Network for Research and Development in Africa
International Journal of Pure and Applied Science Research
ISSN: 2384-5918, Volume 11, Issue 11
PP 176-185 (April, 2024)
DOI: 4572771111121
arcnjournals@gmail.com
https://arcnjournals.org

Lysimetric Impact of Organic Materials on Sorghum Crop Evapotranspiration and Coefficient In Semi-Arid Region of Borno State

Bunu M [1] ., Abubakar A.B [2]., Maina MN [2]., Abdulrahman S.H [4] and Adebayo A.O [5]
[1]Department of Agricultural Engineering Technology, School of Engineering
Ramat Polytechnic Maiduguri P.M.B 1070, Borno State, Nigeria
[2]Department of Mechanical Engineering, School of Engineering
Ramat Polytechnic Maiduguri P.M.B 1070, Borno State, Nigeria
[3]Department Water Resources and Environmental Management, National Water Institute
Mando Road P.M.B 2309, Kaduna, Nigeria
[3]Department Agricultural and Bio-Environmental Engineering, National Water Institute Mando
Road P.M.B 2309, Kaduna, Nigeria

***Abstract**: This research investigates the impact of organic materials on sorghum crop evapotranspiration in the semi-arid region of Nigeria. A drainage-type lysimeter measuring 0.6m in height, 0.3m in diameter, and with a cross-sectional area of 0.85m² was employed to assess the influence of organic materials, namely Moringa Olifera leaves, Groundnut Haulm, and Maize leaves, incorporated into the soil at a rate of 0.45kg/m². The study adopted a Randomized Complete Block Design (RCBD) for laying out the organic material treatments. Consistency in water application was maintained with an irrigation interval of 4 days. Results indicate that Moringa Olifera leaves significantly influenced maize crop evapotranspiration, recording the highest rates of 19.2, 88.1, 127.32, and 86.10mm/day across all growth stages. Moreover, Moringa Olifera demonstrated the highest influence on growth parameters and yield attributes, yielding a grain yield of 3663.8kg/ha for sorghum crop. Statistical analysis, including a T-test, revealed no significant difference between the mean ETc predicted by the model and observed values from the field using the lysimeter. However, comparison of predicted ETc with observed values using Nash-Sutcliffe efficiency (NSE) displayed a high degree of agreement between model output and field data, with an R² of 0.9779, NSE values ranging from 0.98 to 0.66, and corresponding RSR values from 0.11 to 0.58 across initial, development, middle, and late growth stages. Additionally, the RMSE values for these stages ranged from 0.86 to 1.9, indicating the suitability of the Hargreaves model for estimating maize evapotranspiration in semi-arid regions with sandy soil.*

Keywords: Drainage; *Evapotranspiration; Lysimeter; Organic Matter; Nash- Sutcliffe efficiency (NSE)*

1.0 INTRODUCTION

In semi-arid and arid regions, where water usage is regulated due to ecological protection programs, limited resources, and competitive demand, agricultural water users need to plan an annual water budget (Meysam, 2015). Irrigation plays a crucial role in global food production by supplying water to agricultural crops in arid regions, offsetting the effects of drought in semi-arid regions, and ensuring consistent yields even in areas with adequate seasonal rainfall (Vaughan et al., 2007). The semi-arid region of Maiduguri, Nigeria, experiences limited and unreliable rainfall patterns, coupled with high rates of moisture loss through evapotranspiration (Abebe, 2012). Sorghum, a significant cereal crop in sub-Saharan Africa, is primarily rainfed, making it susceptible to water stress due to erratic rainfall patterns (Yitebitu, 2004). This water stress limits sorghum yields, especially in areas with low and variable rainfall. Organic material, such as Moringa Olifera leaves and Groundnut Haulm, can enhance soil moisture retention, promote nutrient absorption, and improve crop productivity (Sendiyama et al., 2009; Maduka, 2011). However, their effectiveness in improving crop evapotranspiration and yield in semi-arid regions needs further investigation.

