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GROUNDWATER CONTRIBUTION TO CROP WATER REQUIREMENT OF WATERLEAF (TALINUM TRIANGULARE) IN OXISOLS OF SOUTH-SOUTH NIGERIA

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Abstract
A drum-culture lysimeter experiment was conducted at the Akwa Ibom State University, Obio Akpa campus research farm to estimate the contribution of groundwater to crop water requirement of waterleaf crop. Soil moisture depletion experiment was undertaken through the use of drums with bases intact and drums with bases removed. The drums were sunk in the field at different depths. The results obtained show that crop water requirements determined for waterleaf varied from 1.32 to 4.76cm for the lysimeter that was solely supplied from groundwater source during the experimental period with no rainfall and no irrigation. Groundwater contribution in the different drums varied with the type of soil and depth of drum from the water table. Greater amount of moisture was contributed from the 300-600mm soil depth which corresponded with the rooting depth of the crop, an area of greatest root proliferation of the crop. It is concluded that soil with shallow groundwater table may need no irrigation or the need for irrigation water may be reduced considerably.

Keywords: Groundwater, water table, capillary rise, soil type, waterleaf, lysimeter.

1. Introduction

Estimation of groundwater contribution to the root zone of crops is an integral part of any water balance scheme. Crop water requirement depletes the soil moisture content in the root zone. Where no recharge through irrigation or rainfall takes place, a difference in potential induces upward (capillary) movement of water into the root zone from the unsaturated underlying soil layers which supplies an appreciable portion of the water use by crops and facilitates the achievement of potential crop yields and savings from withholding irrigation applications[1].

Capillary rise of water from the water table to the root zone depends on the soil type, the depth of the water table, soil moisture depletion in the root zone and recharge [2][3]. It can normally be assumed to be zero when the water table is more than I meter below the bottom of the root zone [4]. Water is an important cost element in irrigated agriculture. However, water resources for agriculture are often misused and overused. The major cause for this is that most irrigators and agronomists do not generally possess adequate knowledge of the soil-plant-water relationships. Their erroneous belief that crop performance is linearly and steeply related to the quantity of irrigation water applied leads them to over irrigate. Over irrigation is an on-farm irrigation water management problem [5].

Improving on-farm irrigation water management involves optimizing irrigation scheduling. This means determining when to irrigate and how much water to apply. Soil water balance method [6] is commonly used to determine timing and depth of future irrigations. Basic assumption in this method is that the soil moisture depletion between two irrigations equals the crop water requirement. The later assumption may not be valid where the plant roots are extracting water from shallow groundwater. Where such conditions exist, flexibility is imposed on irrigation management both in terms of timing and in regulating the amount of water to be applied [7].

Many floodplains in Akwa Ibom State, South-South Nigeria, are under intensively irrigated dry season vegetable farming [8] on soils with shallow groundwater [9]. A large portion of the floodplain soil in Akwa Ibom State is classified as oxisol [10]. The location of Akwa Ibom State and oxisol in south south Nigeria is shown, by an arrow in the inset and main maps respectively, in figure 1.

Waterleaf is important in the meals of the people of Akwa Ibom State where it is used as a softener when cooking fibrous vegetables such as Afang (Gretem africanuum), Atama (Heinsia crinata) and fluted pumpkin (telferia occidentalis). Nutritionally, waterleaf is high in crude-protein (22.1%), ash (33.98%) and crude fibre (11.12%) and medicinally, it is used as an enema and as green forage for rabbit feed management. The demand for waterleaf is increasing among the inhabitants of South-South Nigeria, thus widening the domestic demand and supply gap of the product.

Moreover, the increased participation in dry season irrigated waterleaf production calls for adequate information to facilitate increased crop production, savings from withholding irrigation water and sustainable conservative use of floodplain soils.

Most research efforts on waterleaf production in the study area have focused on economics, technical and resource use efficiencies (excluding water). There is paucity of data on the soil-plant-water relationships in waterleaf production. This study therefore has the objectives of assessing the magnitude of groundwater contribution (capillary rise) if any, in meeting the water need of waterleaf and to establish relationship between capillary rise and water table depth for soils studied.

2. Materials and methods

The water balance principle was used in a lysimetry study of crop water requirement and its application for irrigation scheduling of waterleaf. The experimental set up in the field involved twelve non-weighing type, 60cm diameter, 95cm deep drum culture lysimeters sunk in a 30m x 20m area of land at the Akwa Ibom State University Obio Akpa campus research farm. Six drums with bottoms (bases) intact were designated as B, while six other drums with bottom removed were designated as BL. The twelve drums were divided into two sets for the experimental set up in the field. Each of the two sets of six drums comprised three drums with bottom intact and three drums with bottom removed. They were designated as B(L1), BL(L1) for the first set and B(L2), BL(L2) for the second set.

The twelve drums were buried in the field in three rows and four columns randomized set up (fig. 2) keeping the drums six meters apart from each other and from the boundaries of the plot respectively.

Six of the drums (B(L1) and BL(L1), were buried in the soil keeping the top of the drums 40 cm above the ground level while the top of the other set of six drums, B(L2) and BL(L2) were at ground level. This was designed to vary the depth to the water table between B(L1), BL(L1) and B(L2), BL(L2) set of lysimeters. All the lysimeters were filled from the bottom with 20 cm layer of a mixture of stones, gravel and sand [11] to provide ideal drainage. The remaining space in the first set of six drums, B(L1) and BL(L1),were filled with sandy loam soil while the other set of six drums, B(L2) and BL(L2), were filled with sandy clay soil.

The soils, derived from oxisol of Obio Akpa river floodplain were compacted in 30 cm increments in the lysimeters. The lysimeters were sunk in the soil to gain access to a falling shallow water table. The depth to water table at the experimental site was accessed through a tube well drilled at a distance of 20 m from the center of the experimental plot. The datum from which water level in the well was measured was the top of the well installation by the use of a Popper apparatus [12]. Measurement, which was continued daily throughout the experimental period, provided data for drawdown of the well from beginning to end of experiment. Since pumping was not taking place, crop water requirement was considered to be solely responsible for well drawdown.

In the drums with bottom, applied water, rainfall and stored soil moisture were the expected sources of water and there was no contribution from the groundwater (capillary rise). In the drums without bottoms there was no barrier for upward movement of water from the water table to the root zone. Three different soil depths (0-30, 30-60 and 60-90cm) were studied with points of moisture measurement at 30, 60 and 70 cm. Each soil depth was replicated at random three times in the plots. Two types of tensiometers (1.0 m and 0.3 m long) were used in the study and were installed at the desired depths in the lysimeters to measure soil water potentials. The soil at the different depths were sampled and the tensiometers were calibrated against the standard gravimetric method [13] from soil samples taken from the top 60cm, covering a broad range of soil moisture from wet to dry.

Data obtained from these parallel measurements were used to obtain the soil water characteristic from which subsequent estimation of the moisture profile was based. Particle analysis [14] of the lysimeter soils showed that the sandy soil composed of 62% sand, 12% silt and 26% clay. The sandy clay soil composed of 53%, 5% and 42% sand, silt and clay respectively. These particle percentages were used as input to the Soil Texture Triangle Hydraulic Properties Calculator [15] to obtain values for the soil hydraulic properties (table 1).

