Estimation of irrigation water requirement of maize (*Zea-mays*) using pan evaporation method in maiduguri, Northeastern Nigeria

I. J. Tekwa[1], E. K. Bwade[2]

(1. *Department of Agricultural Technology*, *Federal Polytechnic*, *P. M. B.* 35 *Mubi*;

2. *Department of Agricultural Engineering Tech*., *Federal Polytechnic*, *P. M. B.* 35 *Mubi*)

Abstract: Estimation of irrigation water requirement of maize (*Zea-mays*) was conducted based on a ten (10) year rainfall data (1986-1995) of Maiduguri, Borno state using pan evaporation method. Climatic parameters including potential evapotranspiration (ET_0), maize crop evapotranspiration (ET_m), effective rainfall (P_e), and maize crop irrigation water requirement (IWR_m) were estimated using prescribed procedures. The result showed that the P_e for Maiduguri was lowest in June (1.09 mm/day) and highest in August (3.91 mm/day). Both ET_0 (8.70 mm/day) and ET_m (4.35 mm/day) recorded highest estimates in June and declined sharply in the months of August and October, respectively. The IWR_m for Maiduguri was estimated at 3.26, 0.11, 0.05, 1.81 and 1.24 mm per day for the months of June, July, August, September and October respectively, implying that there exists the need for soil moisture supplementation, especially in the months of September and October based on the inadequate rainfall inputs observed.

Key words: irrigation water estimation, water requirement, Maize plant, Pan-evaporation, Maiduguri and Nigeria

Citation: Tekwa I. J and E. K. Bwade. 2011. Estimation of irrigation water requirement of maize (*Zea-mays*) using pan evaporation method in maiduguri, Northeastern Nigeria. Agric Eng Int: CIGR Journal, 13(1): CIGR MS No.1552.

1 Introduction

Maize constitutes one of the most widely consumed food sources and a basic raw material for feed mill and beverage industries. Its sustainable production promotes adequate food supply; job opportunities, increased family income and foreign exchanges. Maize is a Tropical crop largely grown in various parts of Northern- Nigeria, it performs well when irrigated or rain fed with about 600-900 mm per annum at a temperature of between 20℃ and 25℃. Recent findings by Arora (2004) reveal that adequate water supply could influence an average maize yield of up to 4 000 kg per hectare in most tropical environments. This estimate could drop to as low as 1 400 kg per hectare or lower when grown under inadequate water supply (Euroconsult, 1989). Water requirement has been defined by Verplanke (1985) and Arora (2004) as the quantity of water needed by a crop for normal growth regardless of its supply source for a given period of time under field condition. Climate is one of the main environmental determinants influencing crop yields, and could be used to estimate maize water requirement (Israelson, 1962 and Ezeaku et al 2004). Estimates of Maize water requirement is essential in order to curtail excessive application of water than needed, which could cause crop damage, poor traficability, soil erosion, excessive leaching and the wastage of water, labor and energy (Hudson,1975).

Several evapotranspiration models have been tried and certified effective. Among the most commonly applied is the Evaporation pan (22-gauge galvanized iron of 121 cm diameter, 25.5 cm deep), which could be used to investigate the evaporative capability of the atmosphere. It is inexpensive, simpler and a reliable means of estimating crop evapotranspiration in the tropics (James, 1988 and Arora, 2004). In most parts of North-eastern Nigeria, rain fed crop production is widely

Received date: 2009-10-17 **Accepted date:** 2011-05-21

Corresponding author: I. J. Tekwa, Email: johntekwa@gmail.com

practiced with less emphasis on supplemental irrigation. Knowledge of water use by crops such as maize among other crops within the area of study is a prerequisite to a better planning and design of irrigation systems, and on which this study revolves.

2 Materials and methods

2.1 Study area

Maiduguri falls within the Sudano-Sahelian ecological zone of Northeastern Nigeria, located between latitudes 11°15′ and 12°03′ N, and between longitude 12°43′ and 13°18′ E, at a height of 590 m above sea level. Maiduguri is characterized by low rainfall amount of about 366.4 mm per annum, having short annual rainfall duration mostly between months of June and September, and high temperature (>27℃), that is often accompanied by high relative humidity (>70%) especially in the month of August (Appendix: 1).

