WATER MANAGEMENT OF TOMATO CROP ROOT ZONE USING AQUACROP

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ABSTRACT
Water content at the root zone remains the major source of water to the plants which can be determined using various methods such as oven-dry or gravimetric; neutron moisture meter (NMM); electromagnetic sensors(capacitance sensors); conventional time domain reflectometry; tensiometers and other several new technologies which include FAO aquacrop. The objective of this paper is to study the response of crop growth to water contents at root zone and soil profile with a view to eliminating crop failure due to water stress. The research location was at Epe in Lagos state, Nigeria, and climatic data required include rainfall (mm), radiation (MJ/M^2), maximum and minimum temperature (^{o}C), wind speed (m/sec), mean relative humidity (%) and Carbon Oxide concentration from 1982 to 2018 daily obtained from the archive of National Aeronautics and Space Administration. Aquacrop used was of version 6.1 FAO and crop chosen was tomato and simulation was run from 9th November 2017 to 26th February 2018 under drip irrigation. The results show that maximum water contents in entire soil profile, effective root zone, saturation, field capacity, leaf expansion, stomatal closure, canopy senescence, and permanent wilting point of loamy sand were 330.3, 300.0, 500, 300, 264.8, 195.9, 156.8 and 100 mm respectively. Achieving effective irrigation water management entails a cursory look at water contents in effective root zone since it is only major source of water to plants. Hence, the study contributes among others to the body of knowledge by aiding better understanding of plant- soil- water relationship and providing mitigation information against climate induced drought.

KEYWORDS: Aquacrop, Field capacity, Permanent wilting point, Root zone, Soil profile

1. INTRODUCTION

Amount of water present in the soil is referred to as soil water content or soil moisture and it plays a significance role on plant growth, soil temperature, transport of chemicals and groundwater recharge. Plants make better and effective use of the water available to its root zone for growth and development, and this informs why attention must be paid to management of water at the root zone as it remains the major source of water to the plants. There are various methods of determining soil water content such as oven-dry or gravimetric; neutron moisture meter (NMM); electromagnetic sensors known as capacitance sensors; conventional time domain reflectometry; tensiometers and other several mordant technologies (Hanson *et al.,* 2000; Dane and Topp, 2002; Evett and Parkin, 2005; Evett, 2007; Nolz, 2016). More also, available water contents at the root zone of crops can be estimated or evaluated using aquacrop growth model which is reliable, climate compliant, users' friendly and more effective than most of the already known methods (Hsiao *et al.,* 2009; Steduto *et al.,* 2009; Steduto *et al.,* 2012). Aquacrop gives details of water content in the entire soil profile as well as at various stages of water availability such saturation (Sat), field capacity (FC), permanent wilting point (PWP), and stomatal expansion (exp).

Ojo and Alatishe (2014) explained that water content at saturation is achieved when the soil pores are filled with water and aeration eliminated; field capacity attained after when gravitational is drained off; when plants or crops can no longer obtain water from the soil is permanent wilting point; and the soil water content between field capacity and permanent wilting point is available (usable) Water. The records of previous authors that worked on soil water contents showed that (Pavel Blazka *et al.,* 2014) used soil saturation from capillary rise to determine field capacity, permanent wilting point and available water capacity in the southeast Nigeria soils. Zotarelli *et al.* (2019) made use of soil moisture sensors to determine moisture content and field capacity in sandy soils to avoid over irrigation. Nyakudya *et al.* (2014) emphasized the use of Pedo-Transfer function from soil layer textures and other parameters to calculate available water supply in crop root zone; and Aijuan Wang *et al.* (2016) monitored and predicted soil water content in the deeper soil profile of Loess Plateau, China. Although many authors had worked on different methods of determining soil water content and other related topics but none used aquacrop to determine and assess soil water content at the root zone. This informed the objective of this research which was to study the response of crop growth to water content at root zone and soil profile with a view to eliminating crop failure due to water stress.

2. MATERIALS AND METHODS

2.1 Study Location

The study was conducted at the Department of Agricultural and Bio-environmental Engineering, School of Engineering, Yaba College of Technology, Epe Campus, Lagos Nigeria which lies on the latitude 6^0 58’ N and longitude 3^0 96’E with elevation of 3.98 meters above sea level.

