JEAS

JOURNAL OF ENGINEERING AND APPLIED SCIENCES

Journal of Engineering and Applied Sciences, Volume 15, Number 1, December 2019, 118-129

Hydroponic Water Requirement Estimation for Cucumber Using FAO-CROPWAT Model in Awka, Anambra State, Nigeria.

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Abstract
Anambra State faces water scarcity which mostly occurs in many communities, particularly in Ifite Awka, and agricultural water use is progressively becoming more limited in the light of growing water demands of these various communities.Consequently, available water has not been satisfying demand both in quantity and quality in relation to the booming population of the nation for domestic, industrial and agricultural purposes. The aim of this study was to use CROPWAT model in estimating the water need for cucumber using10-year climate data (2008-2018) of Awka. This study was carried on Cucumber (*Cucumis sativus*L. 'Loeica') which was grown in a specifically designed urethane based recyclable plant growth substrate (UBS) during nursery stage and carbonized rice husk during post nursery stage in a Dutch Bucket Hydroponic production system using gravity-fed drip fertigation techniques. The performance of the test crop in a controlled environment was determined with data analyzed in a completely randomized design (CRD). Crop water requirement was determined using 10-year climate data in CROPWAT version 8 software. Reference crop evapotranspiration (ETo) was also determined using the Food and Agricultural Organizaton (FAO) Penman-Monteith method. Four crop growth stages: initial stage, development stage, mid-season and late season stage were considered. The study shows that reference evapotranspiration (ETo) varies from 2.5 to 3.36 mm/day for the area under study. The gross water requirement was 342.42 mm/year with an application efficiency of 70%. Thus the drip irrigation set up can conveniently supply the water required for crop use in the area. In this way the locally fabricated gravity-fed drip irrigation system was found significant to conveniently supply the water required for irrigation in the area but there is need for automating the setup by adding a timer that will detect when to apply water.

Key words: Hydroponics, Cucumber, Crop Water Requirement, CROPWAT.

1. Introduction

Food security is a central theme of the new millennium and it must be faced at national and international levels, taking into consideration the multidisciplinary nature of the field which involves socio-cultural, political and environmental, as well as agronomic and economic aspects (Deaton and Paxson 1998). From an economic and environmental point of view, food security is defined as a situation in which people have safe and appropriate food with nutritional requirements, for an active and healthy life (FAO 1996). Food security is based on three pillars: food availability, food access, and food uses as reported in the FAO guidelines (Matushke 2009).

Soil is known to provide anchorage, nutrients, air, water, etc. for successful plant growth (Ellis 1974). However, it does pose serious problems for plant growth too. Presence of disease causing organisms and nematodes, unsuitable soil reaction, unfavourable soil compaction, poor drainage, degradation due to erosion etc., are some of these problems (Beibel, 1960). In addition, conventional crop growing in soil (Open Field Agriculture) is somewhat difficult as it involves large space, lot of labour and large volume of water (Beibel 1960). Moreover, some places like metropolitan areas, soil is not available for crop growing at all, or in some areas, we find scarcity of fertile cultivable arable lands due to their unfavourable geographical or topographical conditions (Beibel 1960). Another serious problem experienced is the difficulty to hire labour for conventional open field agriculture (Butler 2006). Under such circumstances, soilless culture can be introduced successfully (Butler 2006).

Study shows that development of an efficient and productive growing protocol such as simplified hydroponic systems could be used to grow horticultural produce and increase the availability of natural and safe food for the poorest classes of the population (Dresher 2004). Hydroponics is a specialized horticultural method of plant production in which plants are grown in a soilless media known as a substrate or in a fully liquid media (Jensen 1997). Hydroponic systems do not require pesticides, it requires less water and space than traditional agricultural systems, and may be stacked in order to limit space use (vertical farming) (Growing Power 2011; Marginson 2010). Hydroponic systems can generally be delineated into open and closed systems. In open systems, which employ no reuse measures, the nutrient solution flows through the system once and is discarded (Jensen, 1997; Nederhoff and Stanghellini, 2010). This type of nutrient solution management helps eliminating the need for nutrient solution maintenance, and reduces the risk of infection on vegetable crop grown (Jones 2005).

