DETERMINATION OF CROP WATER USE FOR VEGETABLES IN SOUTHWESTERN NIGERIA USING LYSIMETER

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ABSTARCT

This study described the design and construction of low cost weighing lysimeter and also investigates the performance evaluation of the lysimeter by determining the crop water requirement of Jute mallow (*Corchorus olitorius*), Lagos spinach (*Celosia argentea*) and Leafy amaranth (*Amarathus cruentus*) vegetables production. This lysimeter was constructed by readily available materials like plastic container which serve as lysimeter tank and inner tyre tubes filled with water connected to a glass U- tube manometer for the weighing system. The daily displacement of water in the glass U- tube manometer due to change in weight of lysimeter as were translated to crop water use. The results showed that the average daily water use of the Lagos Spinach increased from 0.16 mm/day at the early crop growth stages to 5.23 mm/day at mid-season and declined to 1.08 mm/day at the late season of the crop. The leafy Amaranths shows that the average daily water use increase from 0.13mm/day at the early growth stage of the crop to 4.96 mm/day during the mid-season and declined to about 1.60 mm/day at the late season. While Jute mallow shows that average daily water use increased from 0.11mm/day at the early growth stage of the crop to 4.44 mm/day during the mid-season and declined to 1.67 mm/day at the late season. The potential crop water use estimated for all the vegetables showed that the weighing lysimeter is effective and results obtained can be used as a guide by farmers for selecting the amount and frequency of water to be used for the vegetables

Keyword: Cost, Season, Weighing Lysimeter, Crop water Use, Vegetables.

INTRODUCTION

Vegetable production can be adopted as a strategy for improving livelihood and alleviating the nutritional status of the people. It offers a significant opportunity for the poor people in southwestern Nigeria to earn a living because vegetables production can be done with little capital investment. It is also the answer to the perpetual problems of hunger and malnutrition in the country. Adebooye *et al.* (2003) reported an expanded list of twenty-four indigenous leaf vegetables that are eaten in southwest Nigeria only. There is only scattered information concerning water management of indigenous leafy vegetables. For proper irrigation scheduling and high level agricultural production, a precise knowledge of crop water use under field conditions is required. 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 (Igbadun, 2012). All measurement of crop water use depends on knowledge of the soil water balance from which crop evapotranspiration (ET_c) is calculated:

$$ET_c = P + I - R - F - \Delta S \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (1)$$

Where P is precipitation depth, I is irrigation depth, R is the depth of runoff, F is the depth of water lost to deep percolation below the root zone or gained by upward flow from a shallow aquifer or deeper soil horizons and ΔS is the change in the depth of water stored in the soil due to crop water use, irrigation, precipitation, runoff and /or deep percolation with all terms (often mm) per unit time.

However measurements of rainfall and irrigation depths are possible with rain gauges and water metres, it is difficult to measure the change in storages of soil water or loss of water to deep percolation. These two measurements can be made very accurately with a weighing lysimeter because the soil container prevents loss of water to deep percolation and gain of water from a shallow aquifer or lateral water movement because most runoff is prevented by the edge of the box, which is higher than the surrounding soil surface. Weighing lysimeters are potentially the most accurate way to determine crop water use; and many different designs and weighing mechanisms have been used (Howell *et al.*, 1991). The evaluation of lysimeter data allows a much more reliable calculation of the solute load carried towards the groundwater than any other method. If the lysimeters weight is recorded in certain time steps, precipitation and seepage water amount is measured separately, actual evapotranspiration can be deduced from their weight change (Young *et al.*, 1997). 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). Water need of plants in lysimetric experiments is supplied by natural rain, irrigation or by an artificially maintained water table. Therefore, this study described the design and construction of low cost weighing lysimeter and was used to determine the crop water use of vegetables. However, the lysimeter create less disturbance to the environment of inters during installation and easy to install with minimal technical and financial effort.

