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Impact of Agro-Waste on Sorghum Crop Water Consumption and Coefficient Using Lysimeter Studies

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***Abstract**: The research aimed to evaluate the influence of organic materials on the evapotranspiration of sorghum in the semi-arid region of Nigeria. To achieve this, a drainage-type lysimeter with a height of 0.6 m, a diameter of 0.3 m, and a cross-sectional area of 0.85 m^2 was utilized. The organic materials applied were Moringa olifera leaves, groundnut haulm, and maize leaves, which were incorporated into the soil at a rate of 0.45 kg/m^2. The treatments were arranged using a Randomized Complete Block Design (RCBD). To ensure consistency in water application, an irrigation interval of four days was maintained. The highest crop evapotranspiration (ETc) for sorghum was observed with Moringa olifera leaves, recording values of 19.2, 88.1, 127.32, and 86.10 mm/day at the initial, development, middle, and late stages of growth, respectively. The results indicate that Moringa olifera had the most significant influence on crop evapotranspiration, growth parameters, and yield attributes, resulting in a sorghum yield of 3663.8 kg/ha. Statistical analysis using a T-test revealed no significant difference between the predicted ETc (calculated using the Hargreaves model) and the field-observed ETc from the lysimeter. Additionally, a comparison of the predicted ETc and observed values using the Nash-Sutcliffe Efficiency (NSE) demonstrated a high level of agreement, with an R^2 of 0.9779 and NSE values of 0.98, 0.68, 0.78, and 0.66 for the initial, development, middle, and late growth stages, respectively. The Root Mean Square Error (RMSE) for the corresponding stages was 0.86, 1.9, 1.6, and 0.92, while the RSR values were 0.11, 0.64, 0.59, and 0.58. These results imply that the Hargreaves model is a reliable tool for estimating crop evapotranspiration in semi-arid regions with sandy soils.*

***Keywords:** Drainage; Evapotranspiration; Lysimeter; Organic Matter; Nash-Sutcliffe and Efficiency (NSE).*

1.0 Introduction

Agricultural water users in semi-arid and arid regions face challenges such as limited water resources, ecological protection programs, and competitive demands. Therefore, planning an annual water budget is crucial (Meysam, 2015). Globally, irrigation plays a significant role in food production. It involves the artificial supply of water to agricultural crops, enabling farming in arid regions and mitigating the effects of drought in semi-arid regions. Even in areas with adequate seasonal rainfall, irrigation offsets periods of moisture deficit (Vaughan et al., 2007). In Maiduguri, a semi-arid region of Nigeria, rainfall is limited, erratic, and unreliable, while evapotranspiration rates are relatively high, leading to significant moisture loss into the atmosphere (Abebe, 2012). Sorghum, the fourth most important cereal globally and the second most important in sub-Saharan Africa after maize, is primarily grown as a rain-fed crop in semi-arid areas. However, its production is constrained by water stress due to low and variable rainfall both within and between seasons. As a result, sorghum yields in these areas fluctuate significantly, showing a close dependency on rainfall patterns (Yitebitu, 2004). Sorghum production in these regions covers approximately 1.62 million hectares. The accurate determination of evapotranspiration in any region requires either simple or complex equations, often necessitating a wide range of meteorological data, making it challenging to select the most appropriate method. However, increasing the organic material content in sandy soils can enhance crop yield, retain soil moisture, and promote evapotranspiration. This is achieved by improving cation exchange capacity and reducing nutrient losses through leaching (Yanfei et al., 2006). Organic materials also provide essential nutrients to crops, potentially increasing absorption efficiency and boosting productivity (Sendiyama et al., 2009). *Moringa oleifera*, a tropical plant, is valued for its nutritional and medicinal uses. Groundnut haulm, although less commonly utilized as mulch in semi-arid Africa, possesses excellent mulching qualities (Maduka, 2011). Most crops perform best in soils with an organic matter content ranging from 2% to 5% (Pennsylvania, 2009). This study was conducted to determine the most effective organic materials for improving crop evapotranspiration, growth, and yield of sorghum. Additionally, it sought to validate the applicability of the Hargreaves-Samani ETc model for the study area

