreased gradually until the 130th day. During this period, the field was irrigated to meet field capacity requirements. Rainfall increases gradually again until day 160 where it reaches field capacity, hence there was no need to irrigate. Rainfall begins to decline steadily until harvest, hence the field was irrigated according to the crop needs since the crop had matured at this stage. The Graph of Effective rainfall and irrigation requirement against Decadal days is shown in figure 9

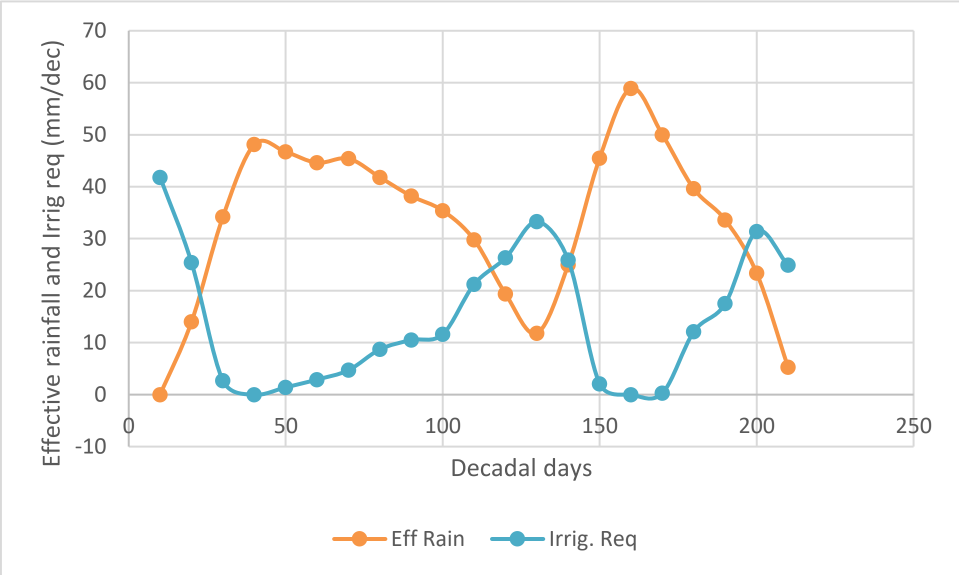

Figure 9 Graph of Effective rainfall and irrigation requirement against Decadal days.

Figure 10 reveals the Crop co-efficient (Kc) and crop evapotranspiration (ETc) for bell pepper in the study area. The Crop co-efficient for the first 30 days (initial stage) is 0.6 and the crop evapotranspiration declined from 41.8 to 36.9. During the development stage (days 31-70) of the crop, Kc rose from 0.6 to 0.67 and gradually increased to 1.07 by the end of the development stage. During the Mid-stage (days 71-180), the crop maintained a Kc of 1.11 while the ETc maintained a zigzag pattern. For the late stage (day 181-210), Kc declines from 1.11 to the final Kc of 0.97.

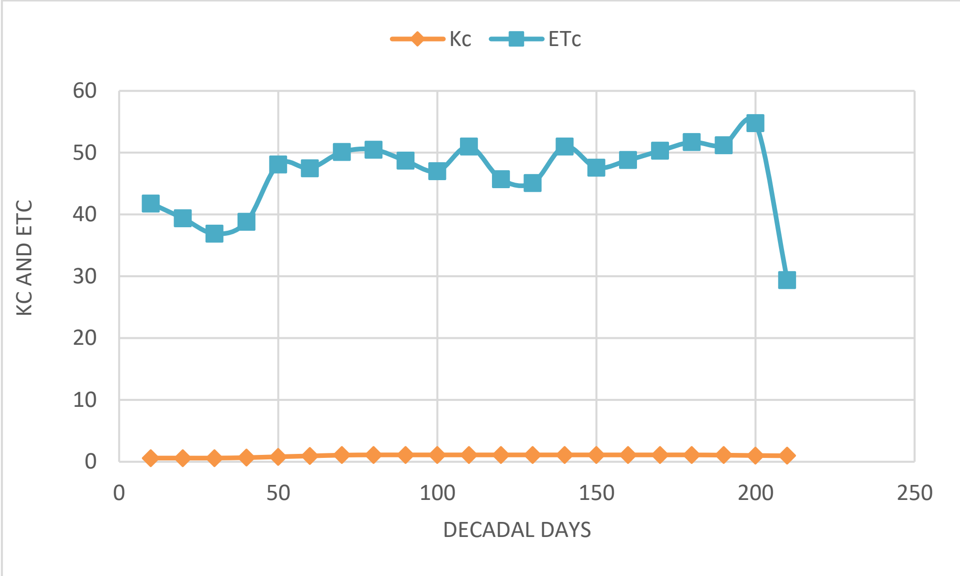

Figure 10 Graph of Crop co-efficient and Crop Evapotranspiration against Decadal Days.

