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Prediction of Amaranthus Crop Evapotranspiration Using Three Models in Maiduguri

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Abstract: *The knowledge of crop evapotranspiration (ETc), the combined process of evaporation and plant transpiration, is important in agriculture for scheduling farm operations and designing and managing irrigation and drainage systems. Development of crop coefficient (Kc) can enhance crop evapotranspiration (ETc) estimates in specific crop growth stages. However, locally determined Kc information is not available for many important crops in Nigeria. This research was, therefore, conducted to determine the growth parameter stage, specific Kc and crop water use for waterleaf at the Ramat Polytechnic Agricultural Research Farm which is located in a semi-arid climatic zone in Maiduguri. Drainage type lysimeter was used to measure crop water use under water balance system and local weather data were used to determine the reference evapotranspiration (ETo). A lysimeter was used to measure the daily evapotranspiration of waterleaf on a sandy loam soil. Crop coefficient was developed from measured ETc and ETo calculated using weather data. Crop evapotranspiration observed from the field using the lysimeter and those estimated using models were compared using Nash- Sutcliffe efficiency (NSE). The outcome of the experiment revealed that, correlation analysis among the growth parameters showed that, there is strong positive relationship of about (82% to 90%).Similarly, crop evapotranspiration values of waterleaf in Maiduguri semi-arid region was found to be averagely 3.65, 4.88, 5.48 and 5.34 mm at each growth stages, respectively, with seasonal total ETc of 177.44 mm. The crop coefficient values of waterleaf were found to be 0.62, 0.82, 0.86 and 0.76 at each growth stages respectively. The values of ETc determined from the lysimeter were validated by Blaney-Morin Nigeria (BMN), Blaney-Criddle (BC) and Hargreaves models and better agreement was recorded between the ETc calculate from empirical model for the waterleaf using Nash- Sutcliffe efficiency (NSE) and T-test software. Therefore, the study revealed that, drainage lysimeter can be said to be functional and efficient to use in the region.*

Keywords: *Waterleaf; Blaney-Morin Nigeria; Blaney-Criddle; Hargreaves and Crop Coefficient*

