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ESTIMATION OF CROP WATER REQUIREMENT FOR ONION IN MAIDUGURI, A SEMI-ARID ENVIRONMENT

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Abstract
The estimation of peak crop water requirement for matching farm sizes with available water is necessary for efficient water management. There are various methods of predicting crop water requirements ranging from those requiring several measured weather data (Penman, Jensen & Haise, and by Radiation); to those requiring single measured weather data (Blaney-Criddle) and the direct evaporation from class "A" pan. Out of these methods the most suitable method for estimating the crop water requirements for onion in Maiduguri a semi arid environment was determined to be the modified Blaney-Criddle method. The method was used to estimate the peak irrigation requirement for onion and was found to be in April amounting to 67 m3/day/ha which is equivalent to 1.28 l/s/ha at 60% efficiency. This value is within the acceptable limits of 1.0-1.5 l/s/ha recommended for canal design in arid and semi-arid regions.

Keywords: Evaporation, crop water requirement, onion, Blaney-Criddle, Maiduguri

1. Introduction

Irrigation is the art of applying water artificially to soil to provide plants with sufficient water to prevent stress that may cause reduced yield or poor quality of harvest. The correct timing and the amount of water to apply depend on climate, crop type and stage of growth; soil moisture- holding capacity and the extent of root development. The soil moisture at saturation and permanent wilting point are two important parameters that influence plant growth. The water content at field capacity and permanent wilting point are defined as the upper and lower limits of available soil water to plant respectively.

Evaporation from the soil surface and transpiration from plant tissue are often combined and called evapotranspiration. Evapotranspiration (ET_{crop}) is obtained from field measurements or estimated based on climatic data. Field measurements are generally too expensive and are mainly used to calibrate methods for estimating (ET_{crop}) from climatic data .The variation of a typical crop actual evapotranspiration rate (mm/day) with soil moisture content is defined as the critical soil moisture content (CP). The actual evapotranspiration associated with soil moisture content reduction between field capacity (FC) and (CP), indicates that water is more readily available and higher crop yield and/or quality are expected (Doorenbos, 1979). Beyond the critical point, yield and/or quality of grain will be affected. Irrigation is normally scheduled to maintain soil moisture content above (CP). The concept of maximum allowable deficiency (MAD) is used to estimate the amount of readily available water without adversely affecting the crop yield. The readily available water (RAW) can be determined from the following expression (James, 1988):

$$RAW = AW \times MAD \qquad 1$$

where:

RAW=readily available soil water (mm)
AW=available soil water (mm)
MAD =maximum allowable deficiency (fraction)

The atmosphere provides the necessary energy needed by the plant to withdraw water from the soil. If soil water is not limiting and stomata are fully open, the atmospheric factor affecting rate of evapotranspiration for a given environment include: air temperature, relative humidity, wind speed and radiation. The crop evapotranspiration can be measured from crop or calculated from climatic data.

Vegetables, like tomato and onion are grown both in wet and dry seasons. However, their best potential is obtained under irrigation during dry season. Water must be available at correct time and right amounts for optimum crop growth. Too much water, not only results in deep percolation losses, but also leaches out relevant nutrients beyond the root zone. On the other hand, limited supply results in moisture stress, and eventually the wilting of plants and poor harvest. The objective of this paper is to determine a method for predicting the crop water requirements for onion in Maiduguri, a semi arid region.

2. Determination of Evapotranspiration

There are several techniques used in determining crop water requirements by calculating the evapotranspiration. The most important among them is by direct measurement and/or calculation from crop and climatic data. Field measurements of evapotranspiration are generally too expensive and are, therefore, restricted to research plots rather than practical use.