MATERIALS AND METHODS

Description of Study location

The field experiment was carried out during rainy and dry season in the experimental field of Department of Agricultural and Environmental Engineering, Obafemi Awolowo University, Ile-Ife, Nigeria. The experimental plot was located on longitude 4.50^0E and latitude 7.50^0N, it has elevation of about 281 meters above the mean sea level using. The study area experiences bimodal rainfall, the peak of the rainfall occurs in August to September, and the dry season is at the peak between March to April each year with slight irregularity in the rainfall distribution yearly. Ile –Ife is described as humid tropical environment with mean annual rainfall of about 1400mm while the mean temperature ranges between 28^0C to 34^0C. Relative humidity is about 75.8% to 86% for dry and wet seasons respectively (Orimoogunje, 2005).

Lysimeter construction

The design criteria for the weighing type lysimeter developed in this research are that they can be able to continuously monitor evapotranspiration at the resolution of 12 hours and they can be easily and rapidly deployed, redeployable (i.e. portable), economical to construct and install with a modification to Igbadun; (2012). In order to minimize surface disturbance during operation owing to the lysimeter hardware, circular containers with minimum wall thickness for holding the soil are desired. Nine (9) sets of weighing lysimeter were constructed for the purpose of this research. Each lysimeter consist of lysimeter tank, the weighing system and the runoff system as shown in Fig 1. The plastic container that serves as lysimeter tank is circular in shape and has dimension of 21-cm depth with top and bottom diameter of 44-cm and 25.5-cm respectively. The 21-cm depth was considered adequate to grow vegetables without significantly restricting normal root development and soil water extraction. Monitoring of the mass of the lysimeter tank is done by placing the lysimeter tank on inflated tyre tube filled with that is connected to U - tube manometer which serves as weighing system. The weighing system has dimension of 5-cm tall and 30-cm diameter. Rubber hose of 0.8-cm diameter was connected to the inflated tyre tube with 0.6-cm diameter valve at one end and the other end of rubber hose connected to a U-tube glass manometer of 1.5-cm long. The U – tube glass manometer was fixed to a graduated pole of 71.5-cm length , the pole was attached with the wooden platform that have stand , the pressure exerted on the inflated tyre tube forced the water in it to rise to a height in the U- tube glass manometer. The change in the water level in the manometer glass tube was related to changes in weight of the lysimeter tank. The weighing system measure the weight lost resulting from vegetables ET and weight gain resulting from precipitation and irrigation. The difference in the water level in the manometer glass tube before and after the evapotranspiration a seen shows the amount of water been used by each vegetables. At the height of 16-cm in the lysimeter tank, an outlet fitting was made and 2-cm diameter rubber hose connect the lysimeter tank to the plastic bucket which serve as runoff collector as shown Fig 1. The runoff system consisted of a plastic bucket of 29-cm diameter and 27-cm deep which serves as the runoff collector. The collector was placed at a lower elevation so that the runoff water from the lysimeter tank flows by gravity into the collector. For this application the bottoms of the low cost lysimeter constructed were sealed forcing drainage to zero i.e. that is no drainage system.