1.0 INTRODUCTION

1.1 Background of the Study

Irrigation plays an important role in food production globally. Irrigation is the supply of water to crops by artificial means, designed to permit farming in arid region and to offset the effect of drought in semi-arid region and even in areas where total seasonal rainfall is adequate or average (Vaughan *et al.,* 2007). Accurate evapotranspiration estimates are essential to identify the time variations on irrigation needs, to improve the allocation of water resources, and to evaluate the effect of the use of the land and changes in the management of the water balance (Ortega – Farias *et al.,* 2009). Evapotranspiration can be obtained by direct or estimate measures of climatic elements, using empirical methods. The direct method is represented by several types of lysimeters, being the most accurate method, and considered standard – tool for the determination of evapotranspiration (Bernardo *et al.,* 2006; Amorim, 1998). There are several empirical methods in literature that use meteorological elements data to estimate the evapotranspiration. These methods are based on observations and statistical analysis, and are generally adequate for a specific climatic or region condition (Gravilan *et al.,* 2006). Vegetables contain 80 to 95 percent water, because they contain so much water, their yield and quality suffers very quickly from drought. When vegetables are sold, a "sack of water" with a small amount of flavoring and some vitamins is being sold. Thus, for good yields and high quality, irrigation is essential to the production of most vegetables. Most vegetables are rather shallow rooted and even short periods of two to three days of stress can hurt marketable yield. Waterleaf (*Talinumtriangulare Jacq.*) is a plant to the family Taliniaceae and commonly found in humid tropics. It has been recognized in many countries of Africa; it is claimed to have South American origin but an African origin may not be doubted (Schippers,.2000). Waterleaf is an erect glabrous perennial herb (80-100cm tall), usually strongly branched; roots are swollen and fleshy. The leaves are alternate, simple, almost sessile and succulent (Oluwole *et al.,* 2018) Waterleaf cultivation like other leafy vegetables cultivation in home gardens improves nutritional quality for the family and may provide additional income for female farmers. As a result of its high nutritional value that provide good source of crude protein (22.1%), and vitamins, waterleaf is playing a major role in efforts to eradicate malnutrition in Africa (Tata *et al.,* 2016). Evapotranspiration (ET) It is the combination of two separate processes through which, water is lost from the soil surface via evaporation process and from the crop by transpiration. (Allen, 1998). Similarly, Konukcu (2007) classified evapotranspiration as actual evapotranspiration ETa, Crop evapotranspiration ETc, reference evapotranspiration ETo or potential evapotranspiration ETp. Crop Evapotranspiration is the evapotranspiration from disease-free, well-fertilized crops, grown in large fields, under optimum soil water conditions and achieving full production potential under the given climatic conditions. Crop coefficient (Kc) is defined as the ratio of the crop evapotranspiration to the reference evapotranspiration and can be calculated by different methods (e.g. single crop coefficient method and dual crop coefficient method) (Jensen et al., 1990; Allen et al., 1998). Crop coefficient Kc is the ratio of potential evapotranspiration for a given crop to the evapotranspiration of a reference crop. It represents an integration of effects of four primary characteristics that adjusts the crop from reference grass (i) Crop height, (ii) Albedo, (iii) Canopy resistance, (iv) Evaporation from soil; especially exposed soil. The factors determining the crop coefficients are crop type, climate, soil moisture evaporation, crop growth stage (Vaughan et al., 2007). According to (Allen *et al*., 1998), there are many models based on meteorological data which allow estimating evapotranspiration in different climates and geographical conditions. The Penman-Monteith FAO model PMF is generally presented as a standard model for estimating ET The main limitation of this model is the need of many meteorological data entries which limits its applicability in areas where data is less available, especially in developing countries. Some simpler models that use parameters or variables that are commonly measured in meteorological stations are more advisable to estimate (ET) in scarce-data areas. Similarly, (Tabari, 2010) reported some simpler mathematical models for calculating evapotranspiration indirectly are the Priestley-Taylor PT method (Priestley and Taylor, 1972), and the Hargreaves-Samani HS method (Samani, 2000; Hargreaves and Allen, 2003). The HS method is a simple method that only requires data such as temperature and latitude of the area of study. Houshang *et al*, (2015) have compared five different evapotranspiration models as shown in equation 2.1 to 2.5 with the observed ET using lysimeter in Kermanshah western part of Iran

(a) FAO56-Penman-Monteith Method by Allen et al 1998

$$ETo = \frac{0.408\Delta(R_n - G) + r\frac{900}{T+273}U_2\ (e_s - e_{sa})}{\Delta + \gamma\ (1+0.034u_2)} \qquad 2.1$$

Where, u_2 and (e_s - e_a) are wind speed at 2 m height (m $^{s-1}$) and saturation vapour pressure deficit (kPa).

(b) FAO-Penman Method, adopted by Doorenboss (2000)

$$ETo = c\left[\left(\frac{\Delta}{\Delta+\gamma}\right)(R_n) + \left(\frac{\gamma}{\Delta+\gamma}\right)(2.7)(w_f)\ (e_z - e_z)\right] \qquad 2.2$$

Where, ETo, ($e^0{}_z$ –e_z), *Y*, , R_n, W_f and C are reference evapotranspiration (mm day^{-1}), vapour pressure deficit at height z (kPa), psychometric constant (kPa ºC-1), slope vapour pressure curve (kPa^{o}C-1), net radiation (MJ m^{-2} per day), the wind function and adjustment factor which is equal to 1 respectively.

(c) FAO-Radiation Method 1975 Revised by Doorenboss (1997)

$$ETo = b\left[\frac{\Delta}{\Delta+\gamma} + \frac{R_s}{\lambda}\right] - 0.3 \qquad 2.3$$

Where, RH is the relative humidity (%) and $b = 1.066 - 0.13 \times 10^{-3}\ RH + 0.045U_d\ - 0.2 \times RHU_d - \ 0.015 \times 10^{-4}\ RH^{-2}\ - 0.11 \times 10^2\ \ U^2$

(d) Turc-Radiation method 1961 adopted by Razzaghi **(2010)**

$$ETo = a_r\ (0.013) = \frac{T_{mean}}{T_{mean}+15}\left(\frac{23.8856R_S+50}{\lambda}\right) \qquad 2.4$$

Where, T mean and Rs are mean daily air temperature (^{o}C), and solar radiation (MJ m^{-2} d^{-1}), a_r is equal 1.0 for RH $_{mean}$ ⍰⍰50% and it is equal 1+ (50-RH_{mean})/70 for RH $_{mean}$ < 50%.