2.0 Materials and Methods

2.1 Experimental Site Description

The experiment was conducted during the dry season (February to April 2018) at the Ramat Polytechnic Teaching and Research Farm, Maiduguri, Nigeria. Maiduguri is located at latitude 11.4°N and longitude 13.05°E, with an altitude of 354 meters above sea level (Bashir, 2015). The area experiences an average annual rainfall of approximately 640 mm, with high temperatures ranging between 20°C and 40°C (Dalorima, 2002). Relative humidity varies between 13% during the dry season and 65% during the rainy season (Bashir, 2014). The region is highly vulnerable to drought and desertification (Dibal, 2002)

2.2 Experimental design

The field experiment was conducted at the Teaching and Research Farm of the Ramat Polytechnic Maiduguri. The experimental site was15m x 15m. The selected area was divided into 3 plots of 14m x 4m each with a foot path of 1.5m in between the plots. Subsequently, the entire land area was fumigated manually to prevent the crops from pest attack. Drainage type lysimeter of 0.6m height, and 0.3 diameter with cross-sectional area of 0.85m^2 was used for this study. A plastic container (5 liters) was placed at 1m away from the lysimeter to serve as drainage collector. However, 0.02m (2cm) diameter plastic pipe was used to link between the lysimeter and the drain collector. The Installation was accomplished by used of backhoe, forklift, hand shovels, and hand tools. An order of returning excavated soil for the lysimeter. “Last out first in and first out last in” was used to maintain same natural soil structure or arrangement as suggested by Shukla et al., (2007). Furthermore, the lysimeter were set into the soil pebbles and wire mesh was placed at the bottom of the lysimeter to a depth of 5cm in order to facilitate easy drainage and help in preventing blockage of the drain. The organic materials used for this study were Moringa Olifera leaves, Groundnut Haulm and Maize Leaves were grown and incorporated into the soil at 0.45kg/m^2 tonnage to a depth of 8inch beneath the soil in the lysimeter for the all experimental unit, the cropwas irrigated as per the design of the treatments. Measured quantity of water was applied. Soil moisture was measured before each irrigation. Since the experiment was carried out in dry season no rainfall part was considered and only change in soil moisture during the period under consideration were subtracted from the applied water to obtain crop evapotranspiration (ET_c).

2.3 Agronomic practices

An improved variety of sorghum developed by (ICRISAT) was obtained from Borno State Agricultural Development Programmed (BOSADP) Maiduguri was planted on the 1st of

February, 2018 and to avoid alteration of the treatments, water was applied using a sprinkling irrigation method i.e. using hand watering-can as suggest by (Howell, 2001). The standard lysimeter spacing of (1m) was used and the sorghum was planted six seed per hole in each lysimeter plots at the depth of 7cm using hoe. It was letter thinned to two seedlings per hole on each experiment unit after germination. (De Rouw and Rajot. 2004). Recommended NPK fertilizer50kg of K_2O per hectare for most cereals crop was applied. The first dosage of fertilizer was applied after the first week of planting at a depth of 5-8cm, while the second dosage was also applied four weeks after planting as recommended by (Onyibe et al. 1997). Weeding was carried out manually throughout the growing period to avoid competition for space, water light and nutrients between the crops (James et al., 2000). The first weeding was done two weeks after planting and the second was carried out 5 weeks after planting. At the fully maturity i.e. late stage of growth (80day after sowing) all plants in each lysimeter experiment unit were manually harvested by use of cutlass, sickles were used to separate the panicle /cobs from their stalks, and were dried using sun drying method, while the threshing was accomplished by the use of local conventional procedure.

2.4 Estimation of crop Evapotranspiration (ETc) using lysimeter

The determination of crop evapotranspiration using lysimeter was achieved using Equation (1) below as suggested by (Sharma 1995). However, the moisture available in the soil at the root zone of the crops in each lysimeter was estimated using speedy moisture meter. Nevertheless, the difference between water applied and water drained was determined using 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,ET_o 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 Determination of the crop yield

The panicle length of the fully matured grain was measured using meter rule and the mean was recorded for each treatment in (cm). Number of panicle per plant was counted and the mean values were recorded. The panicle from each lysimeter in the experiment units were threshed, seeds were counted, and the average seed number per head was recorded.