2.2 Aquacrop

Aquacrop version 6.1 was used for this study. Aquacrop describes the relationship between the plant and the soil from the root zone and how water and nutrients can be extracted by the plant. The major components included environment, climate, crop, management, simulation and run. Climatic parameters such as radiation, maximum temperature, minimum temperature, wind speed, relative humidity and precipitation were the inputs, while management parameters were the field (soil fertility) and irrigation system.

2.3 Climatic Parameter Data Source and Processing

Thirty- six years data (1982-2018) needed for this study was obtained from the archive of National Aeronautics and Space Administration on daily basis. Data were processed into Aqua crop format and saved in Micro soft Excel with csv or text file for compatibility in the directory of aqua crop after removing voids and non numeric elements.

3. RESULTS AND DISCUSSION

The results of the descriptive statistics of the data generated from the simulation on water contents at root zone and soil profile were presented in Table 1. The results showed that maximum water contents of the entire soil profile (Wct), water content in effective root zone (Wr), water content in effective root zone at saturation (Wr Sat) are 330.3 mm, 300.3 mm, 500.0 mm respectively which were not far from the ranges reported by Hodnett *et al*. (2002). While water content in effective root zone at field capacity (Wr Fc), water content in effective root zone at upper threshold for leaf expansion (Wr exp), water content in effective root at upper threshold for stomatal closure (Wr sto), water content in effective root zone at upper threshold for Canopy senescence (Wr Sen) and water content in effective root zone at permanent wilting point (Wr pwp) are 300, 264.8, 195.9, 156.8 and 100 mm respectively and similarly to soil water threshold contained in the technical report of Summon *et al*. (2017).

The kurtosis and skewness demonstrated negative in the trend of water contents from total available water in the entire soil profile to the permanent wilting point if irrigation is not supplied signifying that risk is impeding (Martin *et al*., 2012). The values showed how water content in the soil profile reduced from 330.3 to 300.3 mm at effective root zone and further reduced to 300 mm at effective root zone field capacity. Water content was further reduced from 264.8 mm effective root zone at upper threshold for leaf expansion to 100 mm effective root zone at permanent wilting point.

At stomatal closure, the crop requires less water and hence less water was applied to the field, and this claim was supported by the report of Agurla *et al.* (2018) under the mechanism of stomatal closure in plants exposed to drought and cold stress. Crops attain this stage of stomatal closure at full maturity and yields formation. Meanwhile, water content in effective root zone is 500 mm showing excess than water content in the entire soil profile and available water content in effective root zone, a situation leading to water logging (Xin Jin *et al*., 2022). At saturation, the health of the crops was negatively affected as the voids are filled with water, eliminating soil aeration. At saturation, irrigation water is wasted, while at field capacity the crops make maximum use of water supplied.

Table 1: Descriptive Statistics of Water Contents at Root Zone

Descriptive Statistics	WCt (mm)	Wr (mm)	Wr(sat) mm	Wr(Fc) mm	Wr(exp) mm	Wr(sto) mm	Wr(sen) mm	Wr (pwp) mm
Mean	303.7	243.5	419.4	251.7	217.6	160.6	128.8	83.9
Median	311.9	280.9	500.0	300.0	257.5	190.2	152.5	100.0
Standard Deviation	21.7	64.7	110.6	66.4	58.8	43.7	34.8	22.1
Kurtosis	-1.1	0.0	0.0	0.0	-0.2	-0.2	-0.2	0.0
Skewness	-0.6	-1.1	-1.2	-1.2	-1.1	-1.1	-1.1	-1.2
Minimum	262.4	84.6	150.0	90.0	81.0	56.4	48.0	30.0
Maximum	330.3	300.3	500.0	300.0	264.8	195.9	156.8	100.0
Sum	33410.4	26788.9	46137.1	27682.7	23933.0	17671.1	14172.3	9227.7
Confidence Level (95%)	4.1	12.2	20.9	12.5	11.1	8.3	6.6	4.2

Note: (Wct)-Maximum water contents of the entire soil profile;
(Wr)- water content in effective root zone;
(Wr Sat)- water content in effective root zone at saturation;
(Wr Fc)- Water content in effective root zone at field capacity;
(Wr exp)- Water content in effective root zone at upper threshold for leaf expansion;
(Wr sto)- Water content in effective root at upper threshold for stomatal closure;
(Wr Sen)- Water content in effective root zone at upper threshold for Canopy senescence;
(Wr pwp)- Water content in effective root zone at permanent wilting point.