Open hydroponic systems have one primary disadvantage which is wasting of large amount of water and nutrients (Nederhoff and Stanghellinin, 2010). In closed systems, the nutrient solution is reused, by adding more water and nutrients instead of replacing the entire solution (Jensen, 1997; Nederhoff and Stanghellini, 2010). Due to this procedural change closed systems use 20 – 40% less water and nutrients than open systems, but require more monitoring and maintenance (Nederhoff and Stanghellini 2010). Plants in carefully controlled hydroponic systems may be grown year round, placed closer together physically, or even stacked vertically, leading to higher production yields, (Graves, 1983; Jensen, 1999; Jones Jr., 2005; Resh 2013). As hydroponics uses a nutrient solution instead of open field watering, it consumes approximately 70-95% less water that traditional open field crop production does (Bradley 2001; Despommier 2010).

Further, hydroponic systems can be built in areas that would normally not support soil crop production (e.g., arid, urban environments) (Jensen 1999; Abd-elmoniem*et al.* 2004; Sheikh 2006; Nelkin and Caplow 2008).

Types of Hydroponics System

There are six (6) basic types of hydroponic systems; Wick, Water Culture, Ebb and Flow (Flood and Drain), Drip (recovery or non-recovery), Nutrient Film Technique and Aeroponic.

Wick System

The Wick system is the simplest type of hydroponic system. This is a passive system, which means there are no moving parts. The nutrient solution is drawn into the growing medium from the reservoir with a wick. This system can use a variety of growing medium like Perlite, Vermiculite, Pro-Mix and Coconut Fiber. The biggest drawback of this system is that plants that are large or use large amounts of water may use up the nutrient solution faster than the wick(s) can supply it.

Water Culture

This system is the simplest of all active hydroponic systems. The platform that holds the plants is usually made of Styrofoam and floats directly on the nutrient solution. An air pump supplies air to the air stone that bubbles the nutrient solution and supplies oxygen to the root zone of the plants. The biggest drawback of this kind of system is that it does not work well with large plants or with long-term plants.

EBB and Flow (Flood and Drain)

The Ebb and Flow system works by temporarily flooding the grow tray with nutrient solution and then draining the solution back into the reservoir. This action is normally done with a submerged pump that is connected to a timer. When the timer turns the pump on nutrient solution is pumped into the grow tray. When the timer shuts the pump off the nutrient solution flows back into the reservoir. The Timer is set to come on several times a day, depending on the size and type of plants, temperature and humidity and the type of growing medium used.

The Ebb & Flow is a versatile system that can be used with a variety of growing mediums. The entire grow tray can be filled with Grow Rocks, gravel or granular Rockwool. Many people like to use individual pots filled with growing medium, this makes it easier to move plants around or even move them in or out of the system. The main disadvantage of this type of system is that with some types of growing medium (Gravel, Growrocks, Perlite), there is a vulnerability to power outages as well as pump and timer failures. The roots can dry out quickly when the watering cycles are interrupted. This problem can be relieved somewhat by using growing media that retains more water (Rockwool, Vermiculite, coconut fiber or a good soilless mix like Pro-mix or Faffard's).

Drip Systems Recovery (Non-Recovery)

Drip systems are probably the most widely used type of hydroponic system in the world. The operation is simple; a timer controls a submersed pump. The timer turns the pump on and nutrient solution is dripped onto the base of each plant by a small drip line. In a Recovery Drip System the excess nutrient solution that runs off is collected back in the reservoir for re-use. The Non-Recovery System does not collect the run off.

