Estimation of Crop Water Use of Rain-Fed Maize and Groundnut Using Mini-Lysimeters.

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ABSTRACT

This paper reports the use of weighing-type mini-lysimeters to estimate the crop water use of rain-fed maize and groundnut. The mini-lysimeters were assembled using readily available materials which include plastic containers as the lysimeter tank and vehicular tubes filled with water connected to a manometer glass tubes for the weighing system. The lysimeters were planted to maize and groundnut, and were installed in the midst of fields cultivated to the respective crops. The daily displacement of water in the manometer tube due to change in weight as water enters or leaves the lysimeter tanks were translated to crop water use. The results showed that the average daily water use of the maize crop increased from 2.70 mm/day at the early crop growth stages to 6.00 mm/day at mid-season and declined to 3.30 mm/day at the end of the season. The average daily water use of the groundnut crop was also found to increase from 2.66 mm/day at the early growth stage of the crop to 4.83 mm/day at the mid-season and declined to about 2.70 mm/day at the end of the season. The water use of both crops compared closely with estimates from weather data-crop coefficient with mean differences of 2.75 and 3.15 mm/week for the maize and groundnut crops, respectively.

(Keywords: mini-lysimeter, crop water use, reference evaporation, maize, groundnut)

INTRODUCTION

Information on crop water requirements is very vital in the planning and operation of soil and water management strategies. Besides planning and design of irrigation systems, knowledge of crop water use is required when planning erosion control measures such are terracing and contour bunding, planning and design of micro- and macro-catchment rain/runoff water harvesting systems, surface and subsurface drainage systems, and other soil moisture conservation techniques. Most of the systems mentioned above are usually required to manage soil and water in rainy season. Information on crop water requirements in literature are largely those used for the purpose of irrigation, and were most probably developed during the dry season. Since the micro-climate during the wet season differs from that of the dry season, it is most expected that crop water requirements for irrigation should differ from that under rain-fed condition.

One of the challenges of determining crop water requirement represented by the crop consumptive use (also commonly referred to as evapotranspiration) at field level under rain-fed condition is the fact that the other output components of the soil water balance (e.g. runoff, deep percolation, and capillary movement) are very volatile and difficult to measure. However, this challenge can be overcome with the use of lysimeters. A lysimeter is a device which enables the isolation of a soil column for the purpose of studying water inflow and outflow in the system.

The soil column can be isolated from the surrounding using a container of regular shape (referred to as the lysimeter tank) and planted to a crop. The water input to grow the crop can be measured and the crop water use and other output components of the soil water balance (runoff, deep percolation and moisture retained in the soil column) can also be quantified. The lysimeter tank could be of any dimension, but Clark and Reddell (1990) noted that the surface area and depths of the lysimeter tanks should be large enough to minimize plant root restrictions.

The literature (e.g. Clark et al., 1996; Hama et al., 1997; Simon et al., 1998; Lie et al., 2003) shows that the surface area and depth of standard lysimeter tanks are usually above 1 m^2 and 0.5 m deep. Lysimeter tank with lesser dimensions may therefore be referred to as mini-lysimeters.

Large lysimeters are expensive to construct, install and maintain. The use of mini-lysimeter in fluid studies is common (Clark et al., 1984; Rosenthal et al., 1985; Wight et al., 1986; Dugas and bland, 1989; Isard and Belding, 1989; Uzonwa, 1991). Mini-lysimeters have the advantages that the permit the measurement of the evaporative flux from smaller areas; create less disturbance to the environment of inters during installation; and are considerably cheaper to construct, install and maintain.

Lysimeters are of two types: weighing and non-weighing type. The non-weighing type estimate crop water use as the residual term in the soil water balance equation having measured all other components including water inputs (rain and irrigation), outputs (drainage and runoff), and change in soil water storage (Garcia et al., 2004). Weighing lysimeter on the other hand, measure crop water use directly by measuring the change in weight of an isolated soil volume. The crop water use is calculated from the changes in weight of the lysimeter tank, and adjusted to account for weight changes caused by factors other than crop water use such as drainage or runoff and water input (Malone et al., 2000).