Direct Measurements of Evapotranspiration

a) *Field water balances*: The water balance technique most widely used is based on the principle of conservation of mass, for a time interval (t) in a control volume and expressed as follows:

$$S = Inflow - Outflow$$

$$S = RZD\,(Qf - Qi) \qquad 3$$

$$Inflow = I + P + SRin + Lin + GW \qquad 4$$

$$Outflow = ET + SRout + Le + Dp + Lout \qquad 5$$

where:

S=change in storage (m3), Inflow=total flow (m/hr), Outflow=total flow out (m/hr), Qf, and Qi=final and initial moisture by volume (fraction), I=irrigation (cm), P=precipitation (cm), SRin= surface inflow (cm), SRout=surface outflow (cm), Lin=Subsurface lateral inflow (cm), Lout=Subsurface lateral outflow (cm), GW=Groundwater accretion (cm), Le=leaching requirement (cm), Dp=deep percolation loss (cm) and ET=evapotranspiration (cm)

Combining equations 3, 4 and 5, evapotranspiration (ET) can be obtained as follows:

$$ET = I + P + SRin + Lin + GW - SRout - Le - Dp - Lout - RZD\,(Qf - Qi) \qquad 6$$

Assuming that: P = 0 (no rain), Le = 0 (no leaching), GW=0 (no groundwater accretion), DP=0 (no deep percolation loss) and if Lin = Lout and SRin = Srout equation 6 is expressed as follows:

$$ET = I - RZD\,(Qf - Qi) \qquad 7$$

b) Use of Lysimeter: Lysimeters are devices which facilitate accurate water accounting. They are large containers filled with soil located in the field to represent the local environment with bare or vegetative surfaces (crop or grass) to determine the evapotranspiration of a growing crop or reference vegetative cover (Aboukhaled et al., 1982). Lysimeters can be categorized into two groups: weighing and non-weighing types. The weighing type has three variants, namely the mechanical, electronic as well as the hydraulic and floating. The non-weighing type also has three variants, which are the drainage lysimeter without water table, compensation lysimeter with constant ground water table and the compensation lysimeter with surface water level.

c) Estimating evaporation from free water surface: Method of measuring evaporation from water surfaces involves the use of pans. Pans vary in size and shape. Some are painted black and some white; some are lifted above the ground level, while others are partially buried below the ground (Doorenbos and Pruitt, 1977).

The most complicated problem in the procedure for measuring evaporation from free water surfaces is deciding on the size of the pan to be used to fix a standard value of evaporation. Numerous experimental data indicate a considerable dependency of evaporation rate on the size of the evaporating surface. For example, when the evaporating surface becomes smaller, the rate of evaporation increases. This is because the air humidity above the free water surface of the evaporating pan is generally higher than the air humidity at the same level above the surrounding soil. Therefore, water vapour above the evaporating pan not only ascends, but also moves sideways. The smaller the size of the pan and the drier the surrounding air, the more pronounced this effect becomes (Kenstantinou, 1968).

There are many different types of pans and tanks, since each country or organisation seems to have designed its own instrument to suit particular needs and conditions. The types most frequently used are the British standard tank (UK), the G.G.I. 3000 Tank (USSR) and the Class A Pan (U.S. Weather Bureau). However, the most widely used is Class A Pan. The pan is circular 122 cm in diameter and 25 cm deep. It is set with its base 150 mm above the ground surface on an open wooden frame so that air can circulate freely around and under the pan. The water level is kept at 50 mm below the rim and measured daily with a hook gauge. The difference between the two readings gives a daily value of evaporation (Doorenbos and Pruitt, 1977).

Alternatively, evaporation is obtained by bringing the water level in the pan back to a fixed level with a measured amount of water. Pan evaporation used to estimate evapotranspiration is the simplest method. If a proper reading of the pan is maintained, reference crop evapotranspiration can be calculated from the following relationship (Doorenbus and Pruitt, 1977):

$$ETo = Kp \times Ep \qquad 8$$

where:

ETo= reference crop evapotranspiration (mm/day)
Kp=pan coefficient
Ep=pan evaporation (mm/day)

d) Estimating evapotranspiration from climate data: There are many empirical equations that require climatic data to calculate evapotranspiration. The simplest of one requires only air temperature, day length and crop factor. However, the best equations are those requiring daily radiation, temperature, vapour pressure and speed (Jensen, 1983)

Estimating evapotranspiration from weather parameters is convenient, because the approach is simple compared to field evapotranspiration measurements. The possible evapotranspiration obtained from the empirical formula can then be multiplied with a crop coefficient (to account for soil moisture status and crop growth stage) to obtain reference crop evapotranspiration ETo (Jensen, 1983).