2.2 Field study

A study to estimate irrigation water requirement for a rain fed Maize was conducted in Maiduguri based on a ten year mean monthly rain fall data and/or parameters including: rain fall amount (mm), relative humidity (%), wind speed (km/hr), and sunshine duration (hr) sourced from the meteorological station of the Federal Secretariat, Maiduguri. Hence, Pan Evaporation (E_p mm/day) data was collected from the Borno Water Board, Maiduguri (Table: 1), while potential evapotranspiration was estimated from E_p in accordance with the procedure by James (1988) expressed as:

$$ET_0=K_p*E_p \tag{1}$$

Where, ET_0 = potential evapotranspiration, mm/day; E_p = pan evaporation (mm/day); K_p = pan coefficient (Dimensionless)

ET_0 is related to Maize evapotranspiration (ET_{Maize}) by a coefficient K_c, which corresponds to the changing conditions in the growing season (i.e. bare ground at planting time to maximum leaf area followed by decreasing leaf area (James, 1988; and Doorenbus and Pruitt, 1977), there by expressed as:

$$ET_{\mathrm{Maize}} = K_c*ET_0 \tag{2}$$

Where, ET_{maize} = Maize evapotranspiration, mm/day.

The total annual rain fall of Maiduguri (1986-1995) was analyzed using Gamble approach as described by Smith (1992) and Arora (2004). The annual monthly probability of exceedence corresponding to wet, average, and dry years for ten (10) years (Appendix 1), were estimated by determining the plotting position of Tabulated annual rain fall data in ascending order (TARIDO) and in accordance with the equation:

$$P_p = M/(N+1)*100 \tag{3}$$

Where, P_p = plotting position, %; M = Rank number ($1<M<10$; N=number of annual rain fall records (N=10).

2.3 Determination of IWR for Maize (*Zea-mays)* Plant

The statistical analysis of Maiduguri rain fall using Gamble approach (Smith, 1996) was applied to estimate the plotting positions in percentages from the sourced ten (10) year rainfall data. The annual values of 20%, 50% and 80% corresponding to the $P_{20\%}$, $P_{50\%}$, $P_{80\%}$ probability of exceedence were estimated by linear interpolation of the P_p and TARIDO in accordance with Doorenbus and Pruitt, (1974) (Table 2), expressed as:

$$P_{\mathrm{dry}}\, M_i=\mathrm{mm}R_i*P_{80}/_{50} \tag{4}$$

$$P_{\mathrm{wet}}\, M_i=\mathrm{mm}R_i*P_{20}/P_{50} \tag{5}$$

Where, i = months of Maize growth (June, July, August, September and October).; $P_{\mathrm{dry}}\ M_i$ = P_{dry} value for the month of i.; $\mathrm{mm}R_i$ = mean monthly rainfall for the month of i.

Effective rain fall was defined by Smith (1992) to be 70% of the rain fall in 80% probability of exceedance. Maize irrigation requirement for each month was computed using equation (6) in accordance with James (1988), expressed as:

$$IWR_{\mathrm{maize}}=ET_{\mathrm{maize}}-R_e \tag{6}$$

Where, P_e = Effective rain fall, mm/day.

3 Results and discussion

Pan evaporation (E_p) in millimeters per day in Maiduguri was recorded as 11.60, 6.30, 4.40, 5.50 and 9.40 mm/day for the months of June, July, August, September and October respectively. The highest E_p was recorded in the months of June (11.60 mm/day) and October (9.40 mm/day) while the lowest E_p was recorded in the month of August (4.40 mm/day) as presented in Table 1. The highest E_p corresponded well with the period of optimal estimates of some measured parameters such as wind speed (3.70 km/hr), air temperature (31.48℃), and sun shine duration (8.12 hr/day) (Appendix: 1). A contrasting correlation between these parameters revealed an equal to high positive correlations of r = 0.5233 and r = 0.8232 between E_p, and wind speed, and between air temperature and sunshine durations, respectively. This revealed a corresponding increase in E_p with increase in the parameters over the study months and vice-versa (Joel, 1996).

Table 1 Estimated Maize irrigation water requirement parameters in Maiduguri, (1995)

Estimated parameters	Observation months				
	Jun.	Jul.	Aug.	Sep.	Oct.
E_P/mm • day^{-1}	11.60	6.30	4.40	5.50	9.40
K_p (Dimensionless)	0.75	0.60	0.75	0.65	0.55
ET_0/mm • day^{-1}	8.70	3.78	3.30	3.58	5.17
K_c (Dimensionless)	0.50	0.80	1.20	0.95	0.60
ET_m/mm • day^{-1}	4.35	3.21	3.96	3.40	3.10
P_e/mm • day^{-1}	1.09	3.10	3.91	1.59	1.86
IWR_{Maize}/mm • day^{-1}	3.26	0.11	0.05	1.81	1.24

Potential evapotranspiration (ET_0) had an estimated values of 8.70, 3.78, 3.30, 3.58 and 5.17 mm/day for the months of June, July, August, September and October respectively. The ET_0 was highest in the month of June (8.70 mm/day) and lowest in the month of August (3.30 mm/day), depicting a similar trend with E_p. This was probably due to slight undulation in pan coefficient (K_p) over the observation months, that translated into almost a direct proportional relationship between ET_0 and E_p (James, 1988).

