Determination of Crop Coefficient and Water Use of SUWAN-1-SR with a Mini Lysimeter in Ibadan, Nigeria

*1Adebayo O. Oke, 1Olayinka A. Omotosho, and 2Kolawole Ogedengbe

1Institute of Agricultural Research and Training, Obafemi Awolowo University, Moor plantation, Ibadan, Nigeria
2Agricultural and Environmental Engineering Department, Faculty of Technology, University of Ibadan, Ibadan, Nigeria

{bayooke14101akintoshforever}@gmail.com | kolaogedengbe@yahoo.com

Abstract - Accurate irrigation planning requires basic information about the soil, environment and the water requirements of the crop to be cultivated. With new variety of a crop comes the physiological characteristics that may be somewhat different from known varieties. Crop Water Requirement (CWR) and Crop Coefficient (Kc) are major factors required in irrigation planning and they vary with crop developmental stages. Four non-weighing lysimeters (Diameter, 60cm and Depth, 50cm) were used to determine CWR, Kc as well as crop performances under specific conditions. The CWR and Kc of Maize variety (SUWAN-1-SR) were determined across the four developmental stages (Initial, Development, Mid and Late) using the lysimeter system. The CWR were 58.8, 176.8, 206.0, 59.6 mm and Kc were 1.0, 1.6, 1.4, 0.7 for the respective stages. In comparison with FAO 56 maize Kc and CWR values, SUWAN-1-SR requires more water across the developmental stages and a sum of 501.2mm for the crop cycle. The average yield was 14.1t/ha, while average Water Use Efficiency (WUE) in t/ha was 3.1. Lysimeters are used to define water movement across a soil boundary for agronomic and environmental studies (Christiano 2004; Aboukhaled 1982). Lysimeters are used in the determination of CWR through crop development (Paulina et al., 2013; Evett, et al., 2006). They are either weighing or non-weighing. Non-weighing lysimeters indirectly determine Evapotranspiration (ET) using the volumetric soil-water balance within a boundary (Garcia et al., 2004; Howell et al., 1991). They could also range from simple system to complex systems with high-tech instrumentation. The variation in sizes and designs of lysimeter is a function of intended uses and the required resolution (Jose and Suat, 2007). The accuracy of lysimeter data depends on the ability to achieve identical conditions between the lysimeter and surrounding field.

Howell et al., (1991) indicated that lysimeter accuracy was directly proportional to the surface area and the accuracy of scale, and inversely proportional to the lysimeter mass. If lysimeter is designed to meet specific requirements for the research performed and are operated properly, then they could be utilized as precision tools to measure actual evapotranspiration. Through proper use, lysimeter is the most practical research tool for direct measurement of daily evapotranspiration and an effective approach for the conduct of crop coefficient studies (Marek et al., 2006; Yrisarry and Naves, 2000);. Thus, the practice of picking Kc values as recommended from FAO 56 (Allen et al., 1998) needs to be re-evaluated in the light of possible actual water requirement of newly developed crop varieties. (Paulina et al., 2013).

This works used a simple non-weighing lysimeter for the determination of CWR or Crop Evapotranspiration (ET-)

Keywords - Lysimeter, Crop Coefficient, Crop Water Requirement, SUWAN-1-SR maize variety

1 INTRODUCTION

Irrigation management and planning for crop developmental stages require in-depth knowledge of the volume of water needed for each of the growth stages, method of application and crop –weather relationship. These parameters are germane to the development of appropriate crop water requirement of any crop under prevailing weather conditions. In this regard, there exist gaps in the published information on crops water requirement (Allen et al., 1998) and that of newly developed varieties of same crop type. In either soil or soilless medium, it is required that crop water requirement (CWR) and crop coefficient (Kc) should be known which depends basically on physiological characteristic of a crop. The determination of Kc for newly developed varieties is not always given attention, often in irrigation planning. Kc proposed in FAO 56 (Allen et al., 1998) is often employed for same crop irrespective of differences in physiology of new varieties.