Evapotranspiration predictions from four empirical equations, namely Penman, Blaney-Criddle, Jensen and Haise and radiation were tested and found suitable in Nigeria (Madubuike 987). The data requirement for each method is given in Table 1.

Table 1 Climatic data requirement for predicting evapotranspiration

Method	Temperature	Relative Humidity (%)	Wind speed (km/day)	Sunshine (hrs)	Radiation (mbar)	Evaporation (mm)	Environment
Penman	x	x	x	x	(x)		0
Blaney-Criddle	x	0	0	0			0
Jensen & Haise	x	0	0	x			0
Radiation	x	0	0	x	(x)		0
Pan evaporation		0	0			x	x

x - Measured data, O-estimated data, (x)-if available, but not essential.
Source: Doorenbos and Pruitt (1977)

Although the Penman equation may be the most standard method of predicting potential evapotranspiration for Borno State conditions, Ekwue (1990) reported that values of (ETo) obtained from FAO-24 Blaney-Criddle and Penman methods were close. Therefore, FAO-24 version of Blaney-Criddle method seems adequate for Borno State conditions. Unlike the Penman, the modified Blaney-Criddle method is easy and less data intensive.

e) Reference crop evapotranspiration: In 1950, Blaney-Criddle (Doorendos and Pruitt, (1977) developed a simple equation to calculate the consumptive use from mean air temperature (T oF), percentage (P) of total annual daylight hours for the period considered as follows:

$$CU = \frac{PT}{100} = K_f \qquad 9$$

where

CU=consumptive use of crop for a certain period (inches)
F=sum of consumptive use factor (F) for the same period
K=empirical coefficient (annual, Irrigation seasons)
T=mean daily air temperature, (oF)
P=percentage of day time (hours)

The effect of climate on crop water requirements is insufficiently defined by temperature and day length alone. Crop water requirements will vary widely between climates having similar values of temperature and percentage day light hours. Ultimately, the consumptive use coefficient will need to vary not only with the crop but most importantly with climates.

Doorenbos and Pruitt (1977) modified the Blaney-Criddle approach of temperature and percentage day length related factor to calculate a reference crop evapotranspiration (ETo) using measured temperature data in degrees Celsius (oC) and a generalised level of humidity, sunshine and wind. The recommended relationship is as follows:

$$ETo=C\ [P\ (0.46T + 8)] \qquad 10$$

where:
ETo= reference crop evapotranspiration for the month considered (mm/day)
T=mean daily temperature (oC)
C = adjustment factor which depends on generalised relative humidity, sunshine hours and day time wind estimates (Table 2)
P = mean monthly percentage of total annual day time hours for a given month and latitude (Table 3)

i. High altitude having fairly low mean temperature (cold nights), even though day time radiation is high.
ii. In semi-arid region (ETo) values calculated should be adjusted by 10% for every 1000m altitude change above sea level.
iii. Climates with a wide variability of sunshine hours during transition months (mid-latitude climate during spring and autumn).
iv. High latitude (55o or more) summer days are normally long as compared to low and medium latitude areas having the same day length values. This results in undue weight given to the day length related factor (P). The (ETo) calculated should be reduced by 15% for areas at latitude 55o and above.

Table 2 General information on Humidity, Sunshine and Wind for African Climate (Griffith, 1972)

Month	Relative humidity	Sunshine	Wind (day time)	Block Line
Oct - Mar	Medium	Medium	Light/Moderate	V
April - May	Low/Moderate	High/Moderate	Moderate	IVV
June – July	Medium	High/Moderate	Moderate	
Aug – sept	Medium	High/Moderate	Light/Moderate	

Source: *Doorenbos and Pruitt (1977)*

Table 3 Mean daily percentage (P) of annual day time hours for different latitude

Latitude N	OCT	NOV	DEC	JAN	FEB	MAR	APR
30	0.26	0.24	0.23	0.24	0.25	0.27	0.29
25	0.26	0.25	0.24	0.24	0.26	0.27	0.29
20	0.26	0.25	0.25	0.25	0.26	0.27	0.28
15	.27	0.26	0.25	0.26	0.26	0.27	0.28
10	.27	0.26	0.26	0.26	0.27	0.27	0.28
5	0.27	0.27	0.27	0.27	0.27	0.27	0.28
0	0.27	0.27	0.27	0.27	0.27	0.27	0.27