The objectives of the study reported herein were to estimate crop water use (evapotranspiration) of rainfed maize and groundnut crops using a weighing type mini-lysimeter, and to compare the estimates with those based on weather-crop coefficient data.

MATERIALS AND METHODS

Description of Study location

The field trial was carried out during the 2010 rainy season at the experimental fields of the Department of Agricultural Engineering, Ahmadu Bello University Zaria, Nigeria. Zaria lies on latitude $7^o35'$N, longitude $11^0 11'$E and altitude 686 m above mean sea level. It is located within the Northern Guinea Savannah ecological zone. The climate can be described as semi-arid, with three distinct seasons: the hot dry season which spans from March to May; warm rainy season from June to early October; and the cool dry season which spans from late October to February. The weather data of the study location for the period when the study was carried out is presented in Table 1. The soils of the study area are alfisols based on the USDA (1975) classification. They are mantle of residue overlain by aeolian deposits (Aremu, 1980). The soil texture of the experimental site was predominantly loam. The physical properties of the site are given in Table 2.

Setup of Lysimeter

Ten sets of mini-lysimeters were assembled and used for this study. Each set of mini-lysimeter consisted of a plastic container of 50 cm diameter and 40 cm deep which serve as the lysimeter tank where the crop was planted, the weighing system, the runoff and the drainage systems. The weighing system consisted of a Vespa motorcycle tube filled with water and connected with a rubber hose to a manometer glass tube of 1.5 m long.

The manometer glass tube was fixed to a graduated pole in a vertical position so that water in the vehicular tube rose to a height in the manometer glass tube depending on the pressure exerted on it. The vehicular tube was placed on a wooden platform and the lysimeter tank was placed on the tube directly so the change in weight of the lysimeter tank due to inflow and outflow of water into the tank causes a displacement of the water level in the manometer glass tube.

The runoff system consisted of a plastic bucket of 28 cm diameter and 32 cm deep which serves as the collector. The runoff collector was connected with a rubber hose to an outlet fitting made on the top edge of the lysimeter tank. The collector was placed at a lower elevation so that the runoff water from the lysimeter tank flows by gravity into the collector. The runoff collector was covered with a lid to prevent rainwater from entering into it.

The drainage system consisted of a plastic bowl of 25 cm diameter and 15 cm deep which collects the drained water from the bottom of the lysimeter tank. The lysimeter tank was perforated at the bottom to allow for drainage of water beyond what the soil can hold.

Table 1: Average Monthly Weather Data for Samaru (July – Oct, 2010).

Month	Max. Temp (°C)	Mini. Temp (°C)	Max. Rel. Humidity (%)	Min. Rel. Humidity (%)	Sunshine Hours	Wind Speed (km/day)	Open Pan Evaporation (mm)
July	29.42	19.39	82.42	69.39	5.08	160.57	4.80
August	28.84	20.06	79.13	70.45	5.53	137.49	5.61
September	31.17	20.90	80.03	65.90	5.19	85.56	5.43
October	32.61	21.29	76.71	62.32	6.43	98.00	4.57

Table 2: Physical Properties of the Soil of the Experimental Field.

Oil Depth (cm)	Hydraulic Conductivity (cm/sec)	Bulk Density (g/cm^3)	Particle Size Distribution (%)			
			Clay	Silt	Sand	Textural Class
0-20	0.07	1.46	14	40	46	Loam
20-40	0.22	1.56	20	36	44	Loam
40-60	0.19	1.57	24	30	46	Loam
60-80	0.42	1.42	22	16	44	Sandy clay loam

An opening was made in the center of the platform upon which the tube rested, into which the drainage collector was fitted such that the collector was suspended above the ground surface. This was done to prevent rainwater or runoff from the surrounding from entering into it the drainage collector. Plate 1 shows a typical array of five sets of the mini-lysimeter.