It has been suggested that the development of new varieties of a crop is part of the strategies to improve crop production and meeting the food security drive in Africa and Nigeria in particular (Evenson and Gollin, 2003; Olaoye et al., 2013; Jon et al 2012). This can be achieved when irrigation practices are incorporated in the farming system and the various data required for proper and efficient irrigation planning are reliably generated. Very often, in the development of new crop varieties, CWR and Kc are not always considered as critical factors that must be determined. The SUWAN-1-SR have been known to be drought tolerant and give good yield (Olaoye et al 2013; Bello et al, 2012). However, no previous work on the variety evaluated its water requirement. Atere et al (2016) in the determination of physical properties of some maize varieties also did not consider CWR or Kc of the varieties studied. Information on CWR and Kc for most newly developed maize varieties and other crops in Nigeria have always been missing.

*Corresponding Author
and Crop coefficient (Kc) for SUWAN-1-SR a maize variety developed and released for production in Nigeria.

2 MATERIALS AND METHODS
An evaluation of Crop Water Requirement or Evapotranspiration (CWR or ETc) for Maize variety (SUWAN-1-SR), using non-weighing lysimeters was established between October and December 2016 in the Institute of Agricultural Research and Training, Moor Plantation, Ibadan (Lat. 7.37609; Long 3.846207) Ibadan with mean annual rainfall of 1289.2 mm recorded for over a period of 16 years (Alabi and Ibiyemi, 2000).

There are two growing seasons: early season (March/April to August) and late season (Mid-August to October/November). Annual temperature ranges from a high of 31.2 to 21.8°C. The percentage sunshine ranges between 16% in August and 59% in February and December with an average of 44% (Alabi and Ibiyemi, 2000). Four mini-sized lysimeters were fabricated for evaluation of crop water requirement of arable crops. Design and evaluation of the lysimeters were conducted at the Institute. The lysimeter, with reconstructed/repacked soil, operated based on water balance principles by isolating the soil boundary and monitoring the hydrological elements within the lysimeter.

2.1 LYSIMETER DESIGN, CONSTRUCTION AND INSTALLATION
Four (4) units of mini lysimeter were fabricated from 2.5mm stainless steel. The lysimeter is cylindrical in shape which is the best hydraulic shape to facilitate flow. The diameter and depth of the lysimeter were Ø600mm and 500mm respectively (Figure 1). Holes were made at the base of the lysimeter on which 25.4mm galvanized socket was fixed and connected to 1” PVC pipe.

Plate 1: Lysimeter construction showing the percolation pipes

2.2 LYSIMETER SET-UP
Excavations were made to create pits for the installations of the lysimeter units. The excavations were made in such a way that the profile characteristics of the soil were maintained. The 4 units of lysimeter were produced was to make room for replication. Each lysimeter units has a Percolation Chamber housing a container for the collection of percolated drained water. (Figure 2). Daily drained/percolated water were collected from the PVC drainage pipes (Plate. 1).

2.3 SOIL CHARACTERISTICS
The excavated and repacked soils in the lysimeter were maintained at field capacity consistently. Soil physical characteristics – Soil particle size analysis, Bulk Density, Saturated Hydraulic conductivity (Ksat) and Available Water were determined. Chemical Characteristics - pH, EC, Available Nitrogen, Phosphorous (P), Potassium (K), CEC, were also determined following standard laboratory procedures (Water Resources Department, 2009; Halushack, 2006).

Fig. 1: The lysimeter design
Fig. 2: The set-up of the lysimeter plots
2.4 WATER BALANCE ELEMENTS
The various elements of the Water Balance for the Lysimeter boundary were determined following equation 2.

\[ ET_o = \text{Rainfall} \ (R) + \text{Irrigation} \ (I) - \text{Runoff} - \text{Percolation} \ (P) - \text{change in soil water} \]  

Rainfall (mm) was measured using a bucket rain gauge installed in the experimental site. Runoff (mm) was zero because; each lysimeter was designed with an extra 10.0cm edge to retain excess rain while percolation continues. Percolated water (mm) was collected through holes created at the base of the lysimeters and was measured every day using a measuring cylinder. The measured volume of rain and percolated water were converted to depth (mm) using equation 2. Irrigation was applied when available soil water was found to be below field capacity and this was monitored with the aid of a Tensiometer.

\[ V (m^3) = \text{Area (m}^2\text{)} \times \text{Depth (m)} \]  

\[ V = \text{Volume (m3)} \text{ of water collected either in the bucket} 
\[ A = \text{Area (m}^2\text{)} \text{ of rain gauge or lysimeter as determined} 
\[ D = \text{Depth of rain or depth of percolated water} \]