A recovery system uses nutrient solution a bit more efficiently, as excess solution is reused, this also allows for the use of a more inexpensive timer because a recovery system does not require precise control of the watering cycles. The non-recovery system needs to have a more precise timer so that watering cycles can be adjusted to insure that the plants get enough nutrient solution and the runoff is kept to a minimum.

The non-recovery system requires less maintenance due to the fact that the excess nutrient solution is not recycled back into the reservoir, so the nutrient strength and pH of the reservoir will not vary. This means that you can fill the reservoir with pH adjusted nutrient solution and then forget it until you need to mix more. A recovery system can have large shifts in the pH and nutrient strength levels that require periodic checking and adjusting.

Nutrient Film Technique (N.F.T)

This is the kind of hydroponic system most people think of when they think about hydroponics. This system has a constant flow of nutrient solution so no timer required for the submersible pump. The nutrient solution is pumped into the growing tray (usually a tube) and flows over the roots of the plants, and then drains back into the reservoir.

There is usually non-growing medium used other than air, which saves the expense of replacing the growing medium after every crop. Normally the plant is supported in a small plastic basket with the roots dangling into the nutrient solution. N.F.T. systems are very susceptible to power outages and pump failures. The roots dry out very rapidly when the flow of nutrient solution is interrupted.

Aeroponic System

In this system, plants are kept in containers with their roots exposed to the air. A timer is installed to control a pump that mists the exposed roots with nutrient-rich water at every interval. Aeroponic equipment involves the use of sprayers, misters, foggers, or other devices to create a fine mist of solution to deliver nutrients to plant roots.

Aeroponic systems are normally closed-looped systems providing macro and micro-environments suitable to sustain a reliable, constant air culture.

Crop Water Requirement

Penman-Monteith method (FAO 1998) is used in the present study for determining reference crop evapotranspiration (ET0) since it is reported to provide values that are very consistent with actual crop water use data worldwide (Surendran*et al. 2013*). The irrigation schedule recommendations for various crops should be location-specific, considering the substrate type and agro-ecological conditions. The scientific crop water requirements are required for efficient irrigation scheduling, water balance, canal design capacities, regional drainage, water resources planning, reservoir operation studies, and to assess the potential for crop production (Greiser*et al. 2002*).

The reference evapotranspiration ETo of individual agro-ecological units are calculated by FAO. Penman-Monteith method, using decision support software –CROPWAT 8.0 developed by FAO, based on FAO Irrigation and Drainage Paper 56 (FAO 2009). The FAO CROPWAT program includes procedures for reference crop evapotranspiration and crop water requirements, and allows the simulation of crop water use under various climates, develop irrigation schedules under various management conditions and Scheme water supply, crop and substrate conditions (FAO, 2009). Crop coefficients values (Kc) are taken from available published data of FAO Irrigation and Drainage Paper 56 (FAO 2009). Kc values for initial, mid and late growth stages of annual and seasonal crops are used. In the case of perennial crops, same Kc value is used for the growth period.

Crop water requirements are defined here as "the depth of water needed to meet the water loss through evapotranspiration (ETcrop) of a disease-free crop, growing in large fields under non-restricting soil conditions including soil water and fertility and achieving full production potential under the given growing environment". The water requirement of crops is the amount of water that is required to meet the evapotranspiration rate so that crops may thrive. The evapotranspiration rate is the amount of water that is lost to the atmosphere through the leaves of the plant, as well as the soil surface.