Figures 1 to 8 show the water contents at various stages versus days after planting (DAP). DAP is 109 days for tomato from crop recovery stage to maturity as seen in the graph. There are four stages of tomato growth and development from DAP 1 to DAP 109 which include plant recovery stage (DAP 1 -7), vegetative stage (DAP 8 - 37), flowering stage (DAP 38 - 67) fruit formation and yields (DAP 68 - 109). After the fruit formation, canopy senescence will set in meaning that the crops will begin to die and require little amount of water.

Figures 1 and 2 show the water contents in the entire soil profile and in the effective root zone of the crop. Water requirement of crop increased with the growing DAP until it reached flowering stage before it became stabilized. More water was required at the vegetative stage and flowering stages. Water requirement became stable at the middle of flowering stage to the tail end of fruit formation and yield stage. Meanwhile Figure 3 shows the excess water available in the root zone due to over irrigation, as result of faulty design of irrigation system, water intrusion from the water table, flooding and other occurrences. At the stage of saturation, soil was tending towards water logging, which is very injurious to the health of the crops, as soil aeration was eliminated completely because soil pores and voids were filled with water.

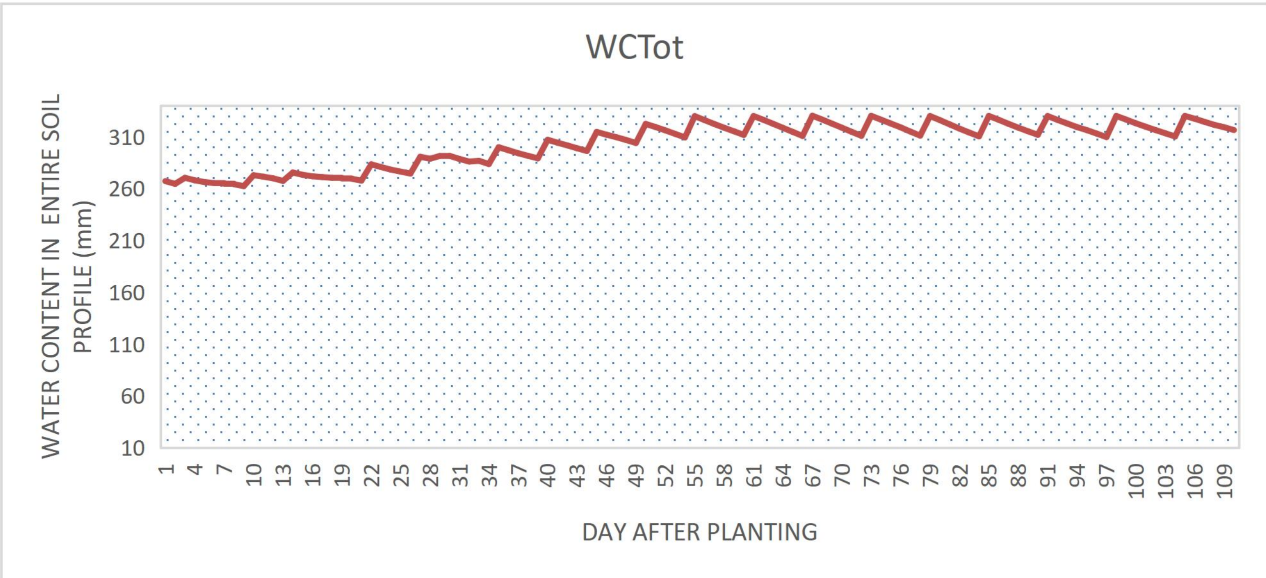

Figure 1: Graph of Water content in Entire soil Profile Vs Days after Planting (DAP)