The Crop Water Requirement (CWR) or Consumptive Use (Cw) of a crop (ETc) is given by equation 3. Also, the ratio of ETc to Et is the crop coefficient (Kc) determined at each crop physiological stages (Allen et al., 1998).

\[ \text{CWR} = \text{ETc} = \text{Kc} \times \text{Et} \]  

The Reference evapo-transpiration (ETr) was determined from CROPWAT 8.0 with the aid of data collected from the Institute of Agricultural Research and Training, Ibadan agrometeorological station. The CROPWAT 8.0 uses Penman-Monteith model for computation of ETc (FAO, 2009).

2.5 SUWAN-1-SR MAIZE VARIETY CULTIVATION IN LYSIMETER
After the installation of the lysimeter plots (Figure 2), maize variety (SUWAN-1-SR) was planted at 2 seeds per hole at 40 cm x 40cm resulting in 4 stands at 8plants/lysimeter plot (0.283m²). This was an intensive plant population (80,000plant stand/hectare) since lysimeter management ought to be optimum. Basic agronomic processes were followed for utmost field management. Fertilizers, 250kg/ha N-P-K 15-15-15 and 100kg/ha Urea (46%) were applied at 3WAP and 7WAP respectively. Basic crop growth parameters (plant height, number of leaves, plant girth) were measured at 4WAP, 6WAP and 8WAP. Yield parameters were also determined. The soil water in the lysimeter was maintained at Field Capacity constantly throughout the experiment (the crop was not water stressed throughout the crop stages).

2.6 WATER USE EFFICIENCY
The water use efficiency (WUE) was computed as the ratio of grain yield to total water used (Weiwei et al., 2015; Liu et al., 2011)

\[ \text{WUE} = \frac{\text{Crop yield}}{\text{Water used}} \]  

3 RESULTS AND DISCUSSION
3.1 SOIL CHARACTERISTICS
The soil characteristics of the experimental lysimeter plots are shown in Table 1. The soil texture is sandy loam. This is same across the 4 lysimeter units since the lysimeters are replications with repacked soil from the same location (Plate 2). The average of Ksat, Bulk Density and Available Water was 18.31cm/hr, 1.11g/cm³ and 0.24 respectively. This shows that the soil is freely drains especially at 0-10cm which has higher Ksat than at the 10-50cm while the water holding capacity was lower at 0-10cm than at 10-50cm. This is because of higher bulk density at the 10-50cm (average of 1.30g/cm³) than at 0-10cm (0.92g/cm³). This enables the movement of drainage water. This is particularly appropriate as soil for crop irrigation. Although, the variability observed across the lysimeter units can be related to the process of repacking of soil.

| Table 1. Soil Physical Characteristics in the Lysimeters Plots |
|------------------|------------------|------------------|------------------|
|                  | Lysimeter 1      | Lysimeter 2      | Lysimeter 3      |
| **Soil Depth**   | 0-10cm 10-50cm   | 0-10cm 10-50cm   | 0-10cm 10-50cm   |
| **Particle Size**| Sandy Loam       | Sandy Loam       | Sandy Loam       |
| **Ksat (cm/hr)** | 22.51 8.75       | 25.23 25.23      | 6.13 33.64       |
| **Bulk density** | 0.82 1.4         | 0.78 0.78        | 1.26 1.31        |
| **Available water (mm)** | 0.279 0.176 | 0.285 0.285 | 0.218 0.273 |

Plate 2: Growing maize in the installed lysimeters
3.3 Crop Performance, Yield and Water Use Efficiency

Table 2 gives the observed agronomic details of SUWAN-1-SR maize variety under lysimetric management. Plant height increased from between 23.5 and 29.0 cm at 4WAP to between 165.0 and 175.5 cm at 8WAP. Similarly, stem girth increased from between 0.9 and 1.4 cm at 4WAP to between 2.0 and 2.8 cm at 8WAP. The growth and vigour of the crop was good throughout the period of cultivation. The WUE ranged between 2.03 and 3.03 kg/m² (Table 3).

