Research Article

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Assessment of Consumptive use and Water use Efficiency of Okra (*abelmoschus esculentus* l. Moench) Using Minilysimeters in Makurdi, Benue State, Nigeria

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Abstract

This study was carried out during the 2015 and 2016 dry cropping seasons at the Teaching and Research Farm of the University of Agriculture, Makurdi, Southern Guinea Savanna Agroecology of Nigeria. The objectives were to determine the consumptive use and water use efficiency of okra using the Lysimetric technique. This involved the use of twelve (12) locally fabricated minilysimeters housing three (3) irrigation treatments corresponding to 50, 75 and 100% of the soil available water capacity replicated four (4) times and laid out in a Randomized Complete Block Design (RCBD). The Blaney-Criddle formula which is latitude dependent derives its strength from a 5-year accumulated temperature, data was used to predict the potential evapotranspiration of okra. The crop evapotranspiration is equivalent to the crop water use. Results show that the consumptive use estimated varied from 263.52 – 1,944.90 mm, water use efficiency was from 22.73 – 2.28 kg/ha/mm and crop coefficients of 0.36 – 2.28 corresponding to 50 – 100% (Low to High) soil available water capacity (SAWC) respectively. Okra performed better under low soil available water capacity.

Introduction

The consumptive use of a crop for water is the total quantity of water supplied to meet the water requirements of the crop at its various stages of development, from planting through to harvest [1]. For much of agriculture, this implies that rainfall or irrigation and evapotranspiration will have to interplay and the result of that relationship will determine whether or not the availability of water throughout the growing season of a crop can be guaranteed [2]. Water Use Efficiency (WUE) is the profit ability of use of the amount of water made available for a particular crop growing for a specific duration (season) in a given place or location. That is, it describes or gives you an idea of the productivity of the water that is at the disposal of a crop or sequence or even combination of crops growing together on a specified field at the same time. It relates the pace of crop development with time based on a given quantity of water present and readily available for the crop use or the overall water used by the crop from sowing/planting to the full development of the useful component of the crop or harvest in a particular season. This means that crop water use efficiency relates the grains or fruits or pods or seeds produced to the quantity of water used by such a crop on a specified quantity of land. Gao et al. (2009) defined water use efficiency as the ratio of grain yield to actual evapotranspiration [3].

Climate change has given rise to erratic rainfall such that even during a rainy season, patches of drought are frequently observed in Makurdi-a humid environment, leading to severe yield reductions [4]. Current food shortages in Nigeria caused by farmers/herdsmen clashes and the global economic down turn that has led Nigeria into economic recession have sky rocketed food prices necessitating dry season farming (irrigation) where there is water to tame the tide.

One of the most important concepts regarding water balance in arid and semi-arid areas is crop evapotranspiration (ETc), which is a key factor for determining proper irrigation scheduling and for improving water use efficiency in irrigated agriculture. Obalum et al. (2011) maintained that the three components of water balance needed for the computation of crop water use were precipitation or irrigation, drainage below the root zone and change in storage [5]. The root zone water balance is expressed in integral form by Verplancke (1989) as:

$$(\Delta s + \Delta v) = (P + I + U) - (R + D + E + T) \quad \text{…….. (1)}$$

Change in storage   Gains – Losses

Where, Δs = change in root zone soil moisture storage, Δv = Increment of water incorporated in the plants, P = Precipitation, I = Irrigation, U = Upward capillary flow into the root zone, R = Runoff, D = Downward drainage out of the root zone, E = Direct evaporation from the soil surface and T = Transpiration by plants [6].

He went further to state that, the change of plant – water (Δv) is relatively unimportant, and that the upward capillary flow (U) and downward drainage (D) can be included under the symbol D, being negative if capillary rise occurs or positive when drainage is present. And thus equation 1 can be written as;

$$\Delta s = P + I - R - D - E - T \qquad \ldots\ldots (2)$$

In their submission, Gao et al. (2009) agreed that estimating crop evapotranspiration (ET_{cr}) and determining irrigation water requirements accurately are necessary for optimal irrigation schedule to ensure yield stability of cropping systems [3]. According to Igbadun (2012), information on crop water requirement (Evapotranspiration) is very vital in the planning and operation of soil and water management strategies [7].

Allen et al. (1998) confirmed that too much water will result in water logging which might damage the root and limit root water uptake by inhibiting respiration [8]. Zeleke and Wade (2012) defined potential evapotranspiration of a crop as being determined by evaporative demand of the atmosphere and crop characteristics [9]. Further, they said the evaporative demand of the air is determined as the evapotranspiration from a reference crop, and that the potential or reference crop evapotranspiration primarily depends on the evaporative demand of the air surrounding it.