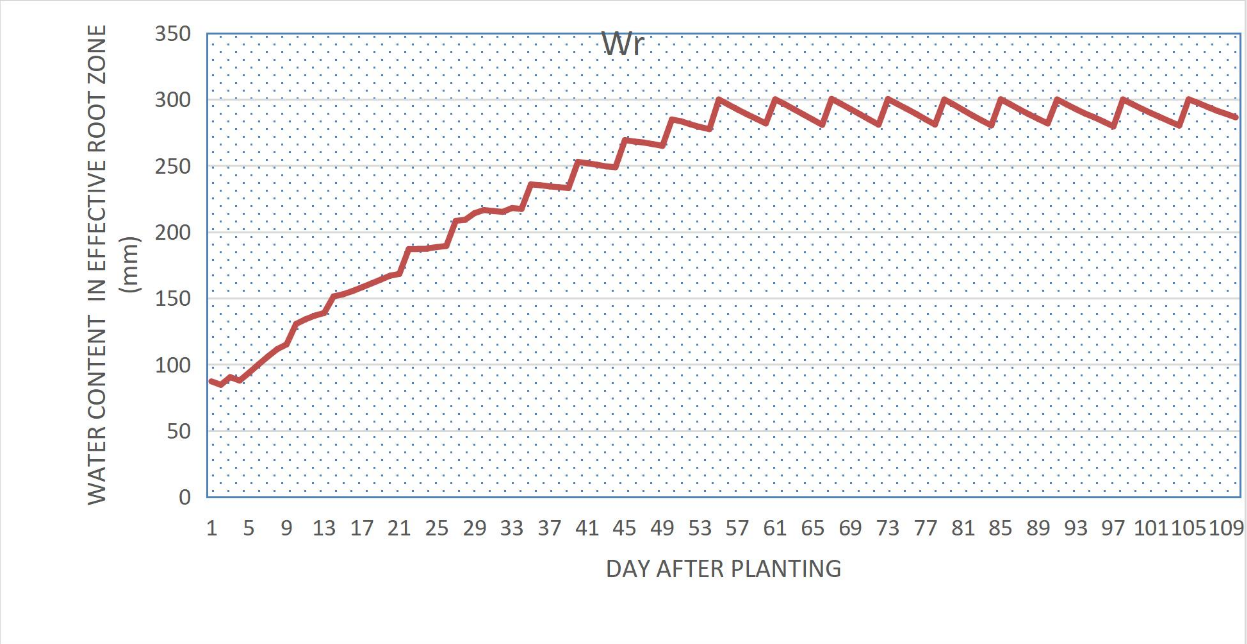

Figure 2: Graph of Water Content in Effective Root zone Versus Days after Planting (DAP)