Estimating the Water Requirements of the Crop

ET_0 represents the maximum, or potential, evapotranspiration rate that can occur. However, the water requirement of the crop is usually less than ETo, as there are factors of the crop itself that have to be taken into account. These include the growth stage of the plant, the leaf coverage that provides shade to the ground, and other particulars of the crops that make them vary from each other. With these factors taken into consideration, ETo is converted into ETc, through the crop-specific coefficient, Kc. ETc represents the evapotranspiration rate of the crop under standard conditions (no stress conditions). When calculating ETc, one must identify the growth stages of the crop, their duration and select the proper Kc coefficient that need to be used.

$$ETc = Kc \; x \; ETo \qquad (1)$$

Research focusing on water-saving agriculture has recently emphasized the use of “crop water requirement”, (CWR), (Qiang, *et al.* 2014) aiming at supplying a precise amount of water to a crop based on crop needs. Crop water requirement can be expressed in millimeters per day, per month, or per season; these can be used for management purposes in estimating irrigation water requirements, irrigation scheduling, and water delivery scheduling (Todorovic 2005; Qiang, *et al.* 2014). In a wet substrate, the water has a high potential energy, is relatively free to move and is easily taken up by plant roots. In a dry substrate, however, the water is bound by capillary and absorptive forces to the substrate matrix, and is less easily extracted by crop plants. When the potential energy of the substrate water decreases to a threshold value (usually, the lower limit of plant extractable substrate water), the crop is unable to extract the water from the substrate and becomes water stressed. Thus, the crop water requirement of a particular crop at a particular growth stage can be estimated by multiplying the crop coefficient, Kc, with the crop reference evapotranspiration, ETo, as follows:

$$CWR = K_s K_C \quad (2)$$

Where, CWR is under water stress, K_s describes the effect of water stress on crop transpiration (K_s is <1 under soil water-limiting conditions, with evaporation from soil not a large component of ET), K_c is the crop coefficient which can be estimated using a "crop coefficient curve" developed for different crop species, and ETo is the crop reference.

The amount of irrigation water needed by a crop is roughly the difference between CWR and precipitation on a weekly or monthly basis (Qiang et al. 2014).

$$IW = CWR - Pr \quad (3)$$

Where, IW is irrigation water required in mm, and
P_r is precipitation during the given period (weekly or monthly) in mm.

Net irrigation requirements
The net irrigation water requirement was calculated as given by (Surendran*et al.,* 2017),

$$NIR = ETc - ER - Ge \quad (4)$$

Where, NIR is net irrigation requirements (mm), ETc is total water requirement, ER is effective rainfall calculated based on rainfall data available from the stations within Awka, using the inbuilt formula (eqs. (5) and (6) of USDA Soil Conservation Service (SCS) in CROPWAT model.

$$Peff\ (dec) = (Pdec * (125 - 0.6 * Pdec))\ {}^{1}/_{125} \text{ for } P_{dec} \leq {}^{250}/_{3}\ \text{mm}, \quad (5)$$

$$Peff\ (dec) = {}^{250}/_{3} + 0.1 * Pdec \qquad \text{for } P_{dec} > (250/3)\ \text{mm}, \quad (6)$$

WhereP_{eff} is the effective rainfall and P_{dec} is the rainfall for 10 days. Ge is groundwater contribution from water table (this is not considered in the calculation as it is negligible),

$$ETc = Kc * ETo \quad (7)$$

ETo for each month was calculated for a 'decade' (every ten days) as defined by FAO 56. Gross depth of water to be applied in single irrigation was obtained as,

$$Dgross = \frac{NIR}{Ea} \quad (8)$$

Where, Ea is the application efficiency (70%).

2.0 MATERIALS AND METHOD

Description of study area

The experiment was conducted in Nnamdi Azikiwe University Awka, Anambra State (Figures 1 and 2) withLatitude 6°, 16'N and Longitude 7°, 07'E and has an altitude of 447m above sea level. It was situated 35km of South West of

Awka. Two main seasons exist in Awka area; the dry season which lasts from November to March and the rainy season which begins in April and ends in October with a short period of reduced rains in August commonly referred to as "August break". Temperature in the dry season ranges from 20 to 38°C, and results in high evapotranspiration, while during the rainy season temperature ranges from 16 to 28°C, with generally lower evapotranspiration. The permanent site of the Nnamdi Azikiwe University falls within the highland region of a low asymmetrical ridge or Cuesta in the northern portion of the Awka-Orlu Uplands (Aghamelu *et al.* 2011). . The average monthly rainfall ranges from 31mm in January to 270mm in July, with the dry season experiencing much reduced volume of rainfall unlike the rainy season, which has high volume of rainfall. Average annual rainfall varies from 1,500 to 1,650mm.

