Determination of water requirement and irrigation timing for *Amaranthus hybridus* in Maiduguri metropolis, north-eastern Nigeria

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Abstract

Crop water requirements and irrigation timing are particularly important in arid and semi-arid regions where water is scarce. In this paper, theoretical crop water requirements and irrigation timing for *Amaranthus hybridus* in Maiduguri metropolis, north-eastern Nigeria were determined under drip irrigation for the dry season. Reference evapotranspiration (ETo) was based on the Penman-Montieth formula and CROPWAT 8.0. An elemental irrigated area (A_i), crop canopy factor (Cp) and emitter application rates (ar) at each growth stage, were assumed. The highest reference evapotranspiration (ETo) of 6.6 mm day^{-1} was obtained in May while the lowest of 3.7 mm day^{-1} in December compared to other months. Also, water requirement (WR) values were computed based on the Freeman Garzoli correction factors. At 30%, 60% and 100% crop canopy coverage, peak water requirements (WR) of 0.7, 1.8, 2.3 L day^{-1} and low values of 0.4, 1.0, 1.3 L day^{-1} were obtained in May and December respectively. Emitter application rates of 0.5, 1 and 1.5 Lh^{-1} resulted to longest irrigation time ($T_{irrig.}$) of 1.4, 3.7, and 3.9 h day^{-1}in May while shortest irrigation were 0.3, 0.7 and 0.9 h day^{-1} in December for early, development and maturity stages respectively.
Keywords: water requirements, drip, irrigation, evapotranspiration, emission, crop, coefficient, conservation, timing, arid, scarce.

WIT Transactions on Ecology and The Environment, Vol 168, © 2012 WIT Press
www.witpress.com, ISSN 1743-3541 (on-line)
doi:10.2495/SI120241

1 Introduction

Water is scarce in arid and semi-arid regions where precipitation is low. Conservation of available water is imperative. Water is important for plant growth and food production. Michael [1] reported that estimating irrigation water requirements is important for water project planning, management and maintaining crop evapotranspiration (ETc) when precipitation is insufficient or not available.

According to FAO [2] and Hess [3], crop water requirement is the total water needed for evapotranspiration, from planting to harvest for a given crop in a specific climate regime, when adequate soil water is maintained by rainfall and/or irrigation for effective plant growth and crop yield.

The United Nations invested about US$20 million in low-cost water technologies such as drip irrigation, to lift 100 million poor farming families worldwide out of extreme poverty (UNEP and UN-Habitat [4]).

Studies by Ihekoronye and Ngoddy [5] showed that vegetables like amaranthus are served as integral parts of meals and Dich *et al.* [6] found that they are among the most low cost means of providing adequate supplies of vitamins A and C, minerals and fibres particularly to those who live in the tropics. It is also important to know that water requirements for amaranthus will differ from one region to another like any other crop (Adeniran *et al.* [7]).

2 The CROPWAT model

The CROPWAT is a programme that uses the FAO [8] Penman-Monteith methods for calculating reference crop evapotranspiration and assisting in crop water requirements and irrigation scheduling calculations. It is most preferred to the older FAO 24 procedures which are no longer used due to over-estimation of evapotranspiration. CROPWAT can be obtained in versions such as 5.7, 7.0 and 8.0 but primarily perform same function. The Penman-Monteith equation is:

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

where,
ET_o = Reference evapotranspiration [mm day^{-1}],
R_n =Net radiation at the crop surface [MJ m^{-2} day^{-1}],
G=Soil heat flux density [MJm^{-2} day^{-1}], T = Mean daily air temperature at 2 m height [°C], u_2 = Wind speed at 2 m height [m s^{-1}],
e_s = Saturation vapour pressure [kPa], e_a = Actual vapour pressure [kPa],
e_s - e_a = Saturation vapour pressure deficit [kPa], Δ = Slope vapour pressure curve [kPa °C^{-1}], γ = Psychrometric constant [kPa °C^{-1}].

Using the conversion factor,

$$u_2 = u_z \frac{4.87}{\ln(67.8z - 5.42)} \quad (2)$$

u_z = wind speed at height above 2 m.

This method uses the combined climatologically effect of temperature variations and aerodynamic variations seems to be more promising in deriving evapotranspiration. Thus the equation used to estimate reference crop evapotranspiration (ETo) and equation are sufficiently adjustable large to stress the importance on water management (Soundar Rajan *et al.* [9]).