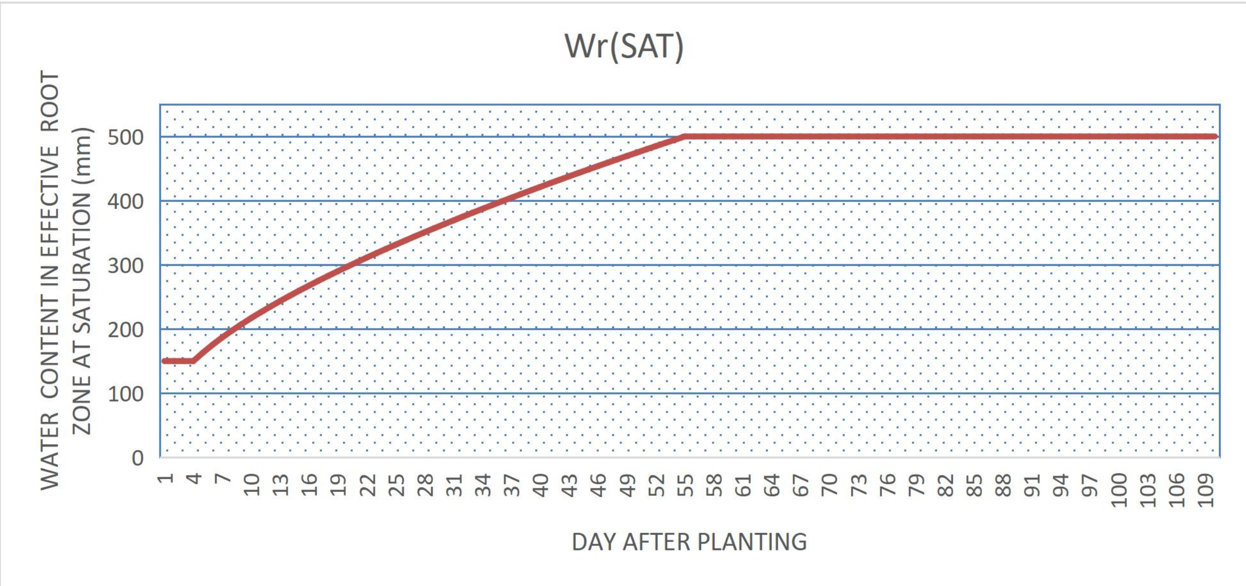

Figure 3: Graph of Water Content in Effective Root Zone at Saturation Versus DAP

Figures 4 to 8 displayed similarity in the behaviors of water contents at different stages of crop growth development. Water requirement of crop was stable at the flowering to yields and fruit formation stages. The difference was that more water was required to get to field capacity than other leaf expansion, stomatal closure, canopy senescence, and permanent wilting point. At field capacity, the available water to the root zone was beneficial to the crops meaning that crops were not water stressed. After the field capacity, the water content in the effective root zone reduced due to leaf expansion because more water was lost to the atmosphere through transpiration and less water than the field capacity was available in the effective root zone.

The water contents continued to reduce from water effective root zone at upper threshold for leaf expansion to effective root zone at upper threshold for stomatal closure and as such continue until permanent wilting point is reached. At permanent wilting point, water available in the soil cannot be accessed by the crop due to force of attraction of the capillarity. In addition, at canopy senescence, crop was not in dear need of water as point of diminishing return has already set in. To every irrigation expert, it must be noted that irrigation of crop field to field capacity at the fruit formation stage is a waste of water resources, logistics, timeliness and cost ineffectiveness.

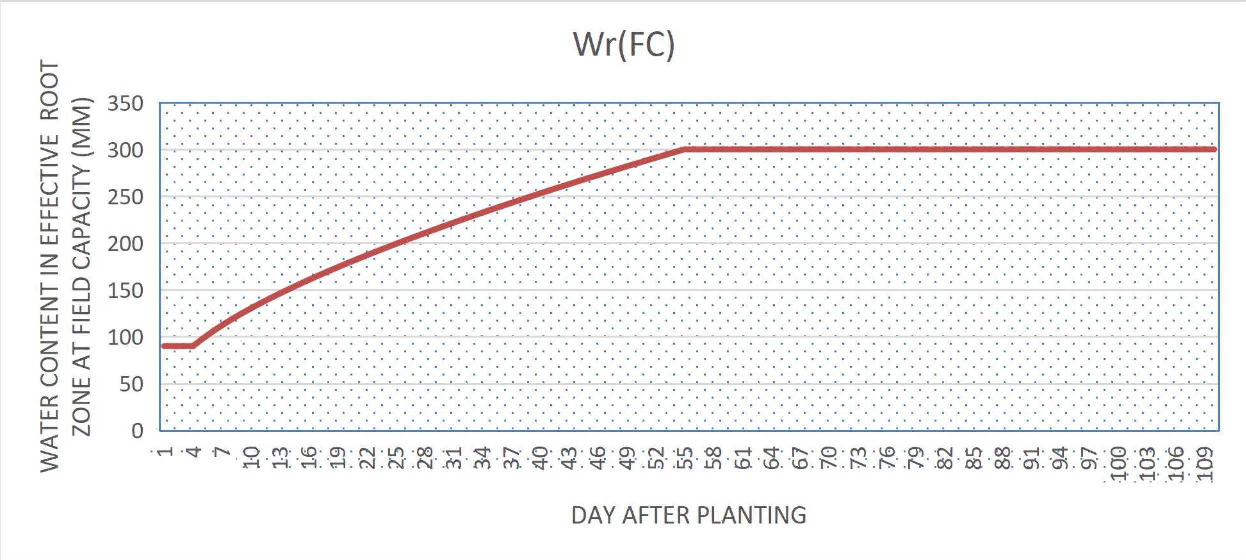

Figure 4: Graph of water content in effective root zone at field capacity versus DAP