3.6. Bell Pepper Irrigation Scheduling Using CROPWAT 8.0 Model.

Figure 11 illustrates the trend of moisture depletion for different growth stages of Bell pepper crop. The red markings indicate the level of moisture depletion in the soil. The brown line represents the level of readily available moisture in the soil and the green line indicates the Total available moisture in the soil. Every time the soil moisture gets depleted, irrigation is to be carried out to restore the soil moisture back to field capacity. For the initial stage (Days 1-30), the maximum moisture depletion is about 17mm. At the stage, the crop does not require large quantities of water. For the development stage (Days 31-70), the crop requires twice as much water as the initial stage. The mid stage and late stage (Days 71-203) require three times the moisture required at the initial stage. For the remaining days of the end stage (205-210,) the crop requires little water; about the quantity required at the initial stage.

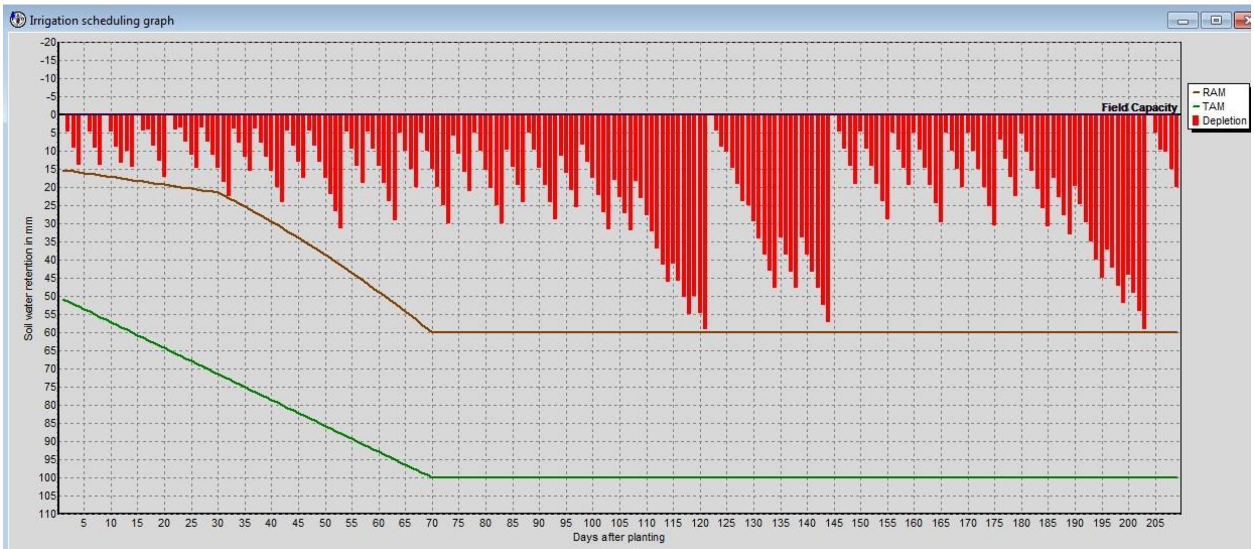

Figure 11 Graph of Irrigation scheduling for bell pepper.

4. CONCLUSION

This study shows that there is a relationship between soil physicochemical properties and water use of *Capsicum anuum L*. grown in a hydraulic weighing lysimeter. The following were deduced from the results: the soil in the study area is a slightly alkaline and the soil micro and macro porosity at depth 0-15cm to be 0.194, 0.536, and 0.73 respectively with that of depth 15-30 cm to be 0.115, 0.425, and 0.54 respectively. Also, bulk density for the 0-15 cm depth was 0.714 g/cm^3 while that of 15-30cm was 1.261g/cm^3 indicating that sample for 15-30cm is more compacted. The results also revealed that the ETc of the bell pepper crop increases during the development and mid stages hence the crop water use is highest during the crop growth mid stage. Farmers therefore who intend to grow *Capsicum anuum L*. during the dry season or in areas with insufficient water need to ensure that the right soil type is utilized, and appropriate irrigation scheduling based on crop consumptive use is put in place to obtain maximum crop yield.

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REFRENCES

[1] Islam M, Saha S, Akand H, and Rahim A. Effect of sowing date on the growth and yield of sweet pepper (Capsicum annuum L.). Agronomski glasnik: Glasilo Hrvatskog agronomskog društva. ;72(1) 2010 pp 3-14.