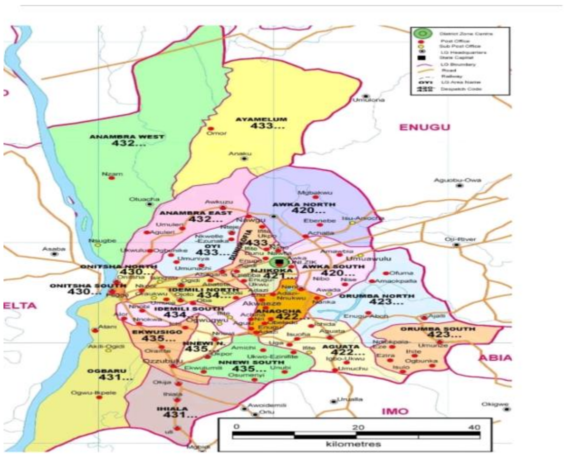

Figure 1: Map of Anambra state showing Awka

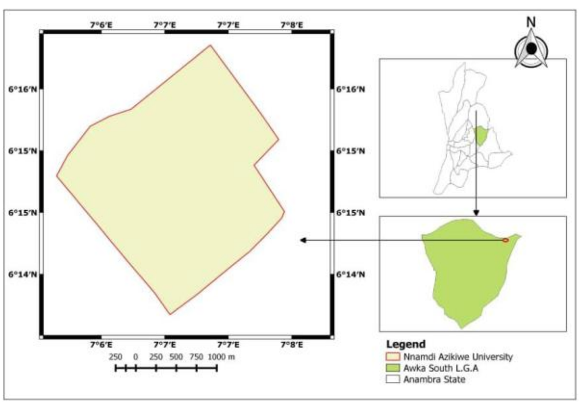

Figure 2: Map of Awka South showing UNIZIK

Experimental Layout and Design

The Dutch Bucket hydroponic(figure 3) system placed in a controlled environment located at Agricultural and Bioresources Engineering experimental site at NnamdiAzikiwe University, Awka, Anambra State of Nigeria, figure 2, is a container in hydroponic and aquaponic grow systems that contained the substrate, rice hull biochar. The rice hull biochar was produced by pouring fresh rice hull into a suitable metal container (e.g. cut drum) for heating in an aerobic condition. The container is placed over the fire and intermittently stirred the rice hull as the container is on the fire to enable those ones at the bottom get charred. The stirring was maintained until the entire rice hulls were charred. When 100% charring without ashing, the container is removed from the fire and the hot carbonized rice husk is then cooled with fresh water which is then allowed to dry properly before usage to store the moisture, provide aeration as well as supporting plants to stand upright as it was used in growing vegetable crop production. Each dutch bucket accommodated one plant which securely held the grow medium and the plant's root system. Each cucumber plant was planted and maintained to grow vertically by winding it around a suspended string tied on the roof.

Figure 3: A simple Dutch Bucket Hydroponic Drip Fertigation System Design

Crop Water Requirement

Irrigation water requirement, crop water requirement and irrigation schedule were obtained using Cropwat 8.0 version with the climate data obtained from the Meteorology Station of the Department of Geometeorology and Geography in NnamdiAzikiwe University, Awka, Anambra State, Nigeria. The substrate data such as initial substrate moisture depletion, and available water obtained from the difference between field capacity and permanent wilting point were also used to determine irrigation water requirement, crop water requirement and irrigation schedule using Cropwat 8.0 version. Also, the crop factor, Kc and maximum rooting depth (table 1 and 2) were also used on the Cropwat 8.0 version in estimating irrigation water requirement, crop water requirement and irrigation schedule which were taken from available published data of FAO Irrigation and Drainage Paper 56 (FAO 1998)..