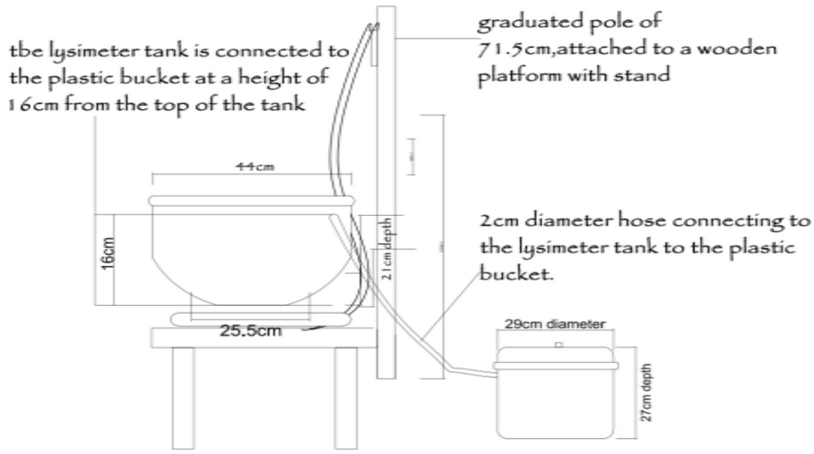

Figure 1: Typical Side View of Lysimeter

Calibration and Testing

The weighing system of the weighing lysimeter constructed was calibrated for its range, stability, repeatability and sensitivity according to Marek *et al.* (1988). Figure 3 shows the relationship between the weight of the lysimeter tank and corresponding water height in the manometer U-tube. The minimal range of mass used in the calibration was determined from the expected maximal mass change during the irrigation or precipitation season with assumption that farmer would not allow the soil in the root zone to dry by more than 50% of available water holding capacity. There was a strong linear relationship between the weight of the lysimeter tank and the corresponding value of water in the U – tube manometer. The coefficient of determination (R^2) between added weight of the lysimeter tank and corresponding value of the height of water in the manometer in the calibration result was very high (≥ 0.98). This indicates that the setup is reliable.

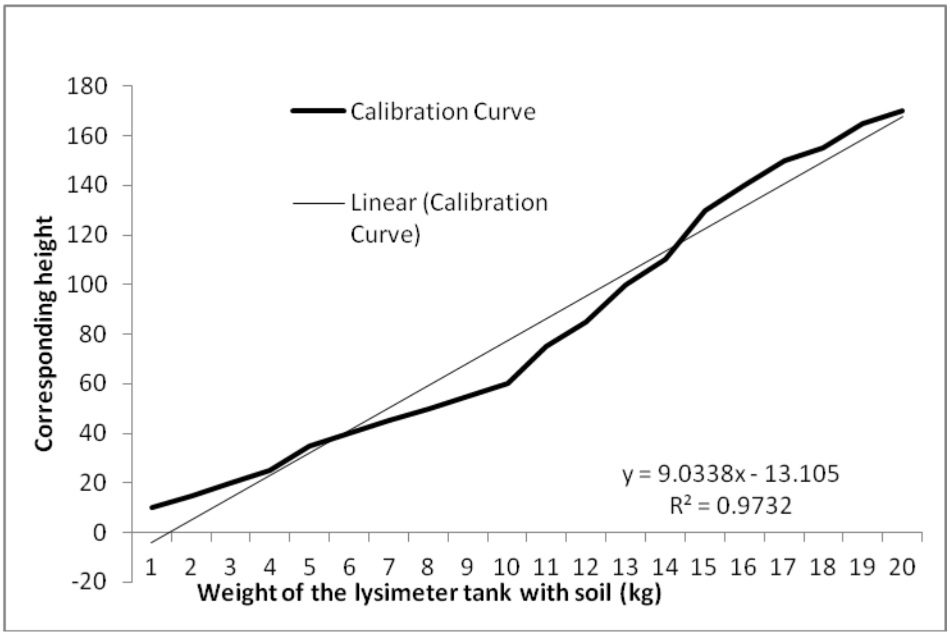

Figure 2: Calibration curve of the experimental setup

Field Experimental Procedures

Nine (9) sets of weighing lysimeter constructed which serve as three (3) replications for each experimental setup for each vegetable were assembled at experimental field. The lysimeters were assembled in 50 m x 10 m field and maintained vertically in a free floating position and separated by a space of 4 m distance between each lysimeter set as shown in Plate 1. The assembled lysimeters caused no disturbance to the environment and the soil structure inside the lysimeter is same to that of the surrounding area. Also, rain gauge was also installed at the study site to measure the amount of rainfall everyday throughout the planting period. The following vegetables were planted in the lysimeter: Jute mallow (*Corchorus olitorius*), Lagos spinach (*Celosia argentea*) and Leafy amaranth (*Amarathus cruentus*) based on their economic and nutritional roles.

Plate 1: Typical Setup of the Weighing Type Lysimeter.