2.0 Materials and Methods

2.1 Experimental Site Description:

The experiment was conducted at the Ramat Polytechnic Teaching and Research farm in Maiduguri during the dry season from February to April 2018. Maiduguri is located at 11.4°N latitude and 13.05°E longitude, with an altitude of 354m above sea level. The region experiences high temperatures ranging from 20-40°C and low annual rainfall of approximately 640mm (Dalorima, 2002).

Table 1: 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
pH	6.8
Field Capacity (vol. %)	16.2
Wilting Point (vol. %)	3.2
Available Water Content (vol. %)	
Bulk Density (g/cm3)	1.70
Organic Matter (%)	3.99

2.2 Experimental Design:

The field experiment utilized a randomized complete block design with three plots of 14m x 4m each. Drainage type lysimeter were installed to measure soil moisture and evapotranspiration. Organic materials such as Moringa Olifera leaves, Groundnut Haulm, and Maize Leaves were incorporated into the soil at 0.45kg/m2 tonnage to a depth of 8 inches.

2.3 Agronomic Practices:

An improved variety of sorghum was planted and managed following standard agronomic practices, including fertilization, weeding, and irrigation using a sprinkling method. The crop was harvested at full maturity, and yield parameters were measured.

2.4 Estimation of crop Evapotranspiration (ETc) using lysimeter

Crop evapotranspiration was determined using lysimeter according to Equation (1) proposed by Sharma (1995). Additionally, the soil moisture available at the root zone of the crops in each lysimeter was estimated using a speedy moisture meter. Subsequently, the disparity between the applied water and drained water was quantified using a measuring cylinder

$$.ET_c = R_w + I_w - QD \pm \Delta S \qquad (1)$$

Where: ET= Evapotranspiration (mm/day), Rw= Rainfall Water (mm) Iw= Irrigation Water (m^3) QD=Quantity of water drained Δs=Surface & Subsurface changes in storage difficulties Involved

2.5 Estimation of Crop Coefficient

Crop coefficient was determined at growth stages of the crop using empirical relation recommended by (Allen *et al*., 1994) shown in equation (2).

$$K_c = \frac{ET_c}{ET_o} \qquad (2)$$

Where, Kc is crop coefficient (-), ETc is crop evapotranspiration in (mm/day) was estimated as stated in equation 1, ETo is reference evapotranspiration in (mm/day) was estimated using pan method as mentioned in shown in equation 3

$$ET_o = K_{pan} \times E_{pan} \qquad (3)$$

2.6 Determination of Leaf Area Index (LAI)

Leaf area index at all stages of growth was determined using Babiker (1999) formular

$$kc = \frac{\text{max } leaf \times \text{max width} \times \text{no.of leaves}}{\text{plant} \times 0.75 \times \text{no.of plants } /m^2} \qquad (4)$$

Where, 0.75 is the Correction factor for crop

2.7 Crop Yield Determination:

Panicle length of fully matured grains was measured using a meter rule, and the mean length was recorded for each treatment in centimeters (cm). The number of panicles per plant was counted, and mean values were recorded. Subsequently, panicles from each lysimeter in the experimental units were threshed, seeds were counted, and the average seed number per head was recorded.

2.8 Hargreaves-Samani Crop Evapotranspiration (ETc) Models:

The Hargreaves-Samani equation for estimating crop ET, which does not require wind speed data, as presented in FAO-56 by Allen et al. (1998), was considered for validation. Adopted by Abhinaya et al. (2015), the model utilizes meteorological parameters such as daily mean minimum and maximum temperature, sunshine duration, mean daily relative humidity, and evaporation using an evaporation pan. These weather parameters, obtained from weather stations at Ramat Polytechnic and Maiduguri International Airport (NIMET), were substituted into the model as presented in Equation 5 below

$$ET_c = \frac{\mathbf{0.0135}\boldsymbol{Rs}\,\boldsymbol{(T+17.8)}}{2} \qquad (5)$$

Where; $Rs=0.758RaS^{0.50}$, and S=0.125(100-Rh),Rh = daily mean relative humidity (%), Tmean is the daily mean air temperature (◦C), and Rs is mean daily sunshine radiation (mm day^{-1})