The ET_m (estimated from ET_0 and K_c) recorded a respective values of 4.35, 3.21, 3.96, 3.40, and 3.10 mm/day for the months of June, July August, September and October.

The highest consumptive use of water by Maize was in June (4.35 mm/day) and the lowest in October (3.10 mm/day). The ET_m range in this study ranged between 366.4 and 628.2 mm/day) compared less to a similar investigation conducted on Maize at Nsukka having a seasonal rainfall of about 1 200-1 600 mm, showed a range of 5.8 mm/day to 6.7 mm/day for the same study months (Ezeaku, 2004). This even was perhaps due to variation in seasonal rainfall amounts from that of Maiduguri (Table 2), and likely due to evapotranspiration dependance on soil moisture being a function of rain fall amounts (James, 1988). The ET_m was observed to be highest in the first month (June) of planting (4.35 mm/day), which corresponded well with the seedling growth stage and then dropped to 3.10 mm/day at ripening stage in October (Table 1). Similar trend of crop evapotranspiration was reported by Arora (2004).

Table 2 Statistical analysis of Maiduguri rain fall using Gamble Approach (Smith, 1992)

Year	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
TAR/mm	502.6	336.4	628.2	610.2	429.0	486.1	582.5	481.5	481.1	453.1
TARINDO/mm	628.2	610.2	528.4	502.6	486.1	481.6	453.1	429.9	415.9	366.4
RN	1	2	3	4	5	6	7	8	9	10
P_p /%	9.09	18.19	27.28	36.37	45.46	54.55	63.64	72.73	81.72	90.91

Key: TAR =Total annual rain fall, TARIDO = Total annual rain fall in descending order, RN = Rank Number, Pp = plotting position.

In sequence, the monthly values for respective months in wet (20%), dry (80%) and effective rain fall (P_e, (70% of P_{dry})) were estimated according to Smith (1992) and the results are presented in Table 3. The study estimated the highest P_e in August (117.31 mm/day) which corresponded to the month of highest rain fall amounts over the observation months (Appendix 1). The study accounted the P_e to be high with high mean maximum monthly rainfall and relative humidity, and at lowest sunshine durations, (Table 1; Appendix 1) (Euroconsult, 1989).

Table 3 Mean monthly rainfall (mm) for average, dry and wet years in Maiduguri (1995)

Month	Jan	Feb	Mar	Apr	May	Jun	J).ul	Aug	Sep	Oct	Nov	Dec
Average	0	0.2	0.2	8.7	28.59	53.79	153.25	192.9	78.37	13.02	0	2.5
P_e=70% Dry	0	0.12	0.12	5.29	17.39	32.19	93.19	117.31	47.66	7.92	0	1.52
Dry	0	0.17	0.17	7.56	24.84	46.73	133.13	167.58	68.08	11.31	0	2.17
Wet	0	0.25	0.25	10.87	35.73	67.23	191.54	241.1	97.95	16.27	0	3.13

Key: P_e = Effective rain fall in mm/month.

The irrigation water requirement of maize (IWR_m) was estimated from ET_m and P_e according to James (1988) as 3.26, 0.11, 0.05, 1.81 and 1.24mm/day for the months of June, July, August, September and October respectively. The IWR_m recorded least estimates in August (0.05 mm/day) and July (0.11 mm/day) being the months with sufficient precipitation and soil moisture regimes that requires less need for supplemental irrigation. Estimates in August (0.05 mm/day) corresponded well with the periods of adequate soil moisture, which indicated less or no need for supplemental irrigation. The IWR_m of 3.26, 1.18 and 1.24 mm/day for the months of June, September and October respectively showed an increasing demand in IWR_m in correspondence to prevailing inset of drier periods characterized by low soil water supply within the root zones (i.e. period of soil-plant-water stress), which limits crop production. A study conducted by Ezeaku (2004) on the IWR of Maize in Nsukka and Agwu locations of South-Eastern, Nigeria recorded similarly. This study also revealed a strong negative correlation (r = -0.9175) between IWR_m and P_e, which tallied with or explains why the IWR_m was highest in June (3.26 mm/day) in this study (Table 1).

Accordingly, the periods of significant soil moisture for Maize growth periods in the study area are designated by the shaded portions in Figure 1. Based on these estimates, profitable maize cultivation in the study area will require a supplemental irrigation for at least three out of the five growing months required for optimum maize production.