Table 1: Approximate duration of growth stages for various field crops

	Total	Initial stage	Crop Dev. Stage	Mid season Stage	Late season Stage
Barley/Oats/Wheat	120	15	25	50	30
	150	15	30	65	40
Bean/green	75	15	25	25	10
	90	20	30	30	10
Bean/dry	95	15	25	35	20
	110	20	30	40	20
Cabbage	120	20	25	60	15
	140	25	30	65	20
Carrot	100	20	30	30	20
	150	25	35	70	20
Cotton/Flax	180	30	50	55	45
	195	30	50	65	50
Cucumber	105	20	30	40	15
	130	25	35	50	20

Source: FAO Irrigation and Drainage Paper 56 (Allen *et al.* 1998)

Table 2: Values of the Crop Factor (Kc) for various Crops And Growth Stages

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Crop	Initial stage	Crop dev. Stage	Mid-season stage	Late season stage
Barley/Oats/Wheat	0.35	0.75	1.15	0.45
Bean, green	0.35	0.70	1.10	0.90
Bean, dry	0.35	0.70	1.10	0.30
Cabbage/Carrot	0.45	0.75	1.05	0.90
Cotton/Flax	0.45	0.75	1.15	0.75
Cucumber/Squash	0.45	0.70	0.90	0.75
Eggplant/Tomato	0.45	0.75	1.15	0.80
Grain/small	0.35	0.75	1.10	0.65
Lentil/Pulses	0.45	0.75	1.10	0.50

Source: FAO Irrigation and Drainage Paper 56 (Allen *et al.*, 1998)

3.0 Results and Discussion

Interpretation of the Climate and ET_O Result

Table 3 shows the climate and ET_O data as computed using CROPWAT version 8 software. This shows that the total average yearly minimum and maximum temperature values were 26.7^{0}C and 32.2^{0}C as computed. The average monthly temperature for the period of ten years was used which is was highest in the months of February and March with the values of minimum and maximum temperature (29^{0}C) and (35^{0}C) respectively. This air temperature is raised by the solar radiation absorbed by the atmosphere and the heat emitted by the earth. The sensible heat of the surrounding air transfers energy to the crop which influences the rate of evapotranspiration. In warm and sunny weather, the loss of water by evapotranspiration is greater than in humid weather.

The evapotranspiration process is determined by the amount of energy available to vapourize water. Solar radiation, table 3, is the largest energy source which is able to change large quantities of liquid water into vapour. This is due to the differences in the position of the sun which makes the potential radiation to differ at various latitudes and in different seasons. The potential amount of radiation that can reach the evaporating surface is determined by its location and time of the year. The actual solar radiation reaching the evaporating surface depends on the humidity of the atmosphere and the presence of clouds which reflect and absorb major parts of the radiation. When assessing the effect of solar radiation on evapotranspiration from table 3, the total average solar radiation is 16.9 MJ/m^2/day which is highest in the month of April with value of 20.1 MJ/m^2/day and lowest in the month of August with the value of 12.9 MJ/m^2/day.

Interpretation of rainfall and effective rain result

Table 4 shows the result of the rainfall and effective rain as developed by cropwat v8 software. These show that the average yearly peak rainfall and effective rain were observed in the month of September with the values of 300.1 mm and 155.0 mm respectively. During this month of September, the cucumber crop has enough water for its performance as the rate of evapotranspiration is minimal due to high relative humidity and low solar radiations. The lowest rainfall and effective rain were observed in the month of December with the value range of 4.5mm each. This shows that the cucumber will be requiring more and appreciable quantity of water for its performance due to low rainfall and high evapotranspiration. The irrigation water requirement would be high during the month of December. The rainfall and effective rain for the period covered were observed to be 1847.2mm and 1140.1 mm respectively