Plate 1: Typical Setup of the Mini-Lysimeter.

Field Experimental Procedures

A field of 0.04 ha was divided two equal strips separated by a space of 2 m distance and was planted with maize and groundnut, respectively. Five sets of the mini-lysimeters serving as five replications of each experimental setup were installed in the midst of the maize and groundnut fields. The lysimeters were set up in an excavated pit at a depth such that the level of soil in the lysimeter tanks was at the same level with the soil surface in other for the cropped field and the lysimeters to be under the same micro environment. Gravel was poured on the floor of the pit to provide good footing for the platforms to prevent them from sinking due to the weight of the lysimeter. A drainage path was also made to allow water flow out of the pit when rain fell.

The lysimeters were filled with repacked soil from the top 30 cm depth of the experimental field. A fine wire mesh was placed at the bottom of each lysimeter container to prevent soil from blocking the perforated drainage holes. The five mini-lysimeters for each crop were arranged along the rows of the ridges in the field such that each unit was representing a ridge point with two plant stands. The cropped fields and the lysimeters were planted the same day. The maize field was planting on 15th July 2010 while the groundnut field was planted on 21st July. The cropped fields and the lysimeters were given the same agronomic attention which including weeding and fertilizer applications. Weeding was carried out thrice on the maize field and twice on the groundnut field. Compound fertilizers (N.P.K. 15:15:15) was applied at the rate of 60 kgN/ha as basal dose in the maize field at two weeks after germination and urea fertilizer was applied at 60 kgN/ha rate at six weeks after germination as topdressing to bring the quantity of nitrogen applied to 120 kg/N, as recommended by Institute for Agricultural Research, Samaru, Zaria for maize crop in the study area. No fertilizer was applied in the groundnut field. The growth of both crops in the field and the lysimeters were satisfactory. Plates 2 and 3 show the lysimeter setup in the groundnut and maize fields, respectively, at mid-season. The maize crop attained physiological maturity 85 days after planting while the groundnut took 100 days.

Plate 2: The Setup in the Groundnut Field.

Plate 3: The Setup in the Maize Field.

Determination of Crop Water Use from the Lysimeters

Each rainfall added water to the lysimeter tank. As a result, the pressure exerted on the tubes due to increase in weight of the lysimeter tank caused a rise in the water level in the manometer glass tube. Excess water beyond what could infiltrate into the soil in the container went into the runoff collector while water beyond what the soil could hold drained by gravity through the bottom of the lysimeter tank into the drainage collector. A rain gauge was installed on the field to measure daily rainfall depth.

As evaporation took place and the crop used water for its metabolic activity on daily basis, the weight of the lysimeter tank and consequently the level of water in the manometer glass tube decreased. The levels of water in the manometer glass tubes were monitored 24 hourly throughout the crop growing season between 7:00 and 8:00 am. The runoff and drainage collectors were also inspected daily, and the depths of water found in them were also noted. The difference in weight of the lysimeter tank between two consecutive measurements indicated by the difference in the level of water in the manometer glass tube was as a result of the water added from rainfall, crop water use (evapotranspiration), water drained or runoff. When there is no rainfall, runoff or drainage, the difference in weight would be due to crop water use. The weight of the lysimeter tank on any given day was determined from the level of water in the manometer glass tube using a relationship early developed in the laboratory between height of water in the manometer glass and known weight packed into the lysimeter tank. The relationship was obtained as:

$$W = 0.468 * H + 1.029 \quad \textbf{(1)}$$

$(r^2 = 0.998)$

where, W is weight of lysimeter in kg and H is height of water in the manometer glass tube in cm.