Okra (*Abelmoschus esculentus* (L) *Moench*) is an important vegetable crop in tropical and Sub-tropical parts of the world [10-12]. Its production constitutes about 4.6% of the total staple food production in Nigeria from 1970-2003 and an important source of calories (4450 kcal/kg) for human consumption with varieties varying by plant height, fruit size, color, early or late maturity varieties including NHAe 47-4 with average yields of 2.5/t/ha obtained in west and central Fanen (2012) reported that the muscilage preparations from the immature pods are used medicinally in the treatment of Ulcer and relief of haemorrhage [13,14]. Tiamiyu et al. (2012) were of the view that the immature stems contains crude fiber which could be used in paper industries and for making ropes [15].

Muller defined lysimeter as a device that isolates a volume of soil or earth between the soil surface and a given depth and includes a percolating water sampling system at the bottom.

Lysimeter measurements are adopted for hydrological balances of crops [16-19]. Recently, mini lysimeters characterized by reduced soil volume have been adopted due to reduced installations and management costs and good accuracy of measurement [20]. They maintain a controlled environment while mimicking field conditions for measurement of water into and out of the soil system [21]. This requires that soil-plant system inside the lysimeter be indistinguishable from the surrounding area in terms of soil moisture, nutrient availability plant height, root density etc [21-23].

Therefore, knowledge of the water use and water use efficiency by crops within this area is required for better planning of the cropping cycles to reduce the risk of crop failure and increase yield. Thus, the objective of this research was to determine the water use and water use efficiency of okra in Makurdi.

Materials and Methods

These field experiments were carried out at the Teaching and Research Farm of the University of Agriculture, Makurdi during the 2015 and 2016 dry farming seasons. The farm is located between latitude 7°41/ to 7° 42/ N and longitude 8° 37/ to 8° 38/ E at an elevation of 97m above mean sea level with a slope of about 3%. The soil is classified as Typic ustropepts (USDA) [24].

Experimental Treatments and Design

The experiment consisted of three (3) treatments replicated four (4) times in a Randomized Complete Block Design (RCBD) and involved a daily water application at various treatment levels as follows: Low (L) water application at 500ml (control), Medium (M) water application at 750ml and High water (H) application at 1000ml. The treatments were assigned to replications (randomized) using the balloting method.

Lysimeter installation

Materials: Twelve (12) 2.09m^3 emulsion paint plastic buckets filled with soil from the site of the experiment, ¾ PVC pipe used for water outlet channel, Abrasive glue for fastening the joints of the pipes and elbows to the bucket, Twelve (12) 1000mls plastic containers were used to collect the drainage or leachet, 0.05mm sieve/net to cover the drainage hole at the bottom of the lysimeter to avoid soil particles leaving with the water draining out lysimeter.

Methodology: The vegetation was manually cleared. A drainage passage was dug at a depth of 0.91m and a width of 0.76m apart and length of 12m, using a digger, hoe and shovel. The exposed profile surface was sealed with cement to avoid the exposure of the length of the pipe longer than is necessary and also prevent future erosion that might set in along the path of the drainage pipes. Twelve (12) mini- lysimeters were placed by the side of the drainage pit. An exit pipe for drainage water was attached at the bottom of each mini- lysimeter so as to receive and deliver leached or percolate water to the drainage collector. The soil removed from the area in which the mini- lysimeters were placed was replaced in opposite pattern as it was removed, to attain a similar representation of the soil profile with the horizons of the adjoining soil. This set up is pictured on plates 1-3.

Plate 1: General Layout of the Minilysimeters on the Field

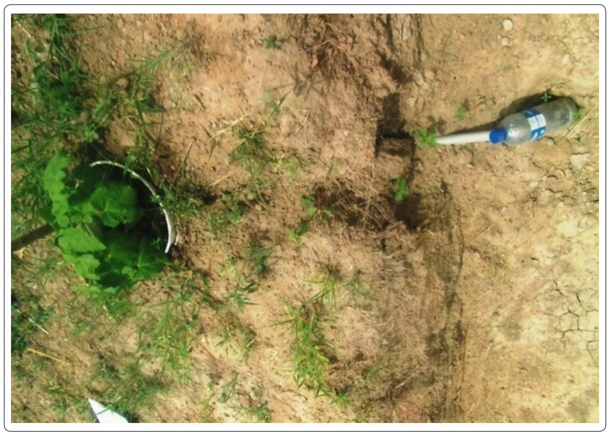

Plate 2: A Unit of the Minilysimeters Showing the Crop Area and the Drainage Collection Point