Each lysimeter consist of a plastic container of 44 cm surface diameter and 21 cm depth which serve as lysimeter tank where the vegetables were planted, the weighing system and the runoff system. The levels of water in the manometer glass tubes were monitored every 12 hours throughout the crop growing season. Excess water that cannot infiltrate into the soil inside the lysimeter tank during the rainy season will go into the runoff collector. The selected vegetables were planted inside the lysimeter tank on the same day during rainy season and also during dry season and no manure or fertilizers were added.

Determination of Crop Water Use from the Lysimeter

Three (3) weighing type lysimeter set for each vegetables as shown in Plates 2, 3 and 4 for Lagos spinach (*Celosia argentea*), Leafy amaranth (*Amarathus cruentus*) and Jute mallow (*Corchorus olitorius*) respectively were used. All the vegetables were planted on the same day (11/8/2013 – 17/9/2013 and 04/03/2014 – 24/04/2014) and they were all exposed to the same environmental conditions, there was no fertilizer application. The weight of the lysimeter tank on any given day was determined by the level of water in the manometer tube using a relationship early determined from calibration curve between the height of water in the manometer glass tube and known weight soil packed into the lysimeter tank.

The relationship was obtained as:

$$W = 0.111 * H + 1.450 \quad (R^2 = 0.973) \ldots\ldots\ldots 2$$

Where; W = Weight of lysimeter (kg) H = Corresponding height of water in the manometer glass tube.

Plate 2: Lysimeter Setup for Lagos Spinach (*Celosia argentea*)

Plate 3: Lysimeter Setup for Leafy Amaranth (*Amarathus cruentus*)

Plate 4: Lysimeter Setup for Jute Mallow (*Corchorus olitorius)*

As water was added to each lysimeter tank through rain or irrigation, the pressure exerted on the tyre tubes due to increase in weight of the lysimeter tank causes a rise in the water level in the manometer glass tube. Excess water beyond that could not infiltrate into the soil in the lysimeter tank will go into the runoff collector. As evaporation took place and the crop used water for its metabolic activity on daily basis, the weight of the lysimeter tank reduced and consequently the level of water in the manometer glass tube decreased. The weight of the lysimeter tank on any given day will be determined from the level of water in the manometer glass tube using a relationship between height of water in the manometer glass and known weight packed into the lysimeter tank. Weight changes, in kilogram, were converted to an equivalent depth of water, in millimeter, by dividing the weight change by the density of water (g/cm^3) and the surface area of the inner tank (m^2). The weight of the lysimeter tank obtained using Equation (2) and their difference was translated to the depth of water in mm/day using a factor of 2.89 which was based on the surface area of the lysimeter tank and the density of water. Equation 3 was used for the computation of daily crop water use:

$$CU_i = P_i - Rf_i - ((W_{i+1} - W_i) * cf \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..3$$

Where;

P_i = Irrigation amount (mm) of day i collected in the rain gauge

Rf_i = Runoff (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

RESULTS AND DISCUSSION

Rainfall and Runoff Depth

The precipitation which is mainly in form of rainfall ranged between 3.4 mm and 24.5 mm as shown in Figure 3 during the planting period (11th Aug – 17th Sept), it is not only the total amount of rainfall that matters; but how effective the rain is in terms of its time of occurrence, spread, intensity, frequency, and availability as soil moisture (Adefolalu, 1988). A total of 13 rainfall events were recorded for all the selected vegetables planted and the peak rainfall occurred on August 29th. There is no difference in depth of rainfall experience at the site where all the selected vegetables were planted because all the vegetables were planted at the same location and on the same day. The depths of rainfall and runoff from the leafy amaranth (*Amaranth cruentus*), Lagos Spinach (*Celosia argentea)* and Jute mallow (*Corchorus olitorius*) lysimeter setup are shown in Figure 3. The runoff depth varied from 0.6 to 7.2 mm for leafy amaranth (*Amaranth cruentus*), 0.6 to 6.6 mm for Lagos Spinach (*Celosia argentea)* and 0.6 to 5.7 mm for Jute mallow (*Corchorus olitorius*) lysimeters setup respectively. Lagos Spinach (*Celosia argentea)* and Jute mallow (*Corchorus olitorius*) lysimeters setup were 14.2%, 12.6% and 14.4% respectively of the total rainfall recorded.