2.8 Hargreaves-Samani Crop evapotranspiration (ETc) models

The model considered for validation is Hargreaves-Samaniequation for estimating crop ET which doesn't require wind speed data Presented in FAO - 56 by Allen et al. (1998) Adopted by Abhinaya *et al* (2015). For the validation studies, some meteorological parameters such as daily values of mean minimum and maximum temperature, sunshine, mean daily relative humidity, and evaporation using evaporation pan was collected and considered. These weather parameters were obtained from Ramat Polytechnic and Maiduguri international airport weather stations (NIMET) and were substituted intomodels as presented in equation 5 below

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

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 validity agreement between the observed and predicted crop evapotranspiration was quantitatively evaluated using the 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 evaluation was rated 'Very Good' (0 ≤ RSR ≤ 0.50 and 0.75 < NSE ≤ 1.00), 'Good' (0.50 < RSR < 0.60 and 0.65 < NSE < 0.75), 'Satisfactory' (0.60 < RSR < 0.70 and 0.50 < NSE < 0.65), or 'Unsatisfactory' (RSR > 0.70 and NSE ≤ 0.50), according to the criteria suggested by Moriasi *et al.* (2007).

$$\boldsymbol{RSR} = \frac{\sqrt{\frac{1}{n}\sum_{i=1}^{n}(ET_{cobs-}\,ET_{cal})^{\wedge}2}}{\sqrt{\frac{1}{n}\sum_{i=1}^{n}(ET_{cobs-}\,ET_{mean})^{\wedge}2}} \quad (5)$$

$$\boldsymbol{RMNS} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(ET_{cobs-}\,ET_{cal}})^{\wedge}2 \quad (6)$$

$$\boldsymbol{N\ S} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(ET_{cobs-}\,ET_{cal}})^{\wedge}2 \quad (7)$$

Where; ETc $_{cal\ =}$ calculated ETc by model, ET c$_{obs}$ = observed ET$_C$ by lysimeter and ETc $_{Mean}$=average daily ET$_{obs}$ over the season

2.9 Data Analysis

All the data collected on the growth and yield parameters of the sorghum were subjected to Analysis of Variance (ANOVA) using Statistic 8.0 package. The difference between treatments means were separated using least significant difference (LSD).

3.0 RESULTS AND DISCUSSION

3.1 Influence of Organic Materials on Crop Evapotranspiration (ETc)

The experimental results on the influence of organic materials on crop evapotranspiration (ETc), crop coefficient (Kc), leaf area index (LAI), yield, and yield attributes of sorghum are presented according to internationally recognized growth stages: initial (10 DAS), development (35 DAS), middle (60 DAS), and late season (80 DAS). Here, DAS refers to days after sowing. The results are summarized in Tables 1–6 below.

Table 1: Influence of Organic Materials on Evapotranspiration (ETc) of Sorghum Crop at Different Growth Stages (mm)

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

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

The organic materials significantly ($P<0.05$) influenced sorghum crop evapotranspiration (Table 1). Moringa leaves produced the highest ETc values of 18.2 mm, 97.8 mm, and 148.0 mm at the initial, development, and middle stages, respectively, and were closely followed by maize leaves (97.7 mm) at the late stage. Conversely, groundnut haulm resulted in the lowest ETc value (68.1 mm) during the late stage. Across all growth stages, the control lysimeter recorded lower ETc values than the treatments. These results align with the findings of Irmak (2009), who reported weekly ETc values for sorghum ranging from 25.2 to 61.9 mm. Higher ETc values were observed during the initial and development stages compared to the middle and late stages of the crop's life cycle.

3.2 Influence of Organic Materials on Stage-Wise Crop Coefficient (Kc) of Sorghum

The results of the influence of organic materials on crop coefficients (Kc) of sorghum across various growth stages are presented in Table 3.