The differences in weight of the lysimeter tank thus obtained on daily basis were translated to depth of water in mm/day using a factor of 6.04. This factor was based on the surface area of the lysimeter tank and the density of water. When rainfall, drainage or runoff events occurred, their depths were first subtracted from the change in weight of the lysimeter tank, and the reminder was the crop water use. The expression used for the computation of daily crop water use is given as:

$$CU_i = P_i - R_{fi} - D_i - [(W_{i+1} - W_i) * cf] \qquad (2)$$

where,
P_i = Rainfall amount (mm) of day *i* collected in the rain gauge
R_{fi} = Runoff (mm) of day *i*.
D_i = Drainage (mm) of day *i*.
W_i = Weight of the lysimeter soil on day *i*.
W_{i+1} = Weight of the lysimeter soil the next day at an interval of 24 hours.
CU_i = Crop water use of day i
cf = A factor converting weight to equivalent depth of water

Estimation of Weather-Crop Coefficient Data Based Crop Water Use

The crop water use based on weather-crop coefficient data was referred to as potential crop water use in this study. This was the expected water use by the crops under field condition if all developmental factors are adequate. Weather data for daily maximum and minimum temperatures, relative humidity, sunshine hours and wind speed were obtained from the Institute for Agricultural Research Meteorological Station Samaru, and were used to compute daily reference evapotranspiration (ET_o) using the FAO-Penman Monteith model (Allen et al., 1998). The potential crop water use was estimated using the expression given as:

$$ET_c = K_c * ET_o \qquad (3)$$

where, ETc is potential crop water use; ETo is reference evapotranspiration, and Kc is crop coefficient.

Crop coefficient (K_c) values of 0.5, 0.8, 1.2, and 0.6 were taken for initial, developing, mid-season and late season, respectively for the maize crop. These values were similar to the average values used by Ayana (2011) and Tekwa and Bwade (2011) for the same maize growth periods, and similar to the FAO crop coefficients (Allen et al., 1998) for maize crop. The crop coefficient values used for the groundnut crop were also taken as 0.5, 0.8, 1.15, and 0.6 for the initial, developing, mid-season, and late season, respectively. The values are similar to the FAO crop coefficients (Allen et al., 1998) of groundnut for the growth period.

RESULTS AND DISCUSSIONS

Rainfall, Runoff, and Drainage Depths

Figures 1 and 2 show the depths of rainfall, runoff and drainage from the maize and groundnut lysimeters, respectively. A total of 39 and 37 rainfall events were recorded in the maize and groundnut fields, respectively. The rainfall depths varied from 0.3 to 90 mm. The peak rainfall amount was experienced in August as it is the characteristics of rainfall in the study location. The seasonal rainfall depths in the maize and groundnut fields were 533.4 and 518.3 mm, respectively. The difference was simply due to planting dates and dates of start and end of data collection for the two crops.

The runoff and drainage depths varied from 0.5 to 66.4 mm and 0.1 to 26.4 mm, respectively. However, the seasonal runoff from the maize and groundnut lysimeters was 117.9 mm and 148.1 mm, respectively, while the seasonal drainage from the maize and groundnut lysimeters were 132.1 mm and 136.9 mm, respectively. The seasonal runoff and drainage from the maize lysimeters was about 22% and 25%, respectively of the total rainfall, while the seasonal runoff and drainage from the groundnut lysimeters was 28.9% and 26.5% of the total rainfall recorded.

Daily Crop Water Use

Figure 3 and 4 show the trend of the daily crop water use of the maize and groundnut crops during the growing season. The daily crop water use of the maize crop varied from 0.5 to 9.4 mm/day with a seasonal average of 4.8 mm/day. The water use of the groundnut crop also varied from 0.7 to 9.5 mm/day with a seasonal average of 3.8 mm/day. There was no definite pattern for the daily crop water use with respect to crop age as the values kept rising and falling throughout the crop growing season. This is typical of daily evaporation during the rainy season as higher evaporation does happen on very sunny and cloudless days and lower evaporation on cloudy and rainy days. However, the pattern of crop water use with respect to crop age was better observed considering the weekly average crop water use.