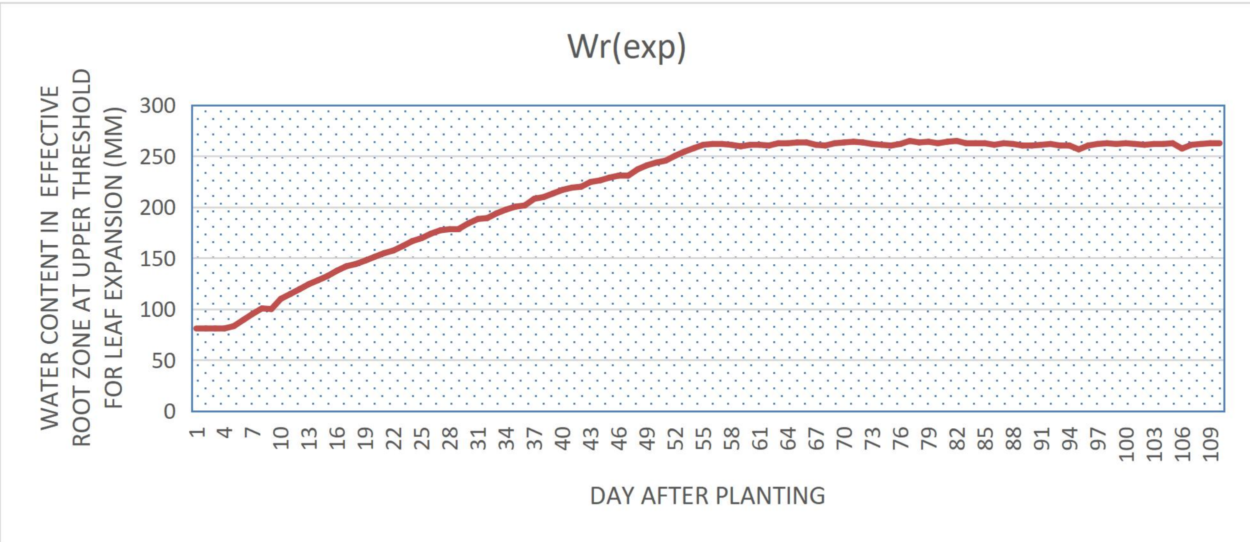

Figure 5: Graph of water content in effective root zone at upper threshold for leaf expansion versus DAP