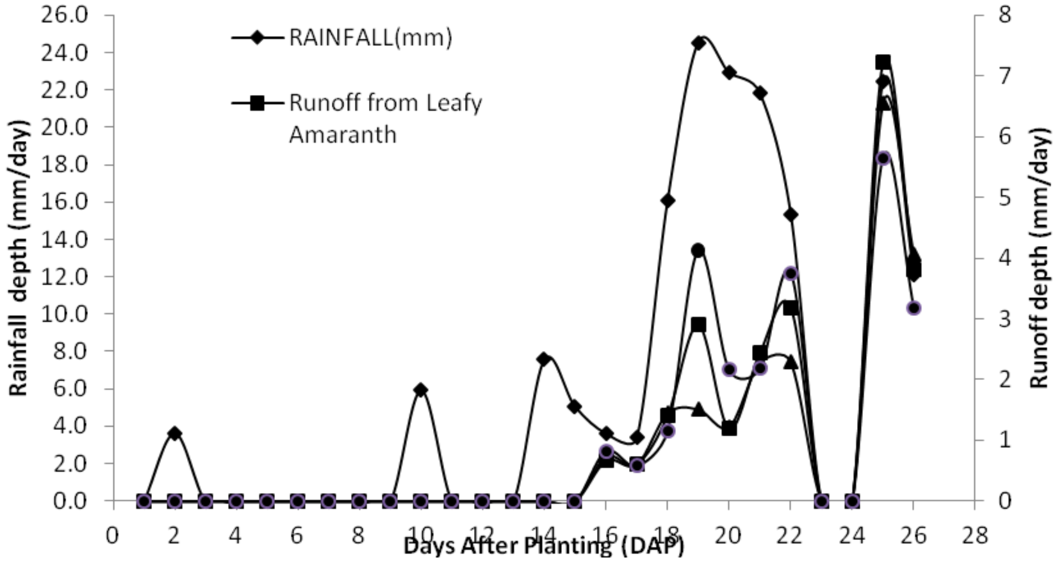

Figure 3: Rainfall and Runoff Depths from all the Vegetables Lysimeter Setup

Daily Crop Water Use during Rainy Season

Figure 4 shows the trend of daily crop water use of leafy amaranth (*Amaranth cruentus*), Lagos Spinach (*Celosia argentea*) and Jute mallow (*Corchorus olitorius*) respectively. The daily crops water use for Leafy Amaranth (Amarathus cruentus) lysimeter setup varied from 0.64 to 9.60 mm/day, Lagos Spinach (*Celosia argentea*) also varied from 0.75 to 9.22 mm/day and daily water use for Jute mallow (*Corchorus olitorius*) varied from 0.51 to 8.57 mm/day. It was observed that there was definite pattern for the daily crop water use with respect to crop age as the values kept risen from the initial season period and falling towards the end of season. This is typical 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. This is typical daily evaporation during the rainy season according to FAO (2005).