2.8.1 Model Performance Evaluation:

The evaluation of model performance in predicting crop evapotranspiration was conducted quantitatively, employing three key metrics: Nash-Sutcliffe efficiency (NSE), the ratio of the root mean square error to the standard deviation of measured data (RSR), and root mean square error (RMSE). The assessment was guided by criteria proposed by Moriasi et al. (2007), which categorized the results as 'Very Good' for RSR ≤ 0.50 and 0.75 < NSE ≤ 1.00, 'Good' for 0.50 < RSR < 0.60 and 0.65 < NSE < 0.75, 'Satisfactory' for 0.60 < RSR < 0.70 and 0.50 < NSE < 0.65, and 'Unsatisfactory' for RSR > 0.70 and NSE ≤ 0.50. These criteria provide a structured framework for assessing the reliability and accuracy of the model outputs, aiding in the interpretation of its effectiveness in predicting crop evapotranspiration

$$\boldsymbol{RSR} = \frac{\sqrt{\boldsymbol{\frac{1}{n}\sum_{i=1}^{n}(ET_{cobs-}\,ET_{cal})}}\hat{}\mathbf{2}}{\sqrt{\boldsymbol{\frac{1}{n}\sum_{i=1}^{n}(ET_{cobs-}\,ET_{mean})}}\hat{}\mathbf{2}} \qquad (6)$$

$$\boldsymbol{RMNS} = \sqrt{\frac{1}{n}\boldsymbol{\sum_{i=1}^{n}(ET_{cobs-}\,ET_{cal})}}\hat{}2 \qquad (7)$$

$$\boldsymbol{N\,S} = \sqrt{\frac{1}{n}\boldsymbol{\sum_{i=1}^{n}(ET_{cobs-}\,ET_{cal})}}\hat{}\mathbf{2} \qquad (9)$$

Where; ETc cal = calculated ETc by model, ET cobs = observed ET_C by lysimeter and ETc Mean=average daily ETobs over the season

2.9 Data Analysis

The growth and yield parameters of the sorghum were analyzed using Analysis of Variance (ANOVA) with the Statistic 8.0 package. This statistical method helped to determine if there were significant differences among the treatments. Additionally, the least significant difference (LSD) test was conducted to separate the means of the treatments and identify any significant variations between them. These analytical techniques allowed for a comprehensive examination of the effects of organic materials on sorghum growth and yield, facilitating the interpretation of experimental results and the identification of treatment differences.

3.0 RESULTS AND DISCUSSION

3.1 Influence of Organic Materials on Crop Evapotranspiration (ETc)

The experimental results concerning the influence of organic materials on crop evapotranspiration (ETc), crop coefficient (Kc), leaf area index (LAI), yield, and yield attributes of sorghum are presented in following tables respectively, at internationally recognized growth stages: Initial (10 DAS), Development (35 DAS), Middle (60 DAS), and Late Season (80 DAS), where DAS represents days after sowing. In Table 1, it is evident that the organic materials significantly influenced the evapotranspiration of sorghum ($P<0.05$). Moringa Olifera leaves resulted in the highest evapotranspiration values of 18.2mm, 97.8mm, and 148.0mm at the initial, development, and middle stages of growth, respectively. Maize leaves showed a notable evapotranspiration value of 97.7mm at the late stage. Significant differences were observed among the organic materials, with groundnut haulm recording the least value (68.1mm) at the late stage. Moreover, the control lysimeter exhibited lower crop evapotranspiration compared to all the treatment groups. These findings align with previous studies, such as Irmak (2009), reporting weekly ETc values for sorghum ranging from 25.2 to 61.9 mm, with higher values during the initial and development stages for

Table 1: Influence of organic materials on evapotranspiration (ETc) of sorghum crop at different growth stages (mm)

Treatments	Initial	Development	Middle	Late
Maize leave	16.3^{b}	62.2^{c}	137.6^{b}	97.7^{a}
Moringa leave	18.2^{a}	97.8^{a}	148.0^{a}	76.6^{b}
Groundnut haulm	18.0^{a}	79.0^{b}	133.3^{c}	$68.1b^{c}$
Control	17.6^{b}	82.3^{b}	137.7^{b}	71.6^{c}
SE±	2.537	4.04	3.331	5.140