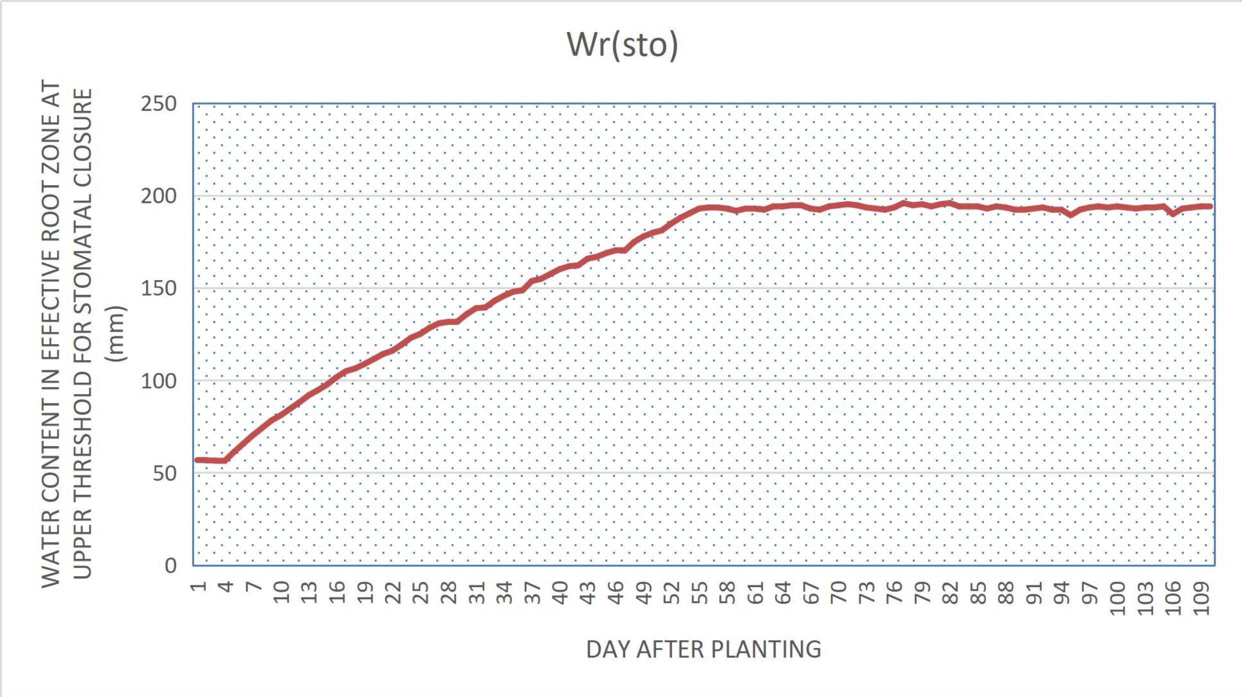

Figure 6: Graph of water content in effective root zone at upper threshold for stomatal closure versus DAP

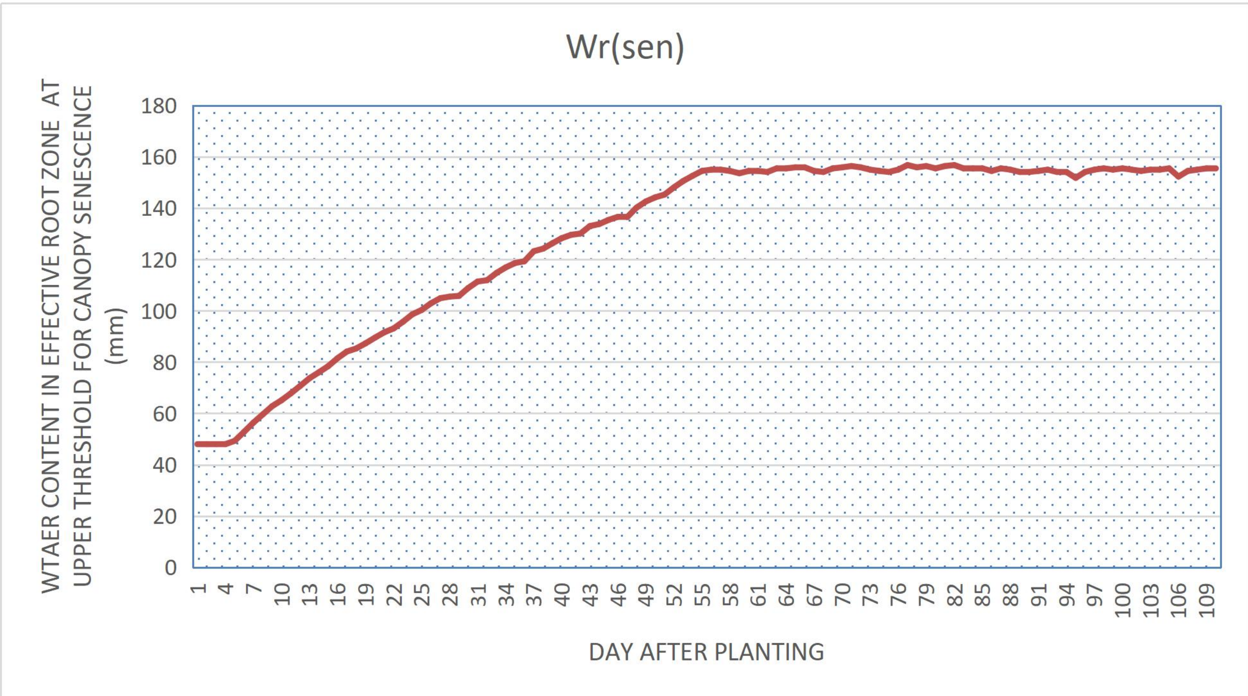

Figure 7: Graph of water content in effective root zone at upper threshold for canopy senescence versus DAP.