Table 2: Influence of Organic Materials on Stage-Wise Crop Coefficient (Kc) of Sorghum at Different Growth Stages

Treatments	Initial	Development	Middle	Late
Maize leaves	0.35c	0.79d	1.27a	0.33b
Moringa leaves	0.40a	1.16a	1.38a	0.93a
Groundnut haulm	0.39ab	0.95c	1.30a	0.69ab
Control	0.35c	1.06b	1.31a	0.66ab

Treatments	Initial	Development	Middle	Late
SE±	0.180	0.093	0.204	0.368

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

The crop coefficient (Kc) values for sorghum at different growth stages were significantly ($P<0.05$) affected by the treatments (Table 2). The highest Kc values (0.40, 1.16, 1.38, and 0.93) were recorded with the application of moringa leaves as an organic material across all growth stages. Groundnut haulm followed closely, with Kc values ranging from 0.39 to 0.69. Maize leaves and the control plot recorded the lowest Kc values. These variations in Kc can be attributed to seasonal changes in leaf area. These results are consistent with the findings of Zhang et al. (2005). For a visual representation of these differences, refer to Figure 1.

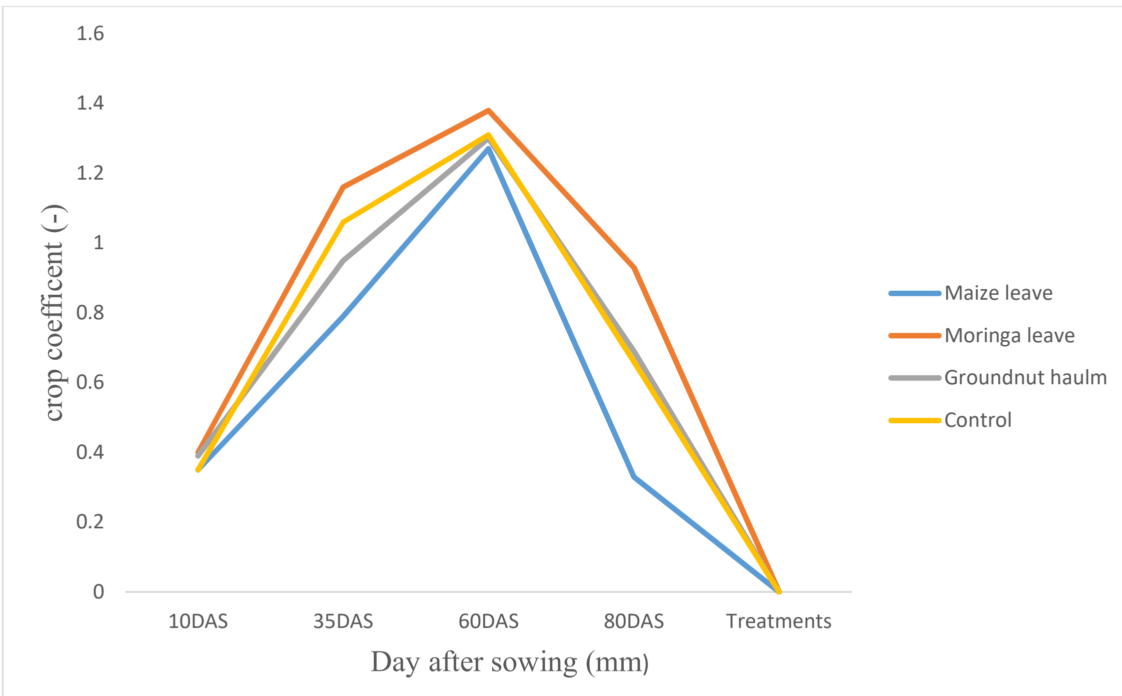

Figure: 1 showing the graph of Kc versus DAS

3.3 Influence of Organic Materials on Crop Leaf Area Index (LAI) of Sorghum

The results on the influence of organic materials on the leaf area index (LAI) of sorghum are summarized in Table 3.

Table 4: Influence of Organic Materials on Leaf Area Index (LAI) of Sorghum Crop at Different Growth Stages (m²)

Treatments	Initial	Development	Middle	Late
Maize Leaves	0.03b	0.25c	2.40b	1.87ab
Moringa Leaves	0.04a	0.34a	3.20a	1.50b
Groundnut Haulm	0.03ab	0.22d	3.00a	1.93a
Control	0.02c	0.28b	2.50b	1.50b
SE±	0.342	0.126	0.2514	0.321

Note: Means within a treatment column followed by the same letter(s) are not significantly different at a 5% probability level.