Sani et al., (2011) have reported WUE as high as between 5.21 and 9.1 kg/m² in maize and have also confirmed that WUE is optimal when the field moisture is maintained at the field capacity. An average yield of 14.5 t/ha was observed in the lysimeter studies. Bello et al., (2012) reported a yield of 6.41 t/ha with SUWAN-1-SR under rainfed. These yields are far from average yield obtained from farmers’ field under rainfed. These yields are far from average yield obtained from farmers’ field under rainfed in Nigeria. The WUE potential of the maize variety if properly managed with intensification in terms of other researchers. (Srinivas and Tiwari, 2018; Jadgiwa et al., 2017; Meysan, 2015). The determination of these parameters, beyond the proposed value in Allen et al., 1998 is strongly encouraged because of the physiological peculiarities of a new crop variety and its response to the ecological realities.

These inputs were at optimum level under this study, hence the reported high yields.

3.4 Crop Consumptive Water Use and Crop Coefficient (Kc)

Table 4 shows the water balance elements. The applied (irrigation), rainfall and percolated water were 579.9, 368.1 and 579.9 mm respectively over the 91 days of crop growth. This resulted in a total consumptive use or actual evapotranspiration of 501.2 mm (Table 4). The computed Kc for each of the stages and the estimated Kc from reference evapotranspiration (ETc), are shown in Table 4. Expectedly, the crop water need peaked at the developmental stages and drops in the late stage of crop growth. Figure 3 shows the distribution of computed Kc and FAO Kc. The computed Kc in the initial 15 days (Initial crop stage) has Kc of 0.98. The next 25 days (developmental stage) has Kc of 1.57. The middle stage was 1.42 while the late maize stage has Kc of 0.68. The Kc pattern shows that crop water requirement increases towards the developmental and middle growth stages while the need for water reduces at the late stage that is about 22 days to the end of the plant development. This is consistent with FAO 56. (Richard et al., 1998). However, the Kc is consistently higher across all the developmental stages for the varieties investigated. The observed variation on determined Kc and CWR for a crop variety as compared to proposed Kc from FAO Paper 56 has been reported by other researchers. (Srinivas and Tiwari, 2018; Jadgiwa et al., 2017; Meysan, 2015). The determination of these parameters, beyond the proposed value in Allen et al., 1998 is strongly encouraged because of the physiological peculiarities of a new crop variety and its response to the ecological realities.

Table 2. Growth parameters and performance of Maize under Lysimetric study

| Lysimeter Plots | Lysimeter Diameter (cm) | Lysimeter Area (cm²) | Plant Population | Plant Plant heigh t (cm) | Stem girth (cm) | No of leaves | Plant Plant heigh t (cm) | Stem girth (cm) | No of leaves | Plant Plant heigh t (cm) | Stem girth (cm) | Numb er of leaves |
|-----------------|--------------------------|----------------------|------------------|-----------------------|-----------------|-------------|-----------------------|-----------------|-------------|-----------------------|-----------------|------------------|
| P1              | 60                       | 0.28                 | 10.0             | 5.0                   | 26.0            | 1.4         | 8.0                   | 79.5            | 2.1         | 15.0                  | 165.0           | 2.5              | 13.0               |
| P2              | 60                       | 0.28                 | 10.0             | 5.0                   | 27.5            | 1.3         | 8.0                   | 80.0            | 1.9         | 13.0                  | 166.0           | 2.4              | 14.0               |
| P3              | 60                       | 0.28                 | 10.0             | 5.0                   | 29.0            | 1.3         | 6.5                   | 82.5            | 2.0         | 13.0                  | 197.5           | 2.8              | 14.0               |
| P4              | 60                       | 0.28                 | 10.0             | 5.0                   | 23.5            | 0.9         | 7.0                   | 69.0            | 1.5         | 11.0                  | 175.5           | 2.0              | 13.0               |

Table 3. Yield and Water Productivity of Maize under Lysimetric study

| Lysimeter Plots | total stov_wt (kg/plot) | stov_wt (kg/plot) | Cob_wt (kg/plot) | Grain_wt (kg/plot) | Est Gr Yield(t/ha) | g/m² | Total Water Applied (m³/ha) | WUE (kg/m²) |
|-----------------|--------------------------|-------------------|------------------|-------------------|--------------------|------|---------------------------|-------------|
| P1              | 1.65                     | 0.37              | 0.27             | 0.20              | 10.2               | 1020 | 5012                      | 2.03        |
| P2              | 1.65                     | 0.70              | 0.60             | 0.40              | 14.1               | 1410 | 5012                      | 2.82        |
| P3              | 1.80                     | 0.75              | 0.60             | 0.43              | 15.2               | 1520 | 5012                      | 3.03        |
| P4              | 1.60                     | 0.80              | 0.52             | 0.40              | 14.1               | 1420 | 5012                      | 2.82        |
The presence of optimum nutrient.