(e) Priestley and Taylor method

$$ETo = \frac{1}{\lambda}\,\alpha == \frac{(\Delta\ )}{\Delta+\gamma}\ \ (R_{n-}\ G) \qquad 2.5$$

Where, ⍰ is a constant (⍰ = 1.26).

(f) Hargreaves and Samani method, Hargreaves [1987]

$$ETo = \frac{1}{\lambda}\ (0.0023)\ R_{A-}\ \ TD^{\ \frac{1}{2}}\ (T + 17.8) \qquad 2.6$$

Where, R_A, TD and T are extra-terrestrial solar radiation received on earth's surface (MJ m^{-2} d^{-1}), difference of mean maximum and mean minimum air temperatures (C^{0}) and mean daily air temperature at 2 m height (^{o}C) respectively.

According to Pereira and Pruitt (2004), although electronic data logging weather stations are becoming the norm for some countries, this is not the case on global basis. the rarely available automatic weather stations require qualified personnel for operation and maintenance of the very sensitive instruments. semi-arid climate, concluded that the values of RMSE indicate that, the FAO56 - Penman-Monteith, Hargreaves and Samani were found to be the most appropriate models for the studied region. Priestley and Taylor method and FAO-Penman methods and Turc-Radiation method had the worst results among the studied models. FAO- Penman-Monteith, Hargreaves-Samani methods recommended for evapotranspiration estimation, irrigation planning and scheduling and irrigation projects water requirement application under different crop patterns in semi-climatic region, however the author emphased the FAO56 penmen method need many meteorological data entries which limits its applicability in areas where data is less available, especially in developing countries. Also Penman-Monteith equation is often difficult and expensive to obtain for practical applications (Stefano and Ferro, 1977). Therefore, the current study is undertaken to determine the growth parameters, crop evapotranspiration (ETc) and crop coefficient (Kc) of waterleaf using drainage in semi-arid region of Maiduguri North-Eastern Nigeria.

2.0 MATERIALS AND METHOD

2.1 Experimental Site

Field experiment was conducted at the Teaching and Research Farm, of the Ramat Polytechnic, Maiduguri, in the Sudano-Sahelian region of northern Nigeria. The site lies between latitude 11^{0}5 N and longitude 13^{0} 09E (Kyari *et al.,* 2014).

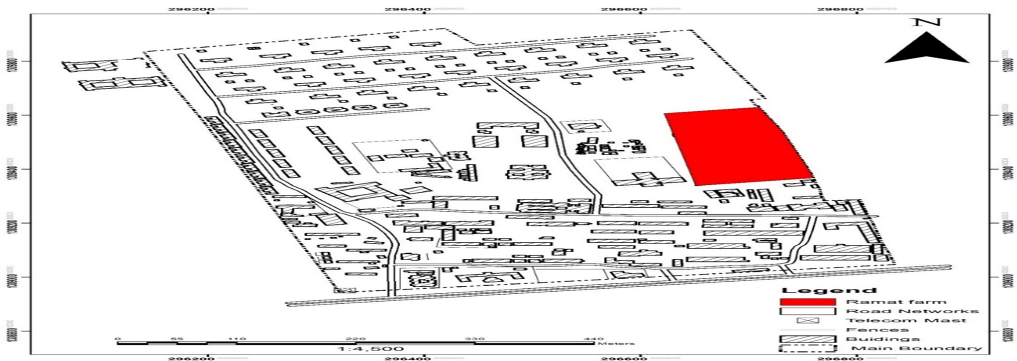

Figure 1: Digitize Map of the Study Area.