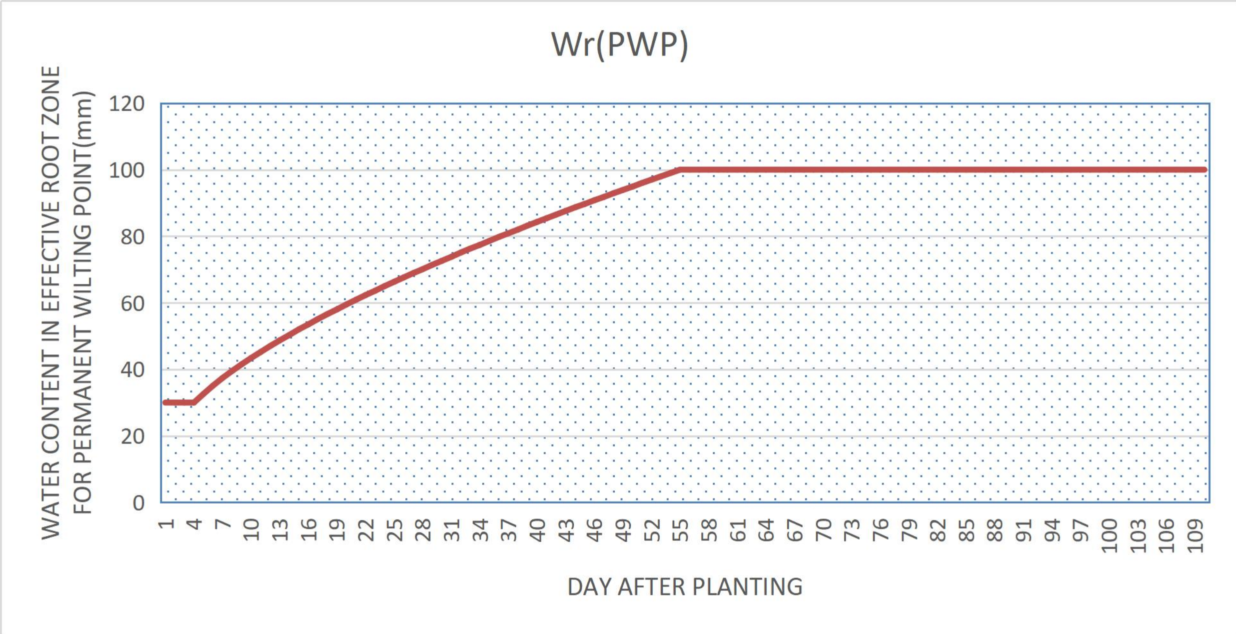

Figure 8: Graph of water content in effective root zone at permanent wilting point versus DAP

4. CONCLUSION

To achieve effective water management in irrigation scheduling, a cursory look must be paid to water contents at effective root zone which remain the only major source of water to plants. Crops responded to water contents in effective root zone in such a way that, as water application increased or decreased, water contents transformed from one stage to another with differential impacts on the health of crops. Increase in water application will cause water content to move from permanent wilting point to field capacity until it gets to saturation which is an injury to crop well-being and vice versa. However, the tomato crop performed better in terms of growth, fruit formation and yields when water supply was maintained at field capacity. The study aids better understanding of plant- soil- water relationship, judicious application of water to crop field, curbing of crop failure due to water related stresses and mitigation information against climate induced drought. The results generated in this report was based on the simulation carried out during the peak of dry season, therefore it is recommended that the simulation be run using data obtained during the rainy season.

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