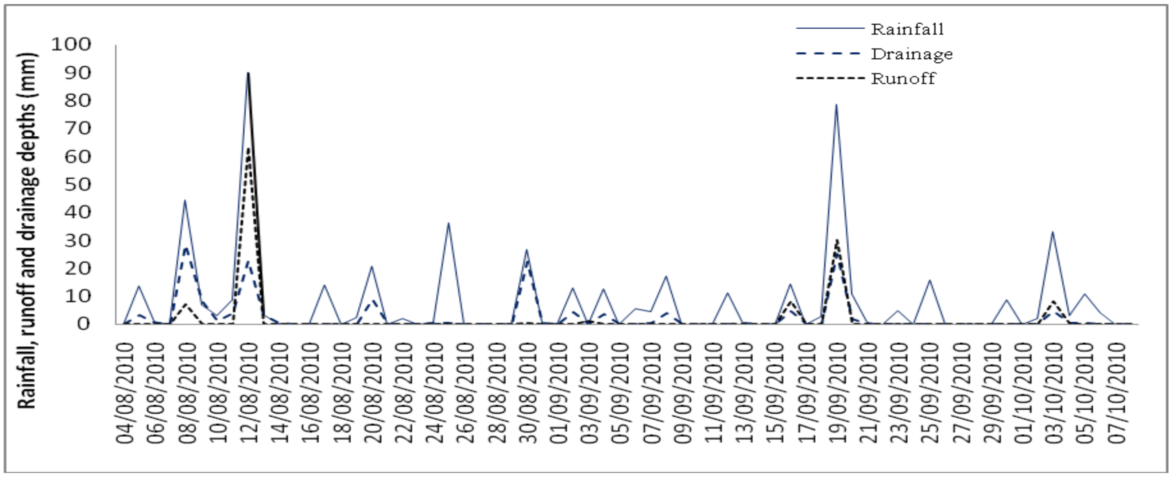

Figure 1: Rainfall, Drainage, and Runoff Depths from the Maize Lysimeter Setup.

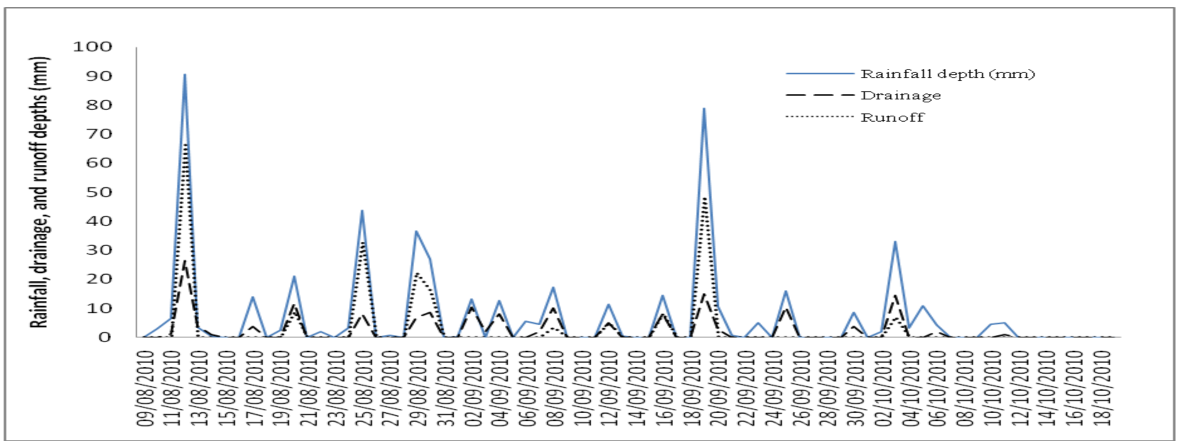

Figure 2: Rainfall, Drainage, and Runoff Depths from the Groundnut Lysimeter Setup.