Table 1: Mean Soil Characteristics of the Experimental Site (0-30 cm)

Soil type (USDA soil classification)	Sand loamy
Clay (%)	8.0
Silt (%)	11.8
Sand (%)	80.2
P^{H}	6.8
Field capacity (vol. %)	16.2
Wilting point (vol. %)	3.2
Available water content (vol. %)	13.0
Bulk Density (g/cm^{3}	1.70
Organic matter (%)	3.99

Source : Agricultural Research Farm Rampoly

2.2 Agronomic practices

The location for excavation was marked after clearing the site from its previous vegetation in preparation for installation of the non -weighing lysimeter. To effect installation, the soil was excavated in layers, with soil from each layer placed in a separate pile. When the proper depth was reached; the bottom of the hole was leveled. The surface area of the excavation – 3.58m2 by 1.6m deep was done manually. This was done to provide some space to allow for the installation of the lysimeter manually. The field layout for the experiment consists of the developed lysimeter planted up with waterleaf stands transplanted from the nursery. The vegetable under study was transplanted on a spacing of 20cm by 15cm. The lysimeter installation was accomplished by six people with the use of shovels, and a few hand tools. The tank was lowered into and centered in the hole upon a stable concrete foundation. The tank was checked to ensure that it sat level on the bottom of the hole. Soil was backfilled around the outer tank to stabilize the tank as can be seen in figure 3.2. In other words, the outside lysimeter was first filled with soil to provide a firm support to the lysimeter. In other to prevent transport of materials from the soil into the drain pipe, a wire mesh of about 0.20mm was placed at the bottom of the lysimeter, upon the hole drilled, to act as a filtering mechanism. The formation of the filter was achieved first by placing a screen over the hole, then gravel and finally sand. Then the inner tank was backfilled with soil, restoring the soil to the depth from which it was excavated. The soil was packed periodically in an attempt to return it to its original bulk density. In the installation, a freeboard of about 10cm from the ground surface was allowed and the process of irrigation was carried out with its attendant drainage. But before the transplanting, the lysimeter has stopped draining from the drainage pipe after saturation and the initial soil moisture data taken. The receiving vessel being a discarded plastic 20-litre emulsion paint container was placed in an adjacent pit for the collection of the percolated water. The field layout for the experiment consists of the developed lysimeter planted up with waterleaf stands transplanted from the nursery. The vegetable under study was transplanted on a spacing of 20cm by 15cm. weeding was done almost on daily basis during the course of this study, this is because weeds do not only compete with the crops for space and nutrients but also, transpire at a rate which affect, negatively the result of the evapotranspiration studies. Farm yard manure (Poultry) was applied to the Research lysimeter at 500g, the first dosage of fertilizer was applied after the first week of transplanting at a depth of 5-8cm, while the second dosage was also applied four weeks after planting.

Plate 1: Installation of a Lysimeter

Plate 2: lysimeter showing Waterleaf Crop

3.0 RESULTS AND DISCUSSION

Table 1 shows the correlation results as among the growth parameter in the study area. The parameters considered were number of leaves per plant, stem diameter, plant height, longest leaf length and longest leaf width of the waterleaf crop experimented using lysimeter was analyzed at ($p<0.05$).

Table 1: Correlation coefficients among growth parameter of waterleaf

WL	NLPP	SD	PH	LLL	LLW
NLPP	1				
SD	0.8386**	1			
PH	0.6639*	0.8120**	1		
LLL	0.3811*	0.8228**	0.9997**	1	
LLW	0.4161	0.7814*	0.9986**	0.9975*	1

NLPP= Number of leaf per plant, SD=Stem diameter, PH= plant height, LLL= Longest leaf length, LLW= Longest leaf width, WL = Waterleaf **=highly significant and *=significant.

As shown in Table 1 number of leave per plant showed a significant positive association with stem diameter (0.8386**), followed by plant height (0.6639**), and the longest leaf length and longest leaf width exhibited not significant association of (0.3811 and 0.4161) respectively. Correspondingly, the stem diameter, showed a highly significant positive association with plant height, longest leaf length and longest leaf with corresponding values (0.8120**, 0.8228**and 0.7814**) respectively. Conversely, plant height exhibited extremely significant positive association values of (0.9907** and 0.9986) with longest leaf length and longest leaf respectively. Likewise, positive significant association (0.9975**) was observed between longest leaf length and longest leaf width. The results are in line with the finding (Egharevba 1999).