Plate 3: A Unit of the Minilysimeters showing an Okra Plant at Canopy Development Stage

Agronomic practices

The first trail (planting) started on the 23rd January, 2015 while the second started on the 14th January, 2016, after initially uniformly and sufficiently watering all the mini-lysimeters to enable good germination, emergence and take off of all the seedlings. Thereafter, application of water was on treatment basis. The source of water for irrigation was the water reservoir of the UAM Teaching and Research Farm. Two seeds per hole of the okra variety LD-88 were planted per mini-lysimeter but later thinned to one at two (2) weeks after planting. Each mini- lysimeter was mulched with dry grass equivalent to 4 t/ha. Weed growth was controlled by annual weeding as the need arose.

Data collection

Water data: By taking measurements at 7-8am which was assumed as the end of each 24-hour drainage period following addition of water, soil water storage was expected to remain constant and the change in storage was therefore zero(0). And by maintaining a condition of non-limiting soil moisture, the mini lysimeters were used to evaluate the consumptive use by subtraction of drainage water collected from total water applied, while water use efficiency was obtained by dividing the yield by the consumptive use per each treatment. This was done daily from sowing to harvest as was done by Lawson (1977), Eldin et al. (1969) and Fritschen and Shaw (1961) [25-27].

The water data collection from the mini- lysimeter was done daily in the drainage collectors. The collected or leached water was measured in a measuring cylinder and recorded in milliliters (ml) (volume basis) and later converted to millimeter (mm) (depth basis).

Crop data: Data on the crop was collected on the weight of pods/ treatment.

Results and Discussion

These environmental conditions point to the fact that no crop production could take place except with the support of irrigation.

Arising from the above, for this study, the root zone water balance equation used was

$$ET = I - D + S$$

Where, ET = okra evapotranspiration (mm), I = Irrigation, D = Drainage and S= Change in soil moisture storage=0, since irrigation was done at a fixed time every 24 hours.

The result of the consumptive use and water use efficiency of okra in the lysimeters in Makurdi as averages for the 2015 and 2016 seasons as presented on Table 1,2 revealed that consumptive use stood at 296.07 mm, 921.15 mm and 1,944.90 mm while water use efficiency was 20.23 kg/ha/mm, 5.73 kg/ha/mm and 2.28 kg/ha/mm, corresponding to low, medium and high water application respectively. This means there was higher conversion of water to food at low soil water capacity, suggesting that okra is a low water requiring crop. The implication is that if the soil is fertile, with low water applied at the various stages of the crop development, it will yield very high. Elsewhere at Ibadan, Lawson (1977) obtained consumptive use ranging from 275-311mm over an 11-week season from cowpea and Gao et al. (2009) got water use efficiency of 21.72 kg/ha/mm in a winter wheat/spring maize intercropping under full irrigation, probably slightly above 50% soil available water capacity (SAWC), while Igbadun (2012) had crop water use of 283.30 and 228.90 mm respectively from maize and groundnut respectively at Zaria using minilysimeters monitored at field moisture capacity of between 50-75% SAWC during the rainy season[3,7,25].

Table 1: Meteorological Data for Makurdi

Year/month	Rainfall (mm)			Temperature (°C)			Relative humidity (%)		
	2015	2016	*	2015	2016	*	2015	2016	*
January	9.00	0.00	0.00	28.85	26.20	26.01	31.50	21.00	24.00
February	27.00	0.00	5.00	30.00	29.95	29.80	56.50	29.50	28.90
March	0.00	47.60	0.00	30.00	30.85	29.90	56.50	62.50	52.70
April	37.00	91.10	41.00	30.45	29.65	30.12	52.00	65.00	60.04

May	14.00	238.00	160.50	29.70	28.75	27.70	62.50	70.50	66.08
June	22.60	49.40	162.70	28.15	27.70	25.83	68.00	73.00	71.83
July**	120.40	215.60	130.18	26.95	27.05	26.18	75.00	77.00	74.83
August**	321.10	213.80	286.60	27.20	27.05	24.63	78.00	78.00	74.42
September**	290.40	269.80	308.47	27.10	27.00	26.10	77.00	78.50	79.50
October**	59.00	116.10	134.95	28.10	28.20	25.97	72.50	73.00	75.00
November	89.80	22.80	15.78	27.05	28.25	27.27	56.00	67.00	64.50
December	0.00	0.00	0.00	25.04	26.40	25.10	23.00	24.00	23.01
Total	987.70	1,264.20	1,245.18	-	-	-	-	-	-
Total for months of interest	788.90	815.30	860.20	-	-	-	-	-	-

* = Long term average of 6 years, spanning from 2009 to 2014, computed for this research.
** = Months of interest in this study.