3 Methodology

3.1 The study area

The study was conducted in Maiduguri, the capital of Borno state, north-eastern Nigeria. It lies between latitude 11^{o} 51' N and longitude 13 ^{o} 05' E at an altitude of 354 m above sea level. The area is dry, with semi-arid climate, savannah or tropical grasslands vegetation, light annual rainfall of about 300 mm and the mean daily temperature ranges from 22–35°C, but sometimes exceeding 40°C between March and June before the rains from July to September. It has mainly sandy loam soils.

3.2 Data collection

The climatic data; temperature – minimum and maximum, sunshine hours, relative humidity and wind speed at 10 m height required for running the CROPWAT 8.0 software were collected from the Nigerian Meteorological (NIMET) centre, Maiduguri [10].

3.3 Computation of Crop evapotranspiration (ETc), water requirement (WR) and irrigation time (T_{irrig}.)

Crop evapotranspiration (ETc), water requirement (WR) and irrigation time (T_{irrig}.) were computed based on the following assumptions:

3.3.1 Irrigated area (A_i)

Consider an elemental irrigated area (A_i) in figure 1 under emission as:

$$A_i = \frac{(L)(S)(P)}{(100)(Ne)} \tag{3}$$

where;
L= spacing between adjacent plant rows, m
S= spacing between emission points, m
P= percent of cropped area being irrigated
(crops spaced less than 1.8 m have p values approach 100%) Ne = number of emission devices at each emission point L = 1.00 m,
S=0.50m, Ne=1P=100%.

$$A_i = \frac{(1.0)(0.50)(100)}{(100)(1)} = 0.50 \text{ m}^2 \tag{4}$$

$$A = \sum_{i=1}^{n} A_i \tag{5}$$

A = irrigated area per lateral; n = number of emitters; A_i = irrigated area per emitter.

If N = number of laterals, the total irrigated area on a particular farm can be expressed as

$$A_{tot} = NA \tag{6}$$

A_{tot}=total irrigated area

Figure 1: Layout of a microtube drip irrigation system.

3.3.2 Crop coefficient factor, Kc

The FAO [8] Kc values for spinach were assumed to be same as that of amaranthus since they are from the same family. The Kc values are 0.70, 1.00, and 0.95 for early, development and maturity growth stages respectively and constant at each growth stage as shown in figure 1.

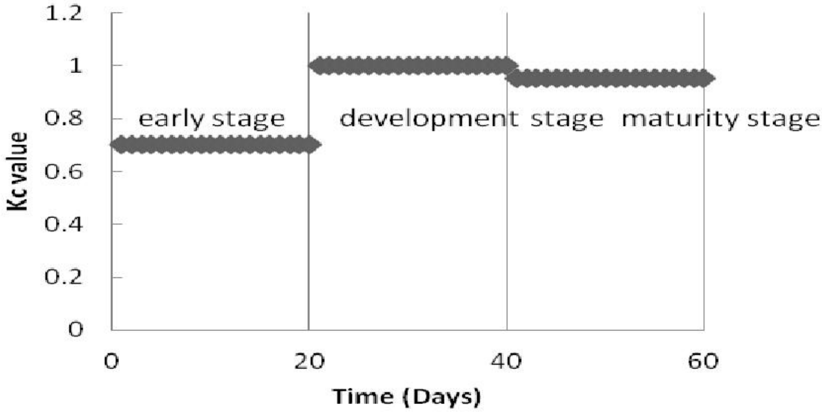

Figure 2: Kc values at different growth stages of amaranthus.

3.3.3 Crop canopy factor (Cp)

The canopy factor at each growth stage was based on the Freeman and Garzoli correction factors in table 2 below.

Table 1: Freeman and Garzoli crop canopy correction factor.

Percent ground coverage by canopy	Correction factor, Kr
10	0.10
20	0.20
30	0.30
40	0.40
50	0.75
60	0.80
70	0.85
80	0.90
90	0.95
100	1.00

(Smith [11].)

Therefore,

$$WR = ETo*Kc*Cp*A_i \quad (7)$$

where
WR = Water requirement, L day^{-1}
ETo = reference evapotranspiration
Kc = crop factor
Cp = Kr = crop canopy factor,
A_i = irrigated area per emitter, m^2.