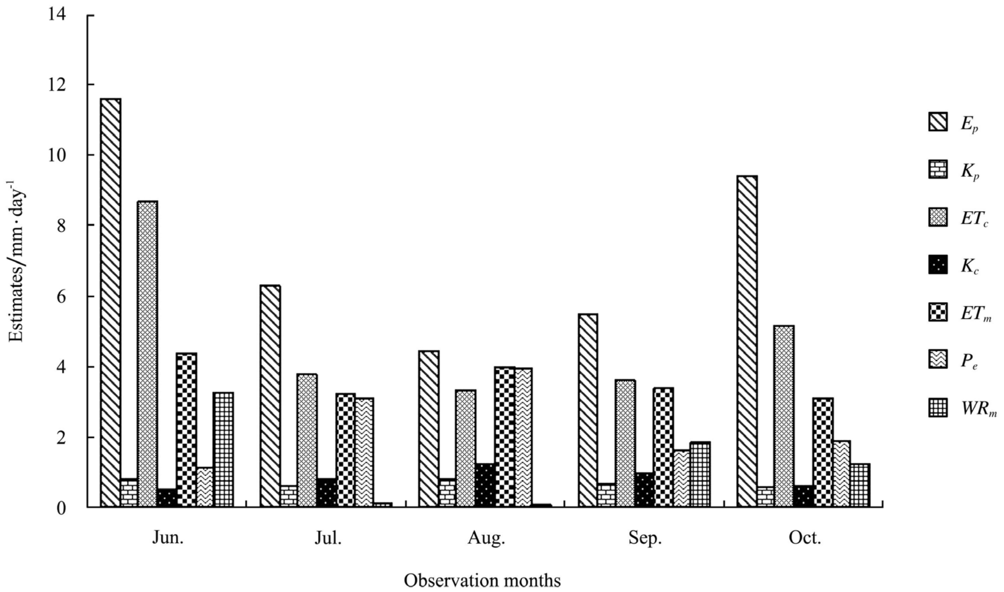

Figure 1 Irrigation requirement of maize in Maiduguri, Borno State (1995)

4 Conclusion

In conclusion, it suffices to mention that the result in this study indicated that the Pan-evaporation (E_p) proportionally increased with increasing wind speed, air temperature and sunshine durations. The evapotranspiration (ET_0) was highest in the month of June (8.70 mm/day) and lowest in August (3.30 mm/day). The estimated evapotranspiration for maize (ET_m) was equally highest (4.35 mm/day) in June and declined sharply in

October (3.10 mm/day), at the inset of drier periods. The consumptive use of water (CU_m) by maize corresponded well with these observed extremes (low and high estimations) for some of the rainfall parameters measured. However, the effective rainfall (P_e) was highest (117.31 mm/day) in the month of August, when ET_0, ET_m and E_p were equally high.

Apparently, the irrigation water requirement (IWR_m) for maize in Maiduguri, generally tallied with the results of E_p, ET_0, ET_m, and CU_m., suggestive of higher need for supplemental rainfall in the months of June, late September and October, as against their soil moisture deficits, compared to July and August being the highest rainfall months. Accordingly, the relationships between the measured parameters revealed a strong negative correlation (r= -0.92) between the IWR_m and P_e, and with strong positive correlation (r = 0.82) between air temperature and sunshine durations, as well as a low positive correlation (r=0.52) between the E_p and wind speed as an attestation to field observations made in this study.

5 Recommendation

It is recommended that supplemental soil moisture should target at the months (June, September and October) with less E_p estimates, in order to achieve optimum IWR_m across all growing months of maize in the study area.

References

[1] Arora K.R 2004. *Irrigation, Water power and Water Resources Engineering*, Standard publishers, Delhi.

[2] Doorenbus J. and Pruitt W.O. 1977. *Guide lines for predicting Crop water requirements*. Irrigation and Drainage paper, FAO: Vol. 24: 1–81.

[3] Euroconsult 1989. *Agricultural compendium for rural development in the Tropics and Subtropics*, Elsevier publishing company New Yoke.

[4] Ezeaku et al 2004. *Estimation of crop Water Requirement from Climate and Soil Data for Maize Production in Two SE Nigeria locations*, a paper presented at the Annual Conference of the Soil Science society of Nigeria 2004.

[5] Huson N.W 1975. *Field Engineering for Agricultural Development*, Oxford publishers London.

[6] James G. Larry 1988. *Principles of farm irrigation Design*, John Willey and Sons Publishers, United Kingdom.

[7] Joel R. 1996. *Basic Engineering Thermodynamics*, Addison Wesley Limited, London.

[8] Martin S. 1992. *Computer programme for irrigation Planning And Management*, Irrigation and Drainage Paper FAO, Vol. 46: 49–62.

[9] Michael A.M 1978. *Irrigation Theories and Practice,* Vikas Publishing House, India.

[10] Verplancke, H. 1985. *The process of evaporation.* Colloquium on energy-flux; The soil atmosphere interface, at College on soil Physics; ICTP, Trieste, Italy.6–10 May.