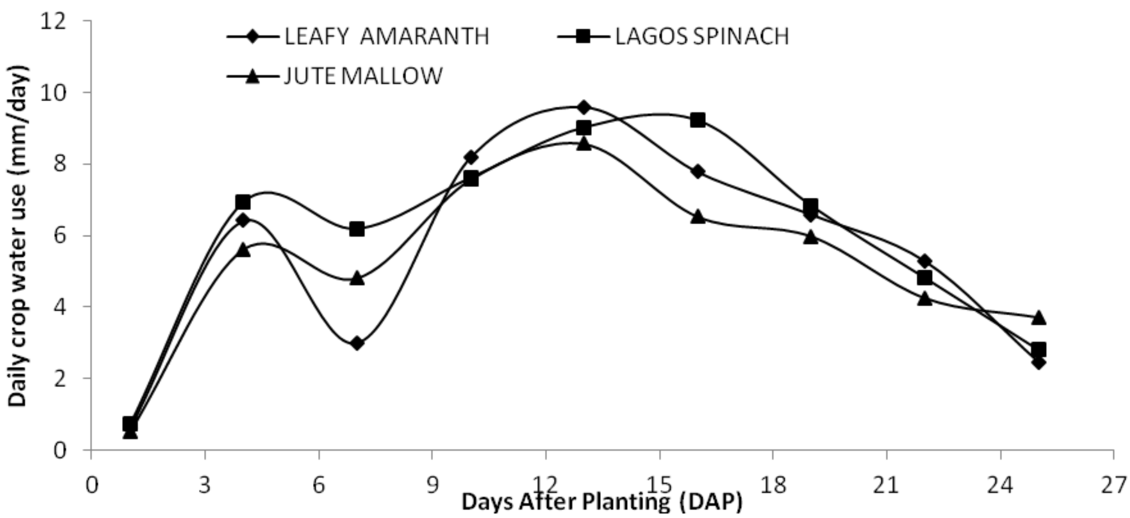

Figure 4: Daily Crop Water Use of Leafy Amaranth, Lagos Spinach and Jute Mallow during Rainy season

Daily Crop Water Use during Dry Season

The trend of daily crop water use of leafy amaranth (*Amaranth cruentus*), Lagos Spinach (*Celosia argentea*) and Jute mallow (*Corchorus olitorius*) respectively during dry season were shown on Figure 5. The daily crops water use for Leafy Amaranth (Amarathus cruentus) lysimeter setup varied from 0.78 to 9.28 mm/day, Lagos Spinach (*Celosia argentea*) also varied from 0.9 to 9.79 mm day and daily water use for Jute mallow (*Corchorus olitorius*) varied from 0.07 to 9.78 mm/day. It was observed that there was definite pattern for the daily crop water use with respect to crop age as the values kept risen from the initial season period and falling towards the end of season.

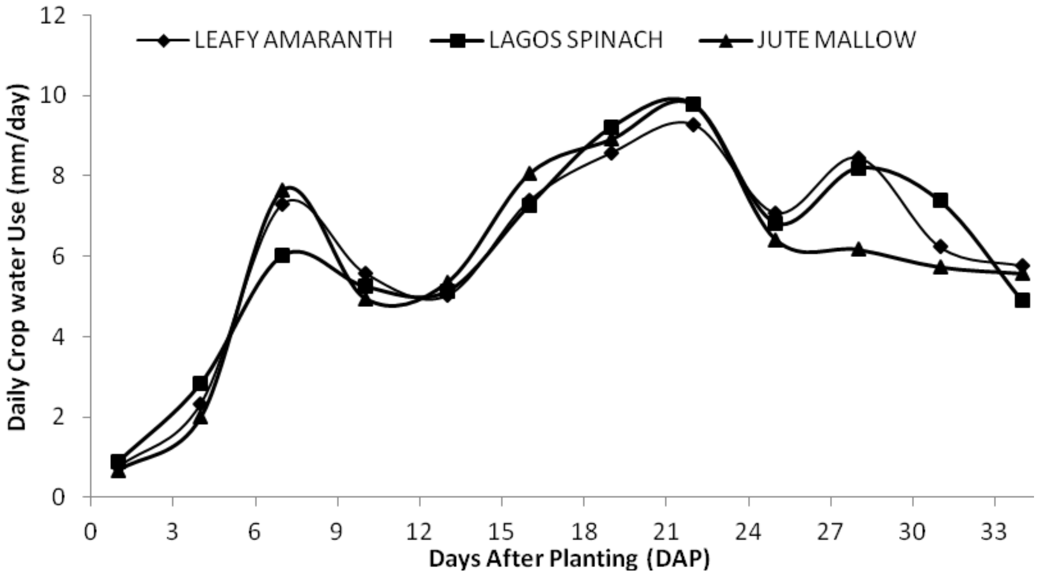

Figure 5: Daily Crop Water Use of Leafy Amaranth, Lagos Spinach and Jute Mallow during Dry season