[2] Hamma, I. L., U. Ibrahim, and M. Haruna. "Effect of planting date and spacing on the growth and yield of sweet pepper (capsicum annuum l.) in samaru area of Zaria in Nigeria." Nigerian Journal of Agriculture, Food and Environment 8, no. 1 ,2012 pp 63-66.

[3] Koske Thomas J., Professor (Horticulture) School of Plant, Environmental and Soil Sciences, Donald M. Ferrin, Asst. Professor Department of Plant Pathology, Alan Morgan, Professor Department of Entomology. “Peppers”. Vegetable Gardening Tips: Growing Information for the Home Gardener Series. Louisiana State University Agricultural Center, n.d. Web. 5 Feb. 2016. < http://lsuagcentre.org>

[4] Raphael, O.D., Ogedengbe, K., Fasinmirin, J.T., Okunade, D., Akande, I. and Gbadamosi,A. Growth-stage-specific crop coefficient and consumptive use of Capsicum chinense using hydraulic weighing lysimeter. Agricultural Water Management, 203, 2018, pp.179-185.

[5] Ufoegbune, G.C., Bello, N.J., Dada, O.F., Eruola, A.O. Makinde, A.A. and Amori, A.A. Estimating Water Availability for Agriculture in Abeokuta, South Western Nigeria. Global Journal of Science Frontier Research Agriculture and Veterinary Sciences Volume 12 Issue 9 Version 1.0 Year 2012. pp 11.

[6] Allen, R.G., Smith, M., Perrier, A., and Pereira, L.S., Crop Evapotranspiration, Guidelines for Computing Crop Water Requirements. FAO Irrigation and Drainage Paper No.56. Food and Agriculture Organization of the United Nations, Rome, Italy, 1998.

[7] Salama, M.A.A. Estimating Water Consumptive Use for Some Crops under Stress Conditions Using Neutron Scattering Method. 2011, pp 35-36, 37, 45.

[8] Fisher D K. Simple weighing lysimeters for measuring evapotranspiration and developing crop coefficients. Int J Agric & Biol Eng., 5(3): 2012 pp35－43.

[9] Opeke, L.M. Essential food crops. 2nd Edition. Spectrum Book Ltd., Ibadan, Nigeria. 2006

[10] Adelana, S. M. A., P. I. Olasehinde, and Peter Vrbka. "Identification of groundwater recharge conditions in crystalline basement rock aquifers of the southwestern Nigeria." Special UNESCO Volume: Recharge systems for protecting and enhancing groundwater resources, IHP-VI, Series on Groundwater 13, 2006, pp 649-655.

[11] Agbede, T. M. and Ojeniyi, S. O. Tillage and poultry manure effects on soil fertility and sorghum yield in southwestern Nigeria. Soil Tillage Research 104: 2009, pp 74-81.

[12] Eleanor, H., Garry W. Measuring soil organic carbon stocks – issues and considerations. 19th World Congress of Soil Science, Soil Solutions for a Changing World 1 – 6 August 2010, Brisbane, Australia. 2009.

[13] Fasinmirin, T. J., Olufayo, A. A., Oguntunde, G. P. and Oguntuase, M. A. Parameterizing Simple Model between Yield and Evapotranspiration for Amaranthus cruentus under Drip and Sprinkler Irrigations. International Journal of Plant Production 3 (1). 2009, pp 1735-8043

[14] Fasinmirin, J.T., Adesigbin, A.J. Degree of Compaction and Compression Strength of Nigerian Alfisol under Tilled Condition and Different Machinery Traffic Passes. Int. J. Agric and Biol. Eng. Vol. 5 No 2. 2012, pp 34-41.

[15] Adesigbin, A. J., and J. T. Fasinmirin. "Soil Physical Properties and Hydraulic Conductivity of Compacted Sandy Clay Loam Planted with Maize (Zea mays) Proceedings of the Environmental Management Conference." University of Agriculture, Abeokuta, Nigeria 2 (2011).

[16] Fasinmirin, J.T. Soil Physical Properties and Yield Response of Melon (Colocynthis citrullus L.) to different Tillage Treatments in a Humid Rainforest Soil of Akure, Nigeria. Proceedings of the International Soil Tillage Research Organization (ISTRO) Nigeria Symposium, Akure 2014 November 3 - 6, Akure, Nigeria. 2014.pp 207-217

[17] Rawls, W. J., Ya A. Pachepsky, J. C. Ritchie, T. M. Sobecki, and H. Bloodworth. "Effect of soil organic carbon on soil water retention." Geoderma 116, no. 1-2 (2003) pp 61-76.