The degree of

This shows the

The designed and constructed lysimeter was used for the monitoring hydrological elements for crop water and crop coefficient determination. This study has revealed that the crop coefficient and the water requirement of SUWAN-1-SR is higher than proposed in the FAO manual on crop for the specific crop type. The differences show the yield potential of SUWAN-1-SR when properly managed under a water-stress-free environment in the presence of optimum nutrient. The use of lysimeter enables the computation of actual evapotranspiration or crop water requirement. The computed crop coefficient can be used to estimate the gross water requirement of the various stages of the maize variety if it were to be cultivated in another agro-climatic environment.

5 ACKNOWLEDGEMENT

The authors are grateful to the management of the Institute of Agricultural Research and Training, Obafemi Awolowo University, Moor Plantation Ibadan which provides funds for this research work. The technical staff of Agricultural Engineering and Environmental Unit and laboratory staff of the Soil Physics laboratory in the Institute are also acknowledged.

4 CONCLUSION

The presence of optimum nutrient. The computed crop coefficient can be used to estimate the gross water requirement of the various stages of the maize variety if it were to be cultivated in another agro-climatic environment.

Table 4. Water balance elements under the lysimeter

| Crop Stages | No of days | Irrigation (mm) | Runoff (mm) | Percolation (mm) | Consumptive Use (mm) | Consumptive Use (m³/ha) | Actual ET (mm/d) | Ref. Ea (mm/day) | Kc Computed | Kc FAO * |
|-------------|------------|----------------|-------------|------------------|----------------------|------------------------|-----------------|-----------------|-------------|----------|
| Initial     | 15         | 127.3          | 203.5       | 272.0            | 58.8                 | 588.0                  | 3.92            | 4.0             | 0.98        | 0.70     |
| Development | 25         | 264.8          | 94.7        | 182.7            | 176.8                | 1768.0                 | 7.07            | 4.5             | 1.57        | 1.20     |
| Mid         | 29         | 244.4          | 69.9        | 108.4            | 206.0                | 2060.0                 | 7.10            | 5.0             | 1.42        | 0.65     |
| Late        | 22         | 76.4           | 0.0         | 16.8             | 59.6                 | 596.0                  | 2.71            | 4.0             | 0.68        | 0.35     |
| Total       | 91         | 712.9          | 368.1       | 579.9            | 501.2                | 5012.0                 |                 |                 |             |          |

*Allen et al (1998) FAO Paper 56

Figure 3: Crop coefficient of different stages of maize under lysimeter

Figure 4: Daily Water Balance Relationship between Rainfall, Irrigation and Percolation as measured in the lysimeter

The Actual ET computed from lysimeter study shows that this particular variety of maize (SUWAN-1-SR) requires more water at all the stages of crop development than what was proposed by the FAO 56 (Allen et al., 1998) generally for maize. This shows the possible inherent differences in the varieties of same crop and the requirement for their management.

REFERENCES

Aboukhaled, A., Alfaro, A., and Smith, M. (1982). Lysimeters. FAO irrigation drainage Paper. No 33. Rome, Italy.

CROPWAT 8.0 http://www.fao.org/landandwater/aglw/cropwat.stm

Alabi, R.T., Ibiyemi, A.G., 2000. Rainfall in Nigeria and food crop production. In: Akoroda, M.O. (Ed.), Agronomy in Nigeria. University of Ibadan, Nigeria, pp 63–66.