Table 3: Result of ETO/Climate as computed by CROPWAT version 8 software

Month	Min. Temp.	Max. Temp.	Humidity (%)	Wind (KM/DAY)	Sunshine (Hour)	Radiation ($MJ/M^2/DAY$)	ETo (MM/DAY)
JANUARY	27.0	34.0	39	319	7.3	19.0	7.49
FEBRUARY	29.0	35.0	40	336	5.3	17.0	7.70
MARCH	29.0	35.0	51	354	6.3	19.2	7.47
APRIL	28.0	33.0	60	336	6.9	20.1	6.57
MAY	27.0	32.0	67	311	6.6	18.9	5.63
JUNE	26.0	31.0	71	293	5.8	17.3	4.93
JULY	25.0	29.0	76	293	4.7	15.8	4.21
AUGUST	25.0	29.0	73	319	2.4	12.9	4.06
SEPTEMBER	25.0	30.0	71	293	4.1	15.6	4.54
OCTOBER	26.0	31.0	66	267	5.3	17.0	4.99
NOVEMBER	27.0	33.0	51	267	4.1	14.5	5.66
DECEMBER	26.0	34.0	40	259	5.3	15.8	6.37
AVERAGE	**26.7**	**32.2**	**59**	**304**	**5.3**	**16.9**	**5.80**

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Table 4: Result of rainfall and effective rainfall data as computed by CROPWAT version 8 software

Month	Rain (mm)	Effective Rain (mm)
January	**20.3**	**19.6**
February	**14.7**	**14.4**
March	**58.8**	**53.3**
April	**159.5**	**118.8**
May	**269.5**	**151.9**
June	**279.7**	**153.0**
July	**236.0**	**146.9**
August	**256.2**	**150.6**
September	**300.1**	**155.0**
October	**215.2**	**141.1**
November	**32.7**	**31.0**
December	**4.5**	**4.5**
Total	**1847.2**	**1140.1**

Interpretation of Crop Water Requirement Result

Table 5 shows that the total crop water requirement for the cucumber crop was 289.2 mm. while total irrigation requirement was 0.00 mm for cucumber crop during the growth stages at NnamdiAzikiwe University, Awka.

At NnamdiAzikiwe University, Awka station, the crop water requirement (ETc) was highest (41.8mm/dec) in the month of October for the late growth stage of cucumber towards dry season during fruiting stage, whereas lowest value (12.9 mm/dec) was recorded in the second decade of October month for late growth stage during when the fruit of the cucumber must have terminated the fruit development.

It was also observed from the Table 5 that the total effective rainfall was 519.7 mm. The effective rainfall was highest (52.5 mm/dec) in the month of September for the mid growth stage in the second decade despite that this is the month of annual peak rainfall and evaporation rate is minimal due to high relative humidity and low sunlight. Also, lowest effective rainfall value (15.5 mm/dec) was recorded in the second decade of month of October for late growth stage. Hence irrigation requirement increased considerably.

Table 5: Crop Water Requirement as computed by CROPWAT version 8 Software

MONTH	DECADE	STAGE	Kc Coefficient.	ETc (mm/day)	ETc (mm/dec.)	Eff. RAIN (mm/dec.)	Irr. Req. (mm/dec.)
JUL	1	**INIT**	0.45	2.00	20.0	49.3	0.0
JUL	2	**INIT**	0.45	1.89	18.9	48.5	0.0
JUL	3	**DEVE**	0.49	2.05	22.6	49.1	0.0
AUG	1	**DEVE**	0.57	2.34	23.4	49.8	0.0
AUG	2	**MID**	0.64	2.60	26.0	50.2	0.0
AUG	3	**MID**	0.67	2.82	31.0	50.7	0.0
SEP	1	**MID**	0.67	2.92	29.2	51.7	0.0
SEP	2	**MID**	0.67	3.03	30.3	52.5	0.0
SEP	3	**LATE**	0.71	3.31	33.1	50.7	0.0
OCT	1	**LATE**	0.86	4.18	41.8	51.6	0.0
OCT	2	**LATE**	0.86	4.31	12.9	15.5	0.0
TOTAL					**289.2**	**519.7**	**0.0**