Comparison of Estimated and Potential Crop Water Use (Dry Season)

Table 2, 3 and 4 show weekly potential crop water use (ET_C) and estimated crop water use using lysimeter for Jute Mallow, Lagos spinach and Leafy Amaranth respectively during Dry season. The CU compared closely with ET_C for all vegetables with mean difference of 0.25 and 2.82 mm/week for the Jute Mallow, Lagos spinach and Leafy Amaranth respectively. The mean difference were not statistically significantly different at the 0.05 level of significance, which implies that the weighing lysimeters is effectively estimated the crop water use of the vegetables.

Table 2**:** Estimation of Potential and Lysimeter Based Water Use for Jute Mallow during Dry Season

DAP	**ET_O**	**ET_C**	**CU**
1 -7	16.38	9.1	**10.33**
8 - 14	23.57	18.11	**18.36**
15 - 21	28.42	25.41	**25.12**
22 - 28	20.65	15.96	**17.47**

Table 3: Estimation of Potential and Lysimeter Based Water Use for Lagos Spinach during Dry Season

DAP	**ET_O**	**ET_C**	**CU**
1 -7	16.38	9.1	**9.78**
8 - 14	25.85	17.27	**17.66**
15 - 21	28.58	23.02	**25.84**
22 - 28	29.17	22.32	**2048**

Table 4: Estimation of Potential and Lysimeter Based Water Use for Amaranth during Dry Season

DAP	**ET_O**	**ET_C**	**CU**
1 -7	16.38	9.1	**10.43**
8 - 14	26.69	18.11	**18.01**
15 - 21	30.76	25.41	**24.94**
22 - 28	20.22	24.24	**20.45**

Comparison of Estimated and Potential Crop Water Use (Dry Season)

Table 5, 6 and 7 show weekly potential crop water use (ET_C) and estimated crop water use using lysimeter for Jute Mallow, Lagos spinach and Leafy Amaranth respectively during Rainy season. The CU compared closely with ET_C for all vegetables with mean difference of 0.88and 2.13 mm/week for the Jute Mallow, Lagos spinach and Leafy Amaranth respectively. The mean difference were not statistically significantly different at the 0.05 level of significance, which implies that the weighing lysimeters is effectively estimated the crop water use of the vegetables

Table 5: Estimation of Potential and Lysimeter Based Water Use for Jute Mallow during Rainy Season

DAP	**ET_O**	**ET_C**	**CU**
1 -7	11.13	11.13	**10.94**
8 - 14	19.25	16.59	**12.51**
15 - 21	23.31	11.27	**12.51**
22 - 28	11.83	8.45	**7.76**

Table 6**:** Estimation of Potential and Lysimeter Based Water Use for Lagos Spinach during Rainy Season

DAP	ET_O	ET_C	CU
1 -7	13.02	13.02	**13.9**
8 - 14	15.54	14.53	**16.66**
15 - 21	16.59	14.92	**16.05**
22 - 28	16.52	8.35	**7.63**

Table 7**:** Estimation of Potential and Lysimeter Based Water Use for Leafy Amaranth during Rainy Season

DAP	ET_O mm/day	ET_C	CU
1 -7	13.09	13.09	**10.43**
8 - 14	15.96	16.72	**18.01**
15 - 21	17.99	25.95	**24.94**
22 - 28	17.29	18.45	**20.45**

CONCLUSION

The study has demonstrated the use of weighing lysimeter that are economically constructed with readily available materials to estimate the crop water use for Jute mallow (*Corchorus olitorius*), Lagos Spinach (*Celosia argentea*) and Leafy Amaranths (*Amaranthus cruentus*). The lysimeter performance is close to expected resolution and accuracy and is entirely adequate for the intended crop water use research. The growth pattern within the lysimeter tank was observed to be similar to those within the field. Potential crop water use estimated compared with daily water use for all selected vegetables implies that the weighing lysimeter setup for the study were quite effective and the system will grants easy opportunity to estimate crop water use.

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