Source: Nigerian Meteorological Agency, Nigerian Air Force Base, Makurdi.

Table 2: Consumptive Use and Water Use Efficiency of Okra in the Lysimeters in Makurdi for 2015 and 2016 dry Cropping Seasons

Level of water application and stage of development	Average partial consumptive use (mm)	Yield (kg/ha)	Water use efficiency (kg/ha/mm)
Low (50% AWC)			
Vegetative	128.52	5,990	22.73
Reproductive	68.09		
Maturation	66.91		
Total	**263.52**		
Medium (75% AWC)			
Vegetative	456.75	5,280	5.73
Reproductive	237.06		
Maturation	227.34		
Total	**921.15**		
High (100% AWC)			
Vegetative	921.58	4,430	2.28
Reproductive	509.83		
Maturity	513.49		
Total	**1,944.90**	Average	

ETo by Blaney–Criddle formula = 731.90 mm from Jan – April 2015 and 2016 dry seasons

Conclusion

This study has demonstrated that for the soil of the Teaching and Research Farm of the University of Agriculture Makurdi, applying water during irrigation above 50% the soil available water capacity may not lead to higher okra performance, meaning that okra thrives better under low soil available water capacity [28-35].

Recommendation

Arising from this study, it is hereby recommended that low soil water application/capacity (50%) is most suitable for profitable irrigated okra production in the study area.

References

1. Oluwasemire KO, Stigter CJ, Owonubi JJ, Jagtap SS (2002) Seasonal Water Use and Water Productivity of Millet-based Cropping Systems in the Nigerian Sudan Savanna near Kano. Agricultural Water Management 56: 207-227. Elsevier Publications.
2. Angus JF, van Herwaarden AF (2001) Increasing water use and water use efficiency in dry land wheat. Agronomy Journal 93: 290-298.
3. Gao Y, Duan A, Sun J, Li F, Liu Z (2009) Crop coefficient and water-use efficiency of winter wheat/spring maize strip intercropping. Field crops Research 111: 65-73. Elsevier Publications.
4. Agbede OO, Jayeoba J, Ogunremi LT, Ali A, Amhakhain S, et al. (2011)Inventory of Farmers' Physical Environments, farming practices and constraints in Southern Guinea Savanna of Nigeria (Desktop Study). RFA-CARGS Programme.
5. Obalum SE, Igwe CA, Obi ME (2011) Water use and grain yield response of rainfed soybean to tillage–mulch practices in Southeastern Nigeria. Scientia Agricola 68.