The leaf area index (LAI) of sorghum was significantly ($P < 0.05$) affected by the organic materials applied during the experimental period. The highest LAI values were recorded with Moringa olifera leaves during the initial, developmental, and middle growth stages, with corresponding values of 0.04, 0.34, and 3.20, respectively. Groundnut haulm followed closely at the middle stage with an LAI of 3.00. In the late stage, the highest LAI values were observed for groundnut haulm and maize leaves, which recorded 1.93 and 1.87, respectively. The reduction in LAI at the late stage is attributed to leaf senescence and natural defoliation as the crop reaches full maturity. These findings align with those of Fasinmirin et al. (2015), who reported similar trends in LAI changes in cereal crops.

3.4 Influence of Organic Materials on Yield Parameters and Yield of Sorghum

The experimental results on the yield parameters and overall yield of sorghum, as influenced by the organic materials used, are shown in Table 4.

Table 5: Influence of Organic Materials on Yield Attributes and Yield of Sorghum Crop

Treatment	Panicle Length (cm)	Panicle Diameter (cm)	No. of Panicles/Plant	Seeds/Panicle	Panicle Weight (kg)	Yield (kg/ha)
Maize Leaves	21.17a	10.2ab	3b	2228.7bc	0.3690bc	2969.5b
Moringa Leaves	21.23a	11.2a	5a	2636.0a	0.4190a	3663.8a
Groundnut Haulm	20.33ab	10.3ab	4ab	2390.0ab	0.3553b	3468.0ab
Control	19.00b	10.3ab	2c	1979.0c	0.2360c	2308.3bc
SE±	2.029	1.351	1.793	349.13	0.0850	364.72

Note: Means within a treatment column followed by the same letter(s) are not significantly different at a 5% probability level.

The results in Table 4 reveal that the treatments significantly ($P < 0.05$) influenced yield parameters and the final yield of sorghum. Moringa leaves treatment produced the highest panicle length (21.23 cm), panicle diameter (11.2 cm), and number of panicles per plant (5). Similarly, it yielded the maximum grain yield of 3663.8 kg/ha and the highest number of seeds per panicle (2636.0). Groundnut haulm followed closely with a grain yield of 3468.0 kg/ha and a panicle weight of 0.3553 kg. Maize leaves also performed well but recorded lower values than Moringa leaves and groundnut haulm. The control plot consistently showed the least performance, with the lowest panicle length, diameter, and grain yield (2308.3 kg/ha). The findings align with those of Wahome *et al.* (2010), who emphasized the role of organic materials in enhancing soil fertility, which subsequently improves yield and its attributes.

3.5 Performance Evaluation of Observed vs. Predicted Evapotranspiration for Sorghum

Table 5: Performance Evaluation of Observed (ET*obs*) and Predicted (ET*cal*) Evapotranspiration for Sorghum Crop

Growth Stage	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

Note: RMSE = Root Mean Square Error, NSE = Nash-Sutcliffe Efficiency, RSR = Ratio of RMSE to Standard Deviation, VG = Very Good, G = Good, ΔET = Difference in ETc.

The results in Table 5 show a strong agreement between evapotranspiration values observed from the lysimeter and those predicted using the Hargreaves–Samani (ABC) model. The model exhibited a high degree of reliability, with NSE values of 0.99, 0.65, 0.69, and 0.68 for the initial, developmental, middle, and late stages, respectively. RMSE values ranged from 0.38 to 1.2, indicating excellent to good model performance.