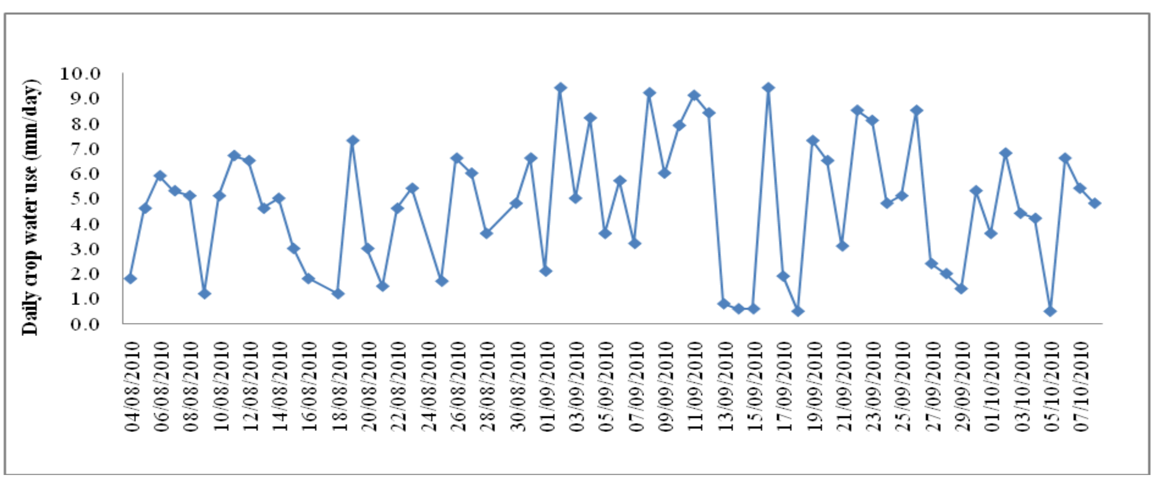

Figure 3: Daily Crop Water Use of the Maize Crop.

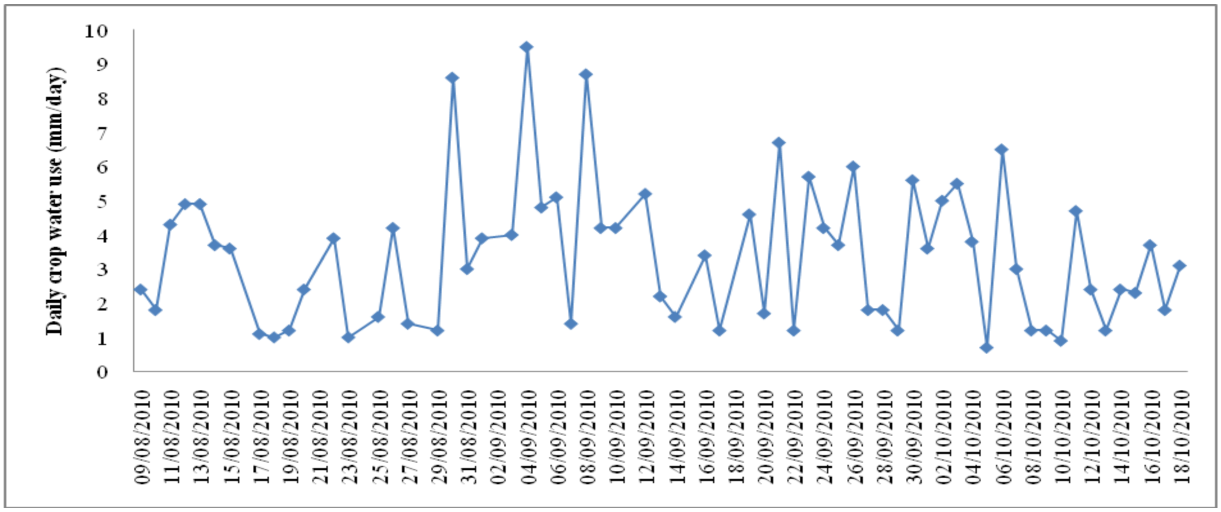

Figure 4: Daily Crop Water Use of the Groundnut Crop.