Christine Lanthaler (2004). Lysimeter Stations and Soil Hydrology Measuring Sites in Europe— Purpose, Equipment, Research Results, Future Developments A thesis for the degree of Magistra der Naturwissenschaften (Mag. rer. nat.), School of Natural Sciences at the Karl-Franzens-University Graz

Evenson R.E and Gollin D. (2003): Crop Genetic Improvement in Developing Countries: Overview and Summary. In Crop Variety Improvement and its Effect on Productivity: the Impact of International Agricultural Research. Ed. R.E. Evenson and D. Gollin, pp 7-38

Garcia M., Raes D, Allen RG., and Herbas C (2004). Dynamics of reference evapotranspiration in the Bolivian highlands (altiplano). Agricultural and Forest Meteorology. Vol. 125 no.1-2, pp 67-82.

Ghulam A., Abid H., Ashfaq A. and Syed A. W. (2005) Water Use Efficiency of Maize as Affected By Irrigation Schedules and Nitrogen Rates. Journal of Agriculture & Social Sciences 339-342

Haluschak P. (2006): Laboratory Methods of Soil Analysis. Canada-Manitoba Soil Survey, Canada

Howell, T. A., Schneider, A. D., and Jensen, M. E. (1991). History of Lysimeter Design and Uses for Evapotranspiration Measurements. Kohnke Vol. 1940, pp 1-9.

Howell, T. A., McCormick, R. L., and Phene, C. J. (1985). Design and installation of large weighing lysimeter. Trans.ASAE, Vol. 28, pp. 106-112.

Information and Communication Support (I.C.S). (2017). Growing Maize in Nigeria. Commercial Crop Production guide series Information and Communication Support for Agricultural Growth in
Jadwiga T., Waldemar T., Krzysztof K. (2017). Determination of Irrigation Requirements And Crop Coefficients Using Weighing Lysimeters in Perennial Plants Infrastructure And Ecology Of Rural Areas Polish Academy of Sciences, pp.1213–1228 DOI: http://dx.medra.org/10.14597/infraeco.2017.3.2.093

Jon H., Bekele S., Jill E. C., Matthew R., Iman R., Kai S. and Roberto L. (2012). Climate change and food security in the developing world: Potential of maize and wheat research to expand options for adaptation and mitigation Journal of Development and Agricultural Economics Vol. 4(12), pp. 311-321 DOI: 10.5897/JDAE11.112

Jose O.F. and Suart I., (2008); Construction, Installation, and Performance of Two Repacked Weighing Lysimeters Irrigation Science Vol. 26, no 2, pp. 191–202;

Liu, K., Y.H. Zhang, Z.M. Wang, H.Y. Feng, S.L. Zhou, L.Q. Lu, et al. 2011. Characteristics of water consumption in water-saving winter wheat and effects on the utilization of subsequent summer rainfall in the North China Plain. International Journal of Plant Production Vol 5, pp. 167-180

Paulina V., Víctor G. C., Raúl F., Cristina A., Carlos Z., Samuel O. F. and Gabriel S. (2013). Estimation of water requirements and Kc values of ‘Thompson Seedless’ table grapes grown in the overhead trellis system, using the Eddy covariance method. Chilean Journal of Agricultural Research Vol. 74, No 2, pp. 213 – 218

Allen R.G., Luis S. P., Dirk R., and Martin S. (1998). Crop evapotranspiration - Guidelines for computing crop water requirements - FAO Irrigation and drainage paper 56 Rome Italy

Schneider, A. D., Ayars, J. E., and Phen, C. J. (1996). Combining monolithic and repacked soil tanks for lysimeter from high water table sites. Applied Engineering in Agriculture, Vol. 12, pp. 303-308.

Shirazi S.M., Sholichin M, Mohammed J, Shatirah A, and Mokhtar A (2011). Effects of different irrigation regimes and nitrogenous fertilizer on yield and growth parameters of maize. International Journal of Physical Sciences Vol. 6(4), pp. 677-683.

Water Resources Department (2009): Laboratory Testing Procedure For Soil & Water Sample Analysis. Directorate of Irrigation Research & Development, Pune - 411 001.

Weiwei M., Zhenwen Y, Yongli Z., Yu S., and Dong W. (2015). Effects of supplemental irrigation on water consumption characteristics and grain yield in different wheat cultivars Chilean Journal of Agricultural Research Vol. 75, No. 2, pp. 216 - 223

Yrisarry, J. J., and Naveso, F. S. (2000). Use of weighing lysimeter and Bowen-Ratio Energy-Balance for reference and actual crop evapotranspiration measurements. Food and Agricultural Organization of the United Nations.