Similarly, scatterplot in figure 2 demonstrates a strong linear relationship (R2=0.977R^2 = 0.977R2=0.977) between observed evapotranspiration (ETc) from the lysimeter and predicted values from the ABC model, indicating high model accuracy. The slope (0.9710.9710.971) is close to 1, suggesting minimal underestimation, while the alignment of data points with the line of best fit confirms the model's reliability in semi-arid conditions with sandy loam soils. The offset intercept (+3278+3278+3278) might indicate a slight systematic bias, but overall, the results validate the ABC model as a robust tool for estimating crop evapotranspiration. Minor discrepancies could be attributed to environmental factors or measurement variability, reinforcing its applicability for similar agro-climatic regions

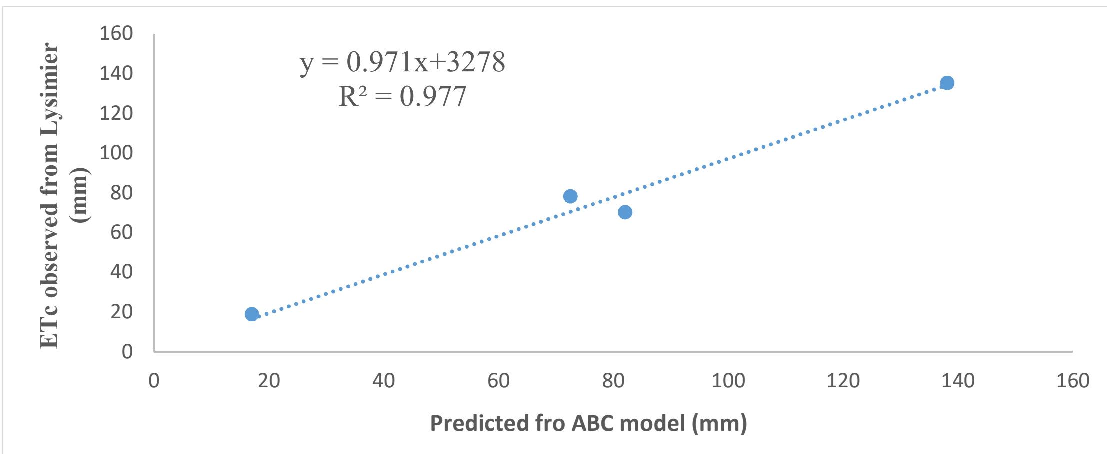

Figure: 2 showing relationship between the predicted and observed ETc

Table 6: Summary of T-Test for comparing ETc by Lysimeter and ABC model at growth stages

Z	*ETc Predicted values (mm)*	*ETc Observed values Sorghum(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

As shown in Table 7, the t-statistic (−0.050-0.050−0.050) is less than the critical t-value (1.9431.9431.943 for one-tail and 2.4462.4462.446 for two-tail tests), indicating no significant difference between the evapotranspiration (ETc) observed using the lysimeter and that predicted by the ABC model (P>0.05P > 0.05P>0.05). This suggests that the ABC model provides comparable results to field-observed ETc values, making it a reliable tool for estimating evapotranspiration in semi-arid regions with sandy loam soils

3.6 Conclusion and Recommendation

This study evaluated the influence of organic materials on the evapotranspiration (ETc) of sorghum to assess their impact on crop water use and yield. The research utilized statistical techniques such as Analysis of Variance (ANOVA), Nash-Sutcliffe Efficiency (NSE), and t-tests, leading to the following conclusions:

1. ANOVA revealed a significant difference among treatments, with *Moringa oleifera* showing the highest influence on ETc, crop coefficient (Kc), and leaf area index (LAI) across all growth stages. Additionally, it significantly enhanced grain yield (3,663.8 kg/ha), outperforming other treatments.
2. The comparison of predicted ETc values from the ABC model and observed values using lysimeter data demonstrated strong agreement, with a high NSE value (R2=0.977R^2 = 0.977R2=0.977), confirming the reliability of the model.
3. The findings suggest that the Hargreaves model is a robust tool for estimating sorghum evapotranspiration in semi-arid regions with sandy loam soils.
4. T-test analysis showed no significant difference between the mean ETc values predicted by the model and those observed in the field, further validating the model's applicability.

Recommendations:

1. Similar studies should be conducted across diverse agro-ecological zones to validate and refine the findings.
2. Future research could explore the long-term effects of organic amendments on soil properties and crop water use efficiency.
3. Farmers in semi-arid regions should consider incorporating *Moringa oleifera* as a soil amendment to improve sorghum yield and water use efficiency.

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