Weekly Average Crop Water Use

Tables 3 and 4 show the weekly total and weekly average water use for the maize and groundnut crops, respectively. The weekly average water use of the maize crop increased from 2.7 mm/day at the early crop growth stages to 6.0 mm/day at mid-season and then declined to 3.30 mm/day at the end of the season. This trend agrees with the characteristic pattern of water use of crops. The weekly average water use for the groundnut crop also increased from 2.66 mm/day at the early growth stage of the crop to 4.83 mm/day at the mid-season and then declined to about 2.70 mm/day at the end of the season. The seasonal water use for the maize and groundnut crop was 283.3 mm and 228.9 mm, being 53.1% and 45 % of the seasonal rainfall, respectively.

Table 3: Weekly Total and Average Daily Water Use (CU) of the Maize Crop.

Days after planting (DAP)	Weekly CU (mm)	Average daily CU (mm/day)
20 – 26	18.90	2.70
27 – 33	27.70	4.00
34 – 40	22.20	3.20
41 – 47	29.40	4.20
48 – 54	37.20	5.30
55 – 61	41.00	6.00
62 – 68	29.30	4.20
69 – 74	39.40	5.60
75 – 85	33.20	3.30

Table 4: Weekly Total and Average Daily Water Use (CU) of the Groundnut Crop.

Days after planting (DAP)	Weekly CU (mm)	Average daily CU (mm/day)
24 – 30	18.6	2.66
31 – 37	22.2	3.20
38 – 44	20.2	2.89
45 – 51	33.8	4.83
52 – 58	30.8	4.40
59 – 65	12.0	2.40
66 – 72	28.2	4.03
73 – 79	24.2	3.50
80 – 86	17.3	2.47
87 – 97	21.6	2.70

Comparisons of Estimated and Potential Crop Water Use

Tables 5 and 6 show the weekly potential crop water use (ET_c) and the crop water use estimated using the mini-lysimeters (CU) for the maize and groundnut crop, respectively. The CU compared closely with ETc for both crops with mean differences of 2.75 and 3.15 mm/week for the maize and groundnut crops, respectively. The mean differences were not statistically significantly different at the 0.05 level of significance, which implies that the mini-lysimeters effectively estimated the crop water use of the crops.

Table 5: Estimated Potential and Lysimeter-Based Water Use of the Maize Crop.

Day after planting	ETo	ETc	CU
20 – 26	34.47	17.2	18.9
27 – 33	35.06	28.0	27.7
34 – 40	32.17	25.7	22.2
41 – 47	31.75	38.1	29.4
48 – 54	30.46	36.6	37.2
55 – 61	34.25	41.1	41
62 – 68	33.53	40.2	29.3
69 – 74	37.56	45.1	39.4
75 – 85	51.57	30.9	33.2
Total	**320.8**	**303.0**	**278.3**

Table 6: Estimated Potential and Lysimeter Water Use of the Maize Crop.

DAP	ETo	ETc	CU
24-30	33.68	16.84	18.6
31-37	22.89	18.31	22.2
38-44	21.93	17.54	20.2
45-51	37.14	42.71	33.8
52-58	31.3	36.00	30.8
59-65	21.82	25.09	12.0
66-72	30.32	34.87	28.2
73-79	29.16	26.24	24.2
80-86	24.37	15.84	17.3
87-97	25.41	16.52	21.6
Total	278.02	257.254	228.9

CONCLUSION

Water use of rain-fed maize and groundnut crops were estimated using mini-lysimeters. The average daily water use of obtained compared very closely with potential crop water use estimated based on weather-crop coefficient data, which implies that the mini-lysimeters setup for the study were quite effective. This technique grants easy opportunity to estimate crop water use and other components of the soil water balance under rainfall condition.