Source: *Doorenbos and P in radiation.*

The crop coefficient (K) employed by the original Blaney-Criddle method is rejected, since: The original crop coefficient (K) is dependent on climate and a wide variety of values were reported, making it difficult to select the correct value. The adjustment factor (C) is adequate to describe the minor variations in relation to humidity, relative sunshine hours and wind speed. Once (ETo) is calculated, crop coefficient (Kc) based an Doorenbos and Pruitt (1977) can be used to determine crop water requirement (ETcrop).

The idea of introducing crop coefficient (Kc) to estimate ETc from vegetated land was given by Van Wilk et al. (1954) and further developed by Doorenbus and Pruitt (1977) and Jensen (1983). Crop coefficient represents an average situation of the field between wet and dry soil surfaces when water is not a limiting factor in the root zone. The crop developmental stages suggested by Jensen (1983) were divided into four as follows:

i. Initial stage: germination and early growth when the soil surface is almost bare, crop cover less then 10%.
ii. Crop developmental stage: effective full ground cover (70-80%).
iii. Mid season: the start of maturity as indicated by leaf colour.
iv. Late season: the end of mid-season to harvest.

During the initial stage evapotranspiration is dominated by evaporation from soil surface. As the plant develops to the second stage transpiration dominates. The respective growth stages, their length and crop coefficient for onion (dry) are presented in Table 4.

Table 4 Length of onion (dry) development stages and crop coefficient

	Stages						Planting date	Region	Total growin period
	Initial	Developmental	Mid	Late	Harvest	Tot			
Length days	20	35	110	45		210	October	Arid	
Crop coefficient (K_c)	0.5	0.75	1.02	0.87	0.8				0.85

Source: Smith (1992

3. Crop Water Requirement

To obtain the crop water requirement, a reference crop evapotranspiration of a disease-free crop growing in a large field under non-restricting soil conditions including soil water and fertility and achieving full production potential under a given growing environment, must be calculated. The crop water requirement (or evapotranspiration for a crop) can be calculated from the following relationship:

$$ETcrop = Kc \times ETo \qquad 11$$

where:
ETcrop=evapotranspiration water requirement, mm/day
Kc=crop coefficient which vary with crop, stage of growth and growing season
ETo=reference crop evapotranspiration, mm/day

Net irrigation requirement (IN) can be obtained from the following relationship:

$$IN = ETcrop - Pe \qquad 12$$

where:
IN=net irrigation requirement, mm/period
ETcrop=crop water requirement, mm/period
Pe=effective rainfall (mm/period), which can be obtained using the following

4. Estimation of effective rainfall, Pe

Crop water needs can be fully or partly met by rainfall. Table 5 shows the monthly rainfall data for Maiduguri. The rainfall data were analysed using the Gumble approach as described in FAO Irrigation and Drainage Paper No. 46 (Smith, 1992). The annual and monthly values of 20%, 50% and 80% probability of exceedence corresponding to wet, average and dry years in the 10-year period were estimated and presented in Table 6 using the following steps.

i. Tabulating and arranging the total rainfall amounts of Table 5 in descending order as in Table 7.

ii. Tabulating the plotting position according to:

$$F_a = \frac{M}{1+N} \times 100 \qquad 13$$

where:

Fa = plotting position, %
M =rank Number
N=number of records

Year values of 20% and 80% probabilities of exceedence were obtained by interpolating using data in Table 6 as:

P80=441mm=Pdry
P20=617mm=Pwet
P50=536mm=Paverage

Table 5: Rainfall (mm) distribution of Maiduguri, for ten year period 1989-1998

Year/Month	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1989	0.00	0.00	0.00	0.00	4.1	90.2	117.0	220.1	104.5	38.4	0.00	1.00	575
1990	0.00	0.00	0.00	0.00	18.4	46.0	183.7	137.7	39.7	11.0	0.00	2.5	439
1991	0.00	0.00	9.1	78.1	100.3	90.3	205.4	6.3	3.6	0.00	0.00	0.00	493
1992	0.00	0.00	2.2	1.0	55.0	40.5	113.3	296.4	61.9	14.7	0.00	0.00	585
1993	0.00	0.00	0.00	5.4	21.4	19.8	20.4	149.8	49.5	0.00	0.00	0.00	450
1994	0.00	0.00	0.00	0.00	0.00	50.4	92.8	168.4	104.5	22.6	0.00	0.00	438
1995	0.00	0.00	0.00	12.1	4.6	44.8	275.3	170.5	19.6	7.1	0.00	0.00	534
1996	0.00	0.00	0.00	0.00	33.4	58.2	195.8	176.6	137.6	24.1	0.00	0.00	626
1997	0.00	0.00	0.00	0.00	38.6	140.0	137.7	130.0	60.3	20.6	0.00	0.00	527
1998	0.00	0.00	0.00	0.00	24.7	59.8	179.0	268.6	157.4	12.0	0.00	0.00	702
Ave	0.00	0.00	0.00	0.00	28.0	65.0	158.0	192.0	74.0	15.0	0.00	0.00	536

Source: *Maiduguri International Airport Meteorological Weather Station*

Table 6 Monthly Rainfall (mm) for Average, Dry and Wet years in 10-year Period (1989 - 1998) at Maiduguri, Borno State

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Ave	0.00	0.00	0.00	3.0	28.0	65.0	158.0	192.0	74.0	15.0	0.00	0.00
Dry	0.00	0.00	0.00	2.0	23.0	53.0	130.0	158.0	61.0	12.0	0.00	0.00
Wet	0.00	0.00	0.00	3.0	32.0	75.0	182.0	221.0	85.0	17.0	0.00	0.00

Table 7: Analysis of Rainfall Data using Gumble Approach

	1998	1996	1992	1989	1995	1997	1991	1995	1990	1994
	702	626	585	575	534	527	493	450	439	438
	1	2	3	4	5	6	7	8	9	10
	9	18	27	36	45	55	64	73	82	91

F_a=Plotting position,(%)

The monthly values for respective months in the wet (20%) and dry (80%) years were calculated using the following relationship:

$$P^{i}_{dry} = P^{i}_{ave} \frac{P_{dry}}{P_{ave}} \quad \textit{(mm/month)} \qquad 14$$

$$P^{i}_{wet} = P^{i}_{ave} \frac{P_{wety}}{P_{ave}} \quad \textit{(mm/month)} \qquad 15$$

The monthly values for these design years are presented in Table 8. The dependable rainfall is summed to be 70% of the rainfall in 80% probability of exceedence.

5. Procedure for predicting crop water requirement for onion (dry)

Step 1 Estimate reference crop evapotranspiration ETo using FAO-24 Blaney-Criddle method (Doorenbos and Pruitt, 1977).
Step 2. Step 2 Estimate the crop coefficient for the respective growth stages of onion using FAO irrigation and drainage paper 46 (Smith, 1992).
Step 3 Estimate the daily ETonion by multiplying (ETo) with the respective crop coefficients Kc; planting date is 1st October and harvest is April ending, assuming every month as 30 days.
Step 4 Estimate the effective rainfall according to Gumble approach (Smith, 1992).
Step 5. Estimate the net irrigation water requirement.
Step 6 Estimate gross irrigation water requirements Dn. This is obtained by dividing the net irrigation requirement by the project efficiency. For surface irrigation methods, the project efficiency can reach a maximum of 60% and for sprinkler systems 65-70% (Doorenbos and Pruitt, 1977). These calculations are presented in Table 9.

6. Conclusions

The seasonal net irrigation water requirement of onion (dry) for Maiduguri predicted using modified Blaney-Criddle method is 336mm. The peak irrigation requirement in April is about $67m^3$/day/ha equivalent to 1.28l/s/ha at 60% efficiency. This value is within the acceptable limits of 1.0-1.5l/s/ha recommended for canal design in arid and semi-arid regions. The estimation of peak water requirement is particularly necessary for matching farm sizes with the available water. The procedures given can be adapted for other environment for predicting crop water requirement.

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