But net irrigation requirement,

$$I_n = WR - R + LR \quad (8)$$

where
R = effective rainfall and
LR = Leaching requirement
Assuming R and LR are negligible for the dry season from October to June, eqn (8) can now be written as:

$$WR = I_n \quad (9)$$

3.3.4 Emitter application rate (ar)

At emitter application rates (ar) of 0.5, 1, and 1.5 Lh^{-1}, the irrigation times ($T_{irrig.}$) were computed at 30%, 60% and 100% for early, development and maturity growth stages respectively.

Hence, irrigation time,

$$T_{irrig.} = \frac{\text{Water Requirement (L day}^{-1})}{\text{Emitter application rate (Lh}^{-1})} \quad (10)$$

Table 2: Mean Monthly ETo values for Maiduguri metropolis. (Country: Nigeria. Station: Maiduguri NI65082. Elevation: 354 m. Location: Latitude 11° 51' N Longitude: 013° 05' E.)

Month	T °C maximum	minimum	RH %	Wind Speed km day^{-1} u_z	u_2	SS h	Rad MJ $day^{-1}m^{-2}$	ETo mm day^{-1}
Jan	12.6	31.9	18.7	87.4	65.6	8.2	24.4	4.1
Feb	15.3	34.6	14.3	110.1	82.6	8.4	26.1	4.9
Mar	19.7	37.8	11.5	116.6	87.5	8.2	27.6	5.6
Apr	23.9	40.1	21.4	126.8	95.1	8.0	28.0	6.4
May	25.5	39.4	35.0	126.5	94.9	8.8	27.5	6.6
Jun	24.5	36.4	49.5	139.8	104.9	8.6	27.0	6.4
Jul	22.9	33.2	63.5	101.8	76.4	7.1	27.2	5.7
Aug	22.3	32.0	72.2	106.2	79.6	6.8	27.7	5.6
Sep	22.4	33.7	64.3	80.5	60.3	7.8	27.6	5.6
Oct	20.7	36.4	45.7	79.2	59.4	9.2	26.4	5.4
Nov	16.0	34.2	22.1	73.1	54.8	9.6	24.7	4.4
Dec	13.1	32.3	19.6	56.3	42.3	9.4	23.8	3.7

(Source: NIMET Centre, Maiduguri [9].)
Note: T temperature RH relative humidity SS sunshine hours Rad radiation u_z wind speed at height higher than 2m u_2 wind speed at 2 m height.

4 Results and discussion

4.1 Reference evapotranspiration (ETo) and crop evapotranspiration (ETc)

4.1.1 Reference evapotranspiration (ETo)

Table 2 shows the mean monthly ETo values of the study area. It increased steadily from 4.1 mm day^{-1} in January to a peak value of 6.6 mm day^{-1} in May and declined to 6.4 mm day^{-1} in June. This continued to a lowest value of 3.7 mm day^{-1} in December.

4.1.2 Crop evapotranspiration (ETc)

The mean monthly ETc values for the dry season (October to June) in table 3 followed the same pattern as that of ETo. The highest value of ETc of 6.3 mm day^{-1} was obtained in May while the lowest of 3.5 mm day^{-1} was obtained December.

Table 3: Mean evapotranspiration (ETc) of amaranthus in Maiduguri metropolis.

Month	ETc mm day^{-1}
Jan	3.9
Feb	4.7
Mar	5.3
Apr	6.1
May	6.3
Jun	6.1
Jul	5.4
Aug	5.3
Sep	5.3
Oct	5.1
Nov	4.2
Dec	3.5

4.2 Water requirement (WR) and irrigation time ($T_{irrig.}$)

4.2.1 Water requirement (WR)

Computed daily water requirements for amaranthus growth in Maiduguri metropolis are presented in tables 4, 5, and 6 below for early, development and maturity growth stages respectively. In table 4, peak water requirements of 0.7 L day^{-1} were obtained in April, May and June and lowest of 0.4 L day^{-1} in December and January. This could be as a result of low temperatures in December and January compared to higher values in April, May and June.

Table 4: Mean daily water requirement for amaranthus in Maiduguri metropolis at early growth stage

Month	WR L day^{-1}
Jan	0.4
Feb	0.5
Mar	0.6
Apr	0.7
May	0.7
Jun	0.7
Oct	0.6
Nov	0.5
Dec	0.4

30% crop canopy coverage

In table 5 at development stage, peak water requirements of 1.8 L day^{-1} were obtained in April, May and June while lowest values of 1.0 and 1.2 L day^{-1} in December and January respectively.

Table 5: Mean daily water requirement for amaranthus in Maiduguri metropolis at development growth stage.