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REFERENCES

1. Aremu, J.A. 1980. “Effect of Different Cultivation Techniques on Infiltration”. M.Sc. Thesis. Department of Soil Science, Postgraduate School of the Ahmadu Bello University: Zaria, Nigeria.

2. Ayana, M. 2011. “Deficit Irrigation Practices as Alternative Means of Improving Water Use Efficiencies in Irrigated Agriculture: Case Study of Maize Crop at Arba Minch, Ethiopia”. *African Journal of Agricultural Research*. 6(2):226-235.

3. Clark, G.A., D.L. Reddel, R.F, Adams, and J.C. McDurnie. 1984. “Evolution of Mini-Lysimeters for Deficit Irrigation Studies”. *ASAE.* Technical paper, 84 – 2621.

4. Clark, G.A., E.E. Albergts, C.D. Stanley, A.G. Smajstrala, and F.S. Zazueta. 1996. “Water Requirements and Crop Coefficients of Drip-Irrigated Strawberry Plants”. *Transactions of ASAE*. 39(3):905-913.

5. Durgas, W.A and W.L. Bland. 1989. “The Accuracy of Evaporation Measures from Small Lysimeters”. *Agric Forest Meteorology*. 46:109-119.

6. Garcia, M., O. Raes, R.G. Allen, and C. Herbas. 2004. “Dynamics of Reference Evapotranspiration in the Bolivian Highlands”. *Agricultural Forest Meteorology*. 125:67 - 82.

7. Haman, D.Z., R.T. Pritchard, A.G. Smajstrla, F.S. Zazueta, and P. M. Lyrene. 1997. “Evapotranspiration and Crop Coefficients for Young Blueberries in Florida”. *Applied Engineering in Agriculture*. 13(2):209-216.

8. Isard, S.A. and M.J. Belding. 1989. “Evapotranspiration from the Alpine Tundra of Colorado, USA”. *Arctic Alpine Res*. 21:71-82.

9. Lie, T., J. Xiao, G. Li, Y. Yu, Z. Liu, and J. Wang. 2003. “Estimating Crop Coefficients of Drip Irrigated Watermelons and Honeydew Melons from Pan Evaporation”. ASAE Paper No.032247. ASAE: St. Joseph, MI.

10. Malone, R.W., J.V. Bonta, D.J. Stewardson, and T. Nelsen. 2000. “Error Analysis and Quality Improvement of the Cosheton Weighing Lysimeters”. *Trans ASAE.* 31:477-484.

11. Rosental, W.R., G.F Arkin, and P.J. Shouse. 1985. “Water Deficit Effects on Sorghum Transpiration”. *National Conference on Advances in Evapotranspiration*. ASAE: St. Joseph, MI. 159-169.

12. Simon, C.M., E.I. Ekwue, F.A. Gumbs, and C.V. Narayan. 1998. “Evapotranspiration and Crop

Coefficients of Irrigated Maize (Zea mays L.) in Trinidad". *Tropical Agriculture*. 75(3):342-346.

13. Tekwa, I.J. and E.K. Bwade. 2011. "Requirement of Maize (*Zea mays*) using Pan Evaporation Mdel in Maiduguri, Northeastern Nigeria". *Agricultural Engineering International. The CIGR E-Journal*. Manuscript No. 1552. 13(1):7.

14. United States Department of Agriculture (USDA). 1975. "Soil Taxonomy: A Basic System of Soil Classification for Making and Interpreting Soil Surveys". USDA: Washington, D.C.

15. Uzonwa, T.C. 1991. "The Lysimeter Determination of Consumptive Use of Wheat". A final year project report submitted to the Department of Agricultural Engineering Technology, Federal Polytechnic: Bauchi, Nigeria.

16. Wight, J.R., C.L. Hanson, and K.R Cooley. 1986. "Modeling Evapotranspiration from Sagebush-Grass Rangeland". *Journal of Ranging Manage*. 39:81 -85.

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