Means within a treatment column followed by similar letter(s) are not significantly different at 5% probability level

Equally sorghum crop stage-wise coefficient as presented in table 2, indicate significant effects ($P<0.05$) of the treatments on crop coefficients. Moringa leaves exhibited the highest Kc values (0.40, 1.16, 1.38, and 0.93) across all growth stages, followed closely by groundnut haulm with corresponding Kc values ranging from 0.39 to 0.95. Conversely, maize leaves and the control plot displayed lower Kc values. These variations in Kc can be attributed to seasonal variations in leaf area. The findings underscore the impact of organic materials on the crop coefficient dynamics throughout the sorghum growth cycle for more detailed see fig 1

.

Table 2: Influence of organic material on stage –wise crop coefficient (Kc) of the sorghum crop at different growth stages.

Treatments	Initial	Development	Middle	Late
Maize leave	0.35^{c}	0.79^{d}	1.27^{a}	0.33^{b}
Moringa leave	0.40^{a}	1.16^{a}	1.38^{a}	0.93^{a}
Groundnut haulm	0.39^{ab}	0.95^{c}	1.30^{a}	0.69^{ab}
Control	0.35^{c}	1.06^{b}	1.31^{a}	0.66^{ab}
SE±	0.180	0.093	0.204	0.368

Means within a treatment column followed by similar letter(s) are not significantly different at 5% probability level

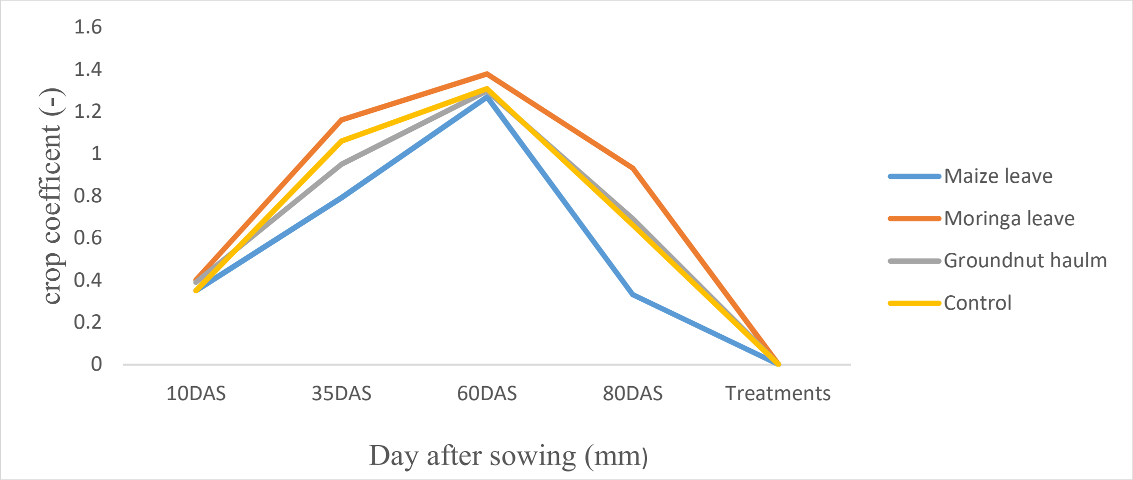

Figure: 1 showing the graph of Kc versus DAS

3.4. Influence of Organic Material on Yield Parameters and Yield of Sorghum

The treatments used were significantly ($P<0.05$) influenced the yield and it parameters of sorghum crop as shown in Table 3. Moringa leaves and maize leaves gave highest number of panicle lengths per plant (21.17and 21.23) respectively. It was followed by groundnut haulm (20.333) and control having the least (19.0). Also, the highest panicle diameter and number of panicle per plant were obtained from moringa leaves were 11.2cm and 5cm respectively. Conversely, followed by groundnut haulm with (10.3cm and 4), while the least was recorded from maize leaves and control. The findings were agreed as stated in (Wahome *et al*, 2010). Similarly, the maximum grain yield of 36637.8 kg/ha with total seed per panicle of (2636.0) was obtained from moringa Olifera. It was closely followed by the groundnut haulm and maize leaves with corresponding yield and number of seed per panicle of (3468.0kg/ha, 2969.5kg/ha) and (2390.0 and 2228.7), respectively. The least yield of 2308.3 kg/ha was recorded in control plot and was achieved with (1979.0) number seed per plant respectively. According to FAO (2010) reported that the number of seed per plant are the most important characters that affect seed yield in most cereal crops.