Interpretation of Irrigation Schedule Table

According to the results obtained from CROPWAT software, Table 6, for crop irrigation schedule when irrigating at critical depletion and the substrate refilled at field capacity with application efficiency of 70%, the total gross irrigation was 102.9 mm while the total net irrigation was 72.0 mm when the total and effective rainfall was 914.8mm and 282 mm respectively and the total rain loss was 631.9 mm. The actual and potential water used by the crop was 284.9 mm. The actual irrigation requirement was 2.0 mm and the rainfall and irrigation schedule efficiency was 30.9% and 100% respectively.

This shows that when the substrate was filled at field capacity, the total available moisture, TAM, which is at zero level, will keep depleting which will also provide water for plant use. This water level will keep depleting until it gets to a constant level known as readily available moisture, RAM, where the plant roots can always, easily and readily access the moisture in the substrate. Any further depletion in moisture level beyond the RAM level might lead to wilting of the cucumber crop due to the inability of the roots to tap the readily available water. These can as well lead to permanent wilting of the crop if not re-irrigated for plant use.

Table 6: Crop Irrigation Schedule as computed by CROPWAT version 8 software

DATE	DAY	STAGE	RAIN (mm)	Ks Fraction (%)	Eta (%)	DEPL. (mm)	NET IRR. (mm)	DEFICIT (mm)	LOSS	Gross irrigation(mm)	FLOW (L/s/ha)
1 JULY	**1**	**INIT**	**0.0**	**1.00**	**100**	**51**	**72.0**	**0.0**	**0.0**	**102.9**	**11.90**
13 OCT	**END**	**END**	**0.0**	**1.00**	**0**	**0**					

4.0 Conclusion

The estimation of crop water requirement and irrigation schedule has been done using software (Cropwat, V8). Combining data from the software allowed us to obtain results and determine the water requirements needed for cucumber production on the research area. The uniformity of distribution obtained is 75% indicating a good efficiency. The total gross irrigation for the entire cycle of cucumber was estimated to be 102.9 mm, while the total net irrigation was 72.0 mm when the total and effective rainfall were 914.8mm and 282 mm respectively and the total rain loss was 631.9 mm.

The actual and potential water used by the crop was 284.9 mm. The actual irrigation requirement was 2.0 mm and the rainfall and irrigation schedule efficiency was 30.9% and 100% respectively. The design of a drip irrigation system is of great importance as it helps to save water loss, checks crop water requirement. This will reduce the application time and crop performance is of great and bountiful yield will be achieved.

5.0 Recommendation

The design of Dutch Bucket Gravity-Fed Drip fertigation system outcome is a milestone towards a hydroponics system however the following are some of the recommendations that would ease the maintenance of the system and also increase the efficiency of the system. The recommendations include; In order to promote vegetable production in water scarcity areas, I strongly recommend that a good Dutch Bucket Gravity-Fed Drip Fertigation technique can be used advantageously. It is recommend that automation of the system would help in management of the irrigation and fertigation requirement in order to meet the specific water and fertilizer requirements for each section which would involve incorporating sensors that determine when to irrigate. This shows that if irrigation is done based on scientific crop water requirement using proper planning based on our study, water would be saved. Finally, CROPWAT model is also recommended as it is a useful tool for calculating reference ETo, which is needed for the accurate calculation of irrigation water requirements.

Acknowledgements

The authors wish to acknowledge the financial contributions of the office of the Executive Assistant (EA) to Enugu State Governor, Government House, Enugu, Enugu State, Nigeria, for funding part of this work, staff of the Department of Soil Science and Land Resources Management, NAU, AWKA, and the Head of Department, Soil Science and Land Resources Management for support to this study.

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