3.2 Estimated stage –wise sorghum crop coefficients (Kc) of the waterleaf crops at different stages of growth

Table 2 shows the estimated crop coefficients of waterleaf at different stages of growth in the experiment farm were presented in an internationally recognized growth stages

Table 2: Estimated stage –wise crop coefficient (Kc) of the waterleaf

Day after Planting	ETc lysimeter (mm/day)	ETo reference (mm/day)	Kc (-)
Initial 1-7DAP	3.65	5.9	0.62
Dev 8-17DAP	4.88	5.95	0.82
Mid 18-29DAP	5.46	6.36	0.86
Late 30-36DAP	5.34	6.99	0.76

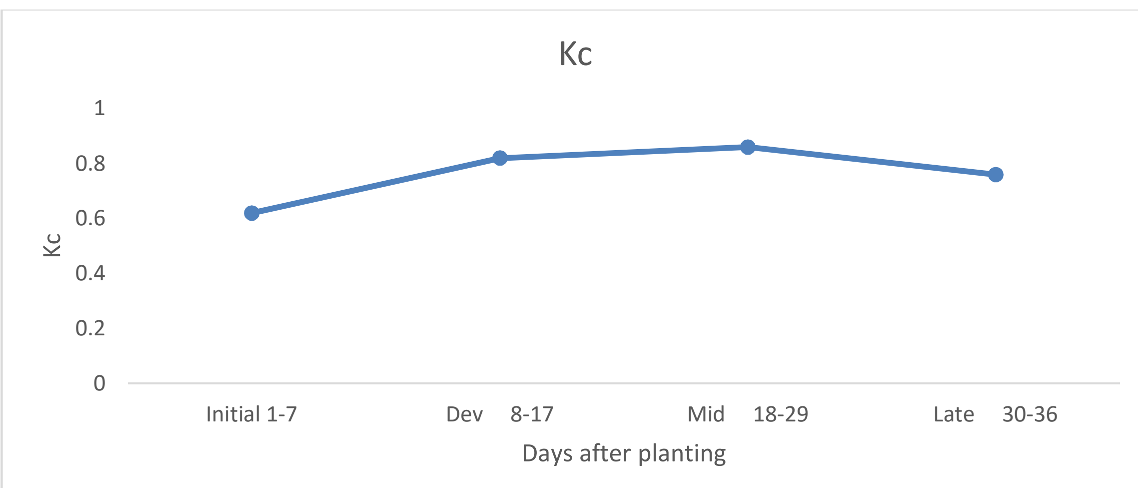

Figure2: Plot of stage –wise crop coefficient (Kc)

The curve presented in Figure 2 represents the changes in the Kc of waterleaf crop over the length of the growing season. The shape of the curve represents the changes in the vegetation and ground cover during plant development and maturation that affect the ratio of ETc to ETo. The Kc increased from the initial to development stages while reached its highest and relatively remained constant at the mid-season stage (Figure 4). The Kc declined rapidly during the late season stage. Higher Kc values were recorded from 18 - 29 days after planting as compared to the values in the initial and late of the crop life cycle. The maximum Kc value was 0.86 at 12 days after planting for the reason that changed in Kc could be attributed to the seasonal variation of leaf size which is in line with the findings of Zhang *et al* (2005).

3.3 Performance evaluation comparison between ETc observed using Lysimeter and other three empirical models for water leaf crop.

Table 3, shows the observed and predicted waterleaf evapotranspiration at different stages of growth respectively. Similarly, Table 4.4 shows the model performance comparison, which resulted in very good agreement. Etc predicted using the three models selected and ETc observed from the field using lysimeter for the waterleaf crop exhibited a high degree of agreement.

Table 3: Performance evaluation comparison between ET observed versus predicted from (BMN, BC and HG models) for waterleaf crop at different growth stages.

Stages of growth (DAP)	Lysimeter Method (mm/day)	Blaney–Morin Nigeria (BMN) (mm/day)	Blaney – Criddle (BC) (mm/day)	Hargreaves (HG) (mm/day)
Initial 17	3.65	5.25	4.16	4.76
Dev8-17	4.88	5.24	4.51	4.54
Mid 18-29	5.48	5.4	5.31	5.42
Late 30-36	5.34	5.96	5.4	5.14

Table 4: Performance evaluation comparison between ETc observed using Lysimeter and other three empirical models for three crops.