Table 3: Influence of organic material on yield attributes and yields of sorghum crop

Treatment	Panicle length (cm	Panicle diameter (cm)	Number of panicle per plant	No seed per panicle	Panicle weight (Kg)	Yield (kg/ha)
Maize leave	21.17^{a}	10.2^{ab}	3^{b}	2228.7^{bc}	0.3690^{bc}	2969.5^{b}
Moringa leave	21.23^{a}	11.2^{a}	5^{a}	2636.0^{a}	0.4190^{a}	3663.8^{a}
G. haulm	20.33^{ab}	10.3^{ab}	4^{ab}	2390.0^{ab}	0.3553^{b}	3468.0^{ab}
Control	19.00^{b}	10.3^{ab}	2^{c}	1979.0^{c}	0.2360^{c}	2308.3^{bc}
SE±	2.029	1.351	1.793	349.13	0.0850	364.72

Means within treatment and a column followed by similar letter(s) are not significantly different at 5% probability level.

The comparison depicted in Table 6 demonstrates a strong agreement between the calculated ETc from the ABC model and the observed ETc from the lysimeter for sorghum crop. The model output, along with experimental results plotted on Fig 2, yielded a slope of 10.971x and an intercept of 3278, resulting in an R^2 of 0.977, signifying a high level of concordance between the model output and the field data. The NSE values of 0.99, 0.65, 0.69, and 0.68, alongside RSR values of 0.12, 0.60, 0.54, and 0.59 for the initial, development, middle, and late growth stages respectively, further support this agreement. Moreover, the RMSE values for these growth stages (0.86, 1.2, 0.93, and 0.38) indicate a 'Very Good' performance of the model in estimating seasonal evapotranspiration for sorghum. However, the level of agreement between the calculated and measured values as indicated varied from 'very good' for the initial stage to 'good' for subsequent stages. Similarly, the comparison between observed and predicted millet crop evapotranspiration, analyzed using a T-test as shown in Table 7, revealed no significant difference ($P<0.05$), suggesting that the ABC model effectively represents evapotranspiration in semi-arid regions with sandy loam soil

Table 6: Performance Evaluation Comparison between Observed and Predicted Crop Evapotranspiration for Sorghum at Different Growth Stages

Growth stages	ETobs (mm)	ETcal (mm)	ΔET	ET mean (mm/day)	RMSE	NSE	RSR	Performance Rating
Initial	17	18.9	-1.9	1.8	0.86	0.99	0.12	VG
Development	82	70.2	11.8	3.0	1.2	0.65	0.60	G
Middle	138.1	135.3	2.8	5.5	0.93	0.69	0.54	G
Late	72.5	78.2	-5.7	3.7	0.38	0.68	0.59	G

RMSE – root mean square error; NSE – Nash-Sutcliffe efficiency; RSR – ratio of the root mean square error to the standard deviation of measured data; S – satisfactory; VG – very good; G – good, and ΔET difference in ETc.