6. Verplancke H (1989) The Field Water Balance. College of Soil Physics, International Centre for Theoretical Physics, Trietse, Italy. SMR/402-15.
7. Igbadun HE (2012) Estimation of Crop water use of Rain-fed maize and groundnut using mini-lysimeters. Pacific Journal of Science and Technology 13: 527-535.
8. Allen RG, Smith M, Perrier A, Pereira LS (1998) Crop Evapotranspiration, Guidelines for computing crop water requirements. FAO Irrigation and Drainage paper No. 56. Food and Agriculture Organization of the United Nations, Rome, Italy.
9. Zeleke KT, Wade LJ (2012) Evapotranspiration Estimation using soil water balance, weather and crop data. In: Evapotranspiration – Remote Sensing and Modeling. Irmak, A. (ed). P 41-57. Intech Publications. https://www.intechopen.com/books/evapo.
10. Tindall HD (1986) Vegetables in the Tropics. 1st edition, Macmillan Publishers. Hong Kong 325-327.
11. Chriso EI, Onuh MO (2005) Influence of plant spacing on the growth and yield of okra (Abelmoschus esculentus (L) Moench). Proceedings of the 39th Conference of the Agricultural Society of Nigeria, Benin 51-53.
12. Katung MD, Kachina BD (2005) Time of partial defoliation and GAS Effects on Growth Indices and yield of okra (Abelmoschus esculentus (L) moench). Proceedings of the 39th conference of the Agricultural Society of Nigeria 210-213.
13. Central Bank of Nigeria (CBN) (2004) Annual Report and Statistical Bulletin Volume 6 No. 12, December.
14. Fanen FT (2012) The Effect of Population Density, Planting Dates and Cropping Systems on Yield of Egusi Melon-Okra Mixture. Unpublished M.Sc. Thesis, Department of Crop Production College of Agronomy, University of Agriculture, Makurdi – Nigeria.
15. Tiamiyu RA, Ahmed HG, Muhammed AS (2001) Effects of Sources of Organic Manure on Growth and yield of Okra (Abelmoschus esculentus L. Moench) in Sokoto, Nigeria. Nigerian Journal of Basic and Applied Science 20: 212-216.
16. Jones HG (2004) Irrigation scheduling: Advantages and Pitfalls of Plant Based Methods. Journal of Experimental Botany 55: 2427-2436.
17. Da Silva RC, Folegatti MV, Araujo DS, Junior JA, Fonseca SC, et al. (2005) Water Relations and Photosynthesis as Criteria for Adequate Irrigation Management in 'Tahiti' Lime Tree. Scientific Agriculture 62: 415-422, Piracicaba, Brazil.
18. Liu F, Savic S, Jensen CR, Shahnazari A, Jaconsen SE, et al. (2007) Water Relations and Yield of Lysimeter Grown Strawberries under limited irrigation. Scientia Horticulture III: 128-132.
19. Cecon P, Dalla-Costa L, Giovanardi RC (2008) The Interaction of sowing date and water availability in determining plant Architecture, fruiting pattern and Yield Components of Soybean (Glycine max L. Merr.). Jour. of Agron. & Crop Sc 173: 172-183.
20. Oke T (2004) Initial Guidance to obtain representative meteorological observation sites, WMO Report 81: 51.
21. McFarland MJ, Worthington JW, Newman JS (1983) Design, Installation and Operation of a twin weighing lysimeter for fruit trees. Trans. American Society of Agricultural Engineers 26: 1717-1721.
22. Allen RG, Fisher J (1990) Low-cost Electronic weighing Lysimeters. Trans American Society of Agricultural Engineers 33: 1823-1832.
23. Howell TA, McCormack RL and Phene CJ (1985) Design and Installation of Large Weighing Lysimeters. Trans American Society of Agricultural Engineers 28: 106- 112.
24. Fagbami A, Akamigbo FOR (1986) Soils of Benue State – their Capabilities. Proceedings of the 14th Annual Conference of the Soil Science Society of Nigeria held in Makurdi between 4th-7th Nov 49-52.
25. Lawson TL (1977) Consumptive Water Use for Cowpea. Paper presented at the International conference on "Role of Soil Physical Properties in Maintaining Productivity of Tropical Soils held at the International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria between 6-10th December.
26. Eldin M, Daudet A, Quencey P (1969) L'evapotranspiration Potentialle: application definition, principale evaluations, measure. L'Agronomie Tropicale 24: 174-180.
27. Fritschen LJ, Shaw RH (1961) Evapotranspiration for corn as related to pan evaporation. Agronomy Journal 53: 149-150.
28. Allison LE (1965) Organic Carbon. In: Black, C. A. (ed.) Methods of Soil Analysis. Agronomy Monograph No. 9 part 2, Madison, Wisconsin 1367-1378.
29. Black CA (1965) Crop Yield Relation to Water Supply and Soil Fertility. In: Plant Environment and Efficient Water Use. Pierre, WH, D. Kirkham and B Shaw (eds.) American Society of Agronomy and Soil Science Society America, Madison, USA.
30. Blaney HF, Criddle WD (1950) Determining Water requirements in irrigated areas from climatological and irrigation data. USDA Soil conservation service. SCS TP 96. 44.
31. Boyoucos GH (1951) A Recalibration of the Hydrometer method for making mechanical analysis. Agronomy Journal 43: 434-438.
32. Bray RH, Kurtz LT (1945) Determination of Total, Organic and Available forms of phosphorus in Soils. Soil Science 59: 39-45.
33. Dewis J, Freitas L (1970) Physical and Chemical Methods of Soil and Water Analysis. FAO, Rome Soils Bulletin No 10: 77.
34. Hullugale NR (1990) Alleviation of soil constraints to crop growth in the upland Alfisols and associated soil groups of the west African Sudan Savanna by tied ridges. Soil Tillage Research 18: 231-248.
35. Thomas GW (1982) Exchangeable Cation. In: Page, A. L., R. H. Miller and D. R. Keeney (eds.) Methods of Soil Analysis. Part 2, Agronomy Monograph, Second edition. ASA and SSA, Madison 159-165.