Month	WR L day^{-1}
Jan	1.2
Feb	1.4
Mar	1.6
Apr	1.8
May	1.8
Jun	1.8
Oct	1.5
Nov	1.2
Dec	1.0

60% crop canopy coverage.

In table 6, the peak water requirement at maturity was 2.3 L day^{-1} in April, May and June while lowest of 1.3 and 1.5 L day^{-1} in December and January respectively.

Table 6: Mean daily water requirement for amaranthus in Maiduguri metropolis at maturity growth stage.

Month	Water requirement L day^{-1}
Jan	1.5
Feb	1.7
Mar	2.0
Apr	2.3
May	2.3
Jun	2.3
Oct	1.9
Nov	1.6
Dec	1.3

100% crop canopy coverage.

The total water needed for growing a plant can be obtained by multiplying the daily water requirement by the number of days in a growth stage.

4.2.2 Irrigation time ($T_{irrig.}$)

Irrigation times ($T_{irrig.}$) in tables 7, 8 and 9 showed that irrigation times ($T_{irrig.}$) are inversely proportional to the application rates (ar).

The longest irrigation times ($T_{irrig.}$) were 1.4, 3.7, and 3.9 h day^{-1}in May while at 0.5 application rate (ar) while the shortest were 0.3, 0.7 and 0.9 h day^{-1} in December for early, development and maturity stages respectively. Hence, less water is saved in May than in December.

Table 7: Irrigation time for amaranthus in Maiduguri metropolis at early growth stage.

Month	WR L day^{-1}	T_{irrig} 0.5 h day^{-1}	$T_{irrig.}$ 1 h day^{-1}	T_{irrig} 1.5 h day^{-1}
Jan	0.4	0.9	0.4	0.3
Feb	0.5	1.0	0.5	0.3
Mar	0.6	1.2	0.6	0.4
Apr	0.6	1.4	0.7	0.5
May	0.7	1.4	0.7	0.5
Jun	0.7	1.4	0.7	0.5
Oct	0.6	1.1	0.6	0.4
Nov	0.5	0.9	0.5	0.3
Dec	0.4	0.8	0.4	0.3

Note: $T_{irrig.}$ 0.5 emitter application rate at 0.5 Lh^{-1} T_{irrig} 1 emitter application rate at 1 Lh^{-1} T_{irrig} 1.5 emitter application rate at 1.5 Lh^{-1}.

Table 8: Irrigation time for amaranthus in Maiduguri metropolis at development growth stage.

Month	WR	T_{irrig} 0.5 h day^{-1}	T_{irrig}. 1 h day^{-1}	$T_{irrig.}$ 1.5 h day^{-1}
Jan	1.2	2.3	1.2	0.8
Feb	1.4	2.7	1.4	0.9
Mar	1.6	3.1	1.6	1.0
Apr	1.8	3.6	1.8	1.2
May	1.8	3.7	1.8	1.2
Jun	1.8	3.6	1.8	1.2
Oct	1.5	3.0	1.5	1.0
Nov	1.2	2.5	1.2	0.8
Dec	1.0	2.1	1.0	0.7

Table 9: Irrigation time for amaranthus in Maiduguri metropolis at maturity growth stage.

Month	WR L day^{-1}	$T_{irrig.}$ 0.5 h day^{-1}	$T_{irrig.}$ 1 h day^{-1}	$T_{irrig.}$ 1.5 h day^{-1}
Jan	1.5	2.5	1.5	1.0
Feb	1.7	2.9	1.7	1.1
Mar	2.0	3.3	2.0	1.3
Apr	2.3	3.8	2.3	1.5
May	2.3	3.9	2.3	1.5
Jun	2.3	3.8	2.3	1.5
Oct	1.9	3.2	1.9	1.3
Nov	1.6	2.6	1.6	1.0
Dec	1.3	2.2	1.3	0.9

In practical terms, the water requirement and irrigation time can be computed based on the dates the crop is planted.

5 Conclusions

Theoretical values of water requirements (WR) and irrigation timing (T_{irrig}) for *Amaranthus hybridus* Maiduguri metropolis were computed using the Penman-Montieth equation in CROPWAT software version 8.0 for dry season drip irrigation system as water saving measure and optimum yield. Results showed that evapotranspiration (ET), water requirement (WR) and irrigation time ($T_{irrig..}$) values were lowest in December and highest in May when compared to other values within the dry season.

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