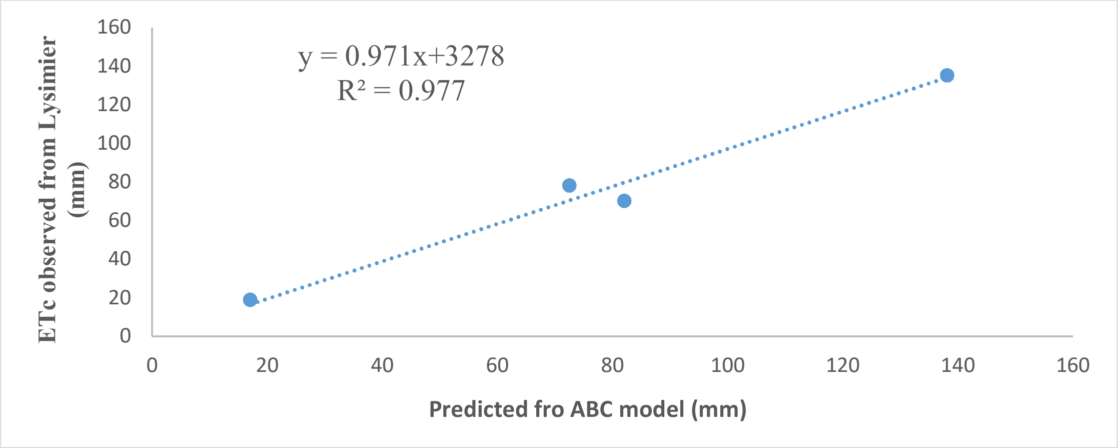

Figure: 2 showing relationship between the predicted and observed ETc

Table 7: Summary of T-Test for comparing ETc by Lysimeter and ABC model at growth stages

Z	*ETc Predicted values (mm)*	*ETc Observed values Millet (mm)*
Mean	75.65	77.4
Variance	2271.63	2459.273333
Observations	4	4
Pooled Variance	2365.452	
Hypothesized Mean Difference	0	
Df	6	
t Stat	-0.050	
P(T<=t) one-tail	0.480	
t Critical one-tail	1.943	
P(T<=t) two-tail	0.461	
t Critical two-tail	2.446	

T Stat < T critical

Conclusion and Recommendations

The research investigated the impact of organic materials on crop evapotranspiration of sorghum, aiming to assess their influence on crop performance. Utilizing statistical techniques such as analysis of variance (ANOVA) and Nash-Sutcliffe efficiency (NSE), the study drew the following conclusions:

1. ANOVA Analysis: Significance was found among the treatments (organic materials) employed. Notably, Moringa Olifera exhibited the highest influence on ETc, Kc, and LAI across all growth stages. It significantly bolstered grain yield, yielding 3663.8 kg/ha, surpassing all other treatments.

2. NSE Comparison: Comparing predicted ETc with observed values from the lysimeter using NSE demonstrated a strong agreement between the model output and field data, with an impressive R^2 of 0.9779.
3. Model Applicability: The study suggests that the Hargreaves model effectively estimates sorghum crop evapotranspiration in semi-arid regions with sandy soil, based on the comparison results.

4. T-test Analysis: Statistical analysis revealed no significant difference between the means of predicted ETc using the model and observed values from the field using the lysimeter, further supporting the model's reliability.

Recommendations:

Additional experiments should be conducted across diverse agro-ecological conditions to validate and expand upon the findings of this study, enhancing the generalizability and applicability of the results. In conclusion, the research underscores the importance of organic materials in influencing crop evapotranspiration and highlights the utility of the Hargreaves model in estimating ETc for sorghum in specific environmental conditions. Further research endeavors will enrich our understanding and applicability in broader contexts

References

Abebe, S. (2012). Determination of water requirement and crop coefficient for sorghum (sorghum bicolor l.) at melkassa, Ethiopia haramayauniversity Msc thesis pp 23-45

Allen, R.G., Smith, M., Perrier, A., Pereira, L.S., 1994. An update for the definition of reference evapotranspiration. ICID Bull, 43 (2): 1- 34.

Allen, R.G., L.S. Pereira, D. Raes and M. Smith, 1998. Crop evapotranspiration. Guidelines for computing crop water requirements. FAO Irrigation and Drainage paper No. 56. FAO, Rome, Italy, Pp. 469.

Bashir, 2014. Response of Maize to Irrigation Scheduling Method under Drip Irrigation Method, unpublished paper pp 35-37.

Bashir, M.A., T. Hata, A.W. Abdelhadi, H. Tanakamaru and A. Tada, 2006. Satellite-based evapotranspiration and crop coefficient for irrigated sorghum in the Gezira scheme, Sudan. *Journal of Hydrology and Earth System Sciences,* 3: 793 – 817.