Models	RMSE	NSE	RSR	Performance Rating
Blaney-Morin Nigeria	3.12	0.68	0.51	Good
Blaney-Criddle	2.81	0.94	0.04	Very Good
Hargreaves	0.87	0.96	0.02	Very Good

The output of the validation revealed NSE values of (0.68, 0.94, and 0.96) and RSR values of (0.51, 0.04, and 0.02) for Blaney –Morin Nigeria, Blaney-Criddle and Hargreaves respectively, which indicated that their performance was very good for predicting evapotranspiration of water leaf in the region and performance output of the models were rated ‟ Good, Very Good’ and Very Good" for the corresponded BMN, BC and HG model respectively. Similarly, the observed and predicted water leaf evapotranspiration were also analyzed using z-test as shown in Table 5-.7 which indicating that there was no significance difference between the predicted and observed crop evapotranspiration at ($P<0.05$) since the value of z-cal is less than Z critical. Thus, the applicability of BMN, BC and HG models is a good representation of calculating evapotranspiration for semi-arid region with sandy loam in the study area.

Table 5: Calculated z-test for ETc Lysimeter and Blaney-Morin Nigeria (BMN) for four stages of growth

z-test	ETc Lysimeter	ET BMN
Mean	5.030119	5.475191
Variance	0.526241	0.33857
Stage of growth	4	
level of significance 5%		
z-cal	-0.76478	
Z critical two-tail	1.9634	

Table 6: Calculated z-test for ETc Lysimeter and Blaney-Criddle (BC) for four stages of growth

z-test	ETc Lysimeter	ETBC
Mean	5.030319	4.945594
Variance	0.526341	0.36157
Stage of growth	4	
level of significance 5%		
z-cal	0.140969	
Z critical two-tail	2.4732	

Table 7: Calculated z-test for ETc Lysimeter and Hargreaves (HG) for four stages of growth

z-test	ETc Lysimeter	ETHG
Mean	5.030319	3.945594
Variance	0.526341	0.36157
Stage of growth	4	
level of significance 5%		
z-cal	0.140969	
Z critical two-tail	2.4732	

4.0
CONCLUSION AND RECOMMENDATIONS

4.1 Conclusion

An experiment was conducted to determine the values of the growth parameters and crop evapotranspiration at stages of growth of waterleaf crop. The study was conducted at the research farm in Ramat Polytechnic, Maiduguri, Nigeria, from 16th February to 23rd March 2020. The observed crop evapotranspiration and predicted was analysed using Nash- Sutcliffe efficiency (NSE) and statistical analyses (z-test) as follows; Correlation analysis among the growth parameters showed that, there is strong positive relationship of about (82% to 90%).The crop evapotranspiration values of waterleaf in Maiduguri semi-arid climate and sandy loam soil is averagely 3.65, 4.88, 5.48 and 5.34 mm at each growth stage, respectively, with seasonal total ETc of 177.44 mm. The crop coefficient values of this crop for in region and soil is found to be 0.62,0.82, 0.86 and 0.76 at each growth stage, respectively. The values of ETc determined from the lysimeter were validated by Blaney-Morin Nigeria (BMN), Blaney-Criddle (BC) and Hargreaves models, better agreement was recorded between the ETc calculate from empirical model for the waterleaf using Nash- Sutcliffe efficiency (NSE) and T-test soft wire. Therefore, the study revealed that drainage lysimeter can be said to be functional and efficient to use in the region.

4.2 Recommendations

The results from this study have shown that a locally made, well designed and developed simple drainage lysimeter can be used to generate ET data for waterleaf crop and other similar crops where standard climatic data measurements are not available. Therefore, the following recommendations are onward:

(i) Since this experiment is season study in a single environment, further research over seasons are required so as to develop reliable values.

(ii) The experiment should be repeated in similar agro-climatic condition in order to confirm the findings.

(iii) Similar experiment are needed to be conducted at different agro-ecological zone of Nigeria.

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