Chiroma, A. M. (2004). Effects of land configuration and wood-shavings mulch on soil properties, yield and water use of sorghum. Unpublished Ph.D. Thesis, University of Maiduguri.

Dalorima L (2002) Effects of Different organic matters on the Growth Performance of Amaranthus in Maiduguri International Research Journal of Agricultural Science and Soil Science, 3(6):240-339.

Dibal, J.M (2002). Desertification in Nigeria. Causes, effect and review of control measures. University of Maiduguri, faculty of engineering seminar series, 2(1):59-74.

Fasinmirin J, Toyin R, Miguel, Oguntunde, Philip G, Ayodele E. Green house evapotranspiration and crop factor of *Amaranthus cruentus* grown in weighing lysimeters. African *Journal of Agricultural Research*2015; Vol. 10(34), pp. 3453-3461, 20

FAO, 2000. Crop evapotranspiration – Guidelines for computing crop water requirements, By: R. Allen, L. Pereira, D. Raes, M. Smith, Irrigation and drainage paper 56.

FAO, United Nations, 2001, Expert consultation Italy, on revision of FAO methodologies, 28-31May for crop water requirements, Annex V. Rome.

FAO (2010).Soil Biota and Biodiversity" The "Root" of Sustainable Development" ftp.fao/010/i0112e07.pdf, February, 2010.

Howell, T.A., 2001. Enhancing water use efficiency in irrigated agriculture. Journal of Agronomy, 93:281-289.

Irmak, S., Haman, D.Z., Bastug, R., 2000. Determination of crop water stress index for irrigation timing and yield estimation of corn. Agron. J. 92, 1221–1227.

Lu, J., Sun, G., McNulty, S.G., Amatya, D.M., 2005. A comparison of six potential evapotranspiration methods for regional use in the southeastern united states. J. Am. Water Resour. Assoc. 41 (3), 621–633.

Martínez-Cob, A., Tejero-Juste, M., 2004. A wind-based qualitative calibration of the Hargreaves ET0 estimation equation in semiarid regions. Agric. Water Manag. 6, 251–264. JSC (1999). Effect of organic amendments on some physicalproperties of a tropical ultisol. *Biol. astes*. 27: 1-13

Meysam, A. (2015) Evaluation of Growth-Stage-Specific Crop Coefficients of Maize Using Weighing Lysimeter Kashmar Higher Education Institute, Kashmar, Iran..,Soil& Water Res., doi: 10.17221/63/ (2): 99–104

Moriasi D.N., Amold J., Van Liew M.W., Bingner R.L., Harmel R.D., Veith T.L. (2007): Model evaluation guidelines for systematic quantification of accuracy in watershed simulations. Transactions of the ASABE, 50: 885–900.

Nukenine, E.N (2010). Stored product production in Africa, past present and future. 10th International conference in Stored Product Production, pp. 26-30 doi; 10:5073 JKA 2010, pp. 425- 177.

Obilana A. B (2007) overview: Importance of millets in Africa ICRISAT, Nairobi, Kenya, pp. 36-45.

Piccinni, G., J. Ko, T. Marek and T. Howell, 2006. Determination of growth-stage-specificcrop coefficients (Kc) of millet and sorghum: Chesterfield, USA. *Journal of AgriculturalWater Management,* 96: 1698–1704

Rashid Niaghi A, Majnooni-Heris A, ZareHaghi D, Mahtabi GH. Evaluate several potential evapotranspiration methods for regional use in Tabriz, Iran. J. Appl. Environ. Biol. Sci. 2013; 3(6):31-41.

Roy, K.C., Sharma K and Mainuddin. M. (2004). Response of maize to irrigation by pan evaporation method. *Bangladesh J.Agril. Res.* 19 :(2) l25-l33.

Sharma, M.L. 1995. Estimating evapotranspiration. Adv. Irr. 3:213-281

Zhang, X. Y., Chen, S. Y., Pei, D., Liu, M. Y., & Sun, H. Y. (2005). Evapotranspiration, yield and crop coefficient of irrigated maize under straw mulch. *PEDOSPHERE*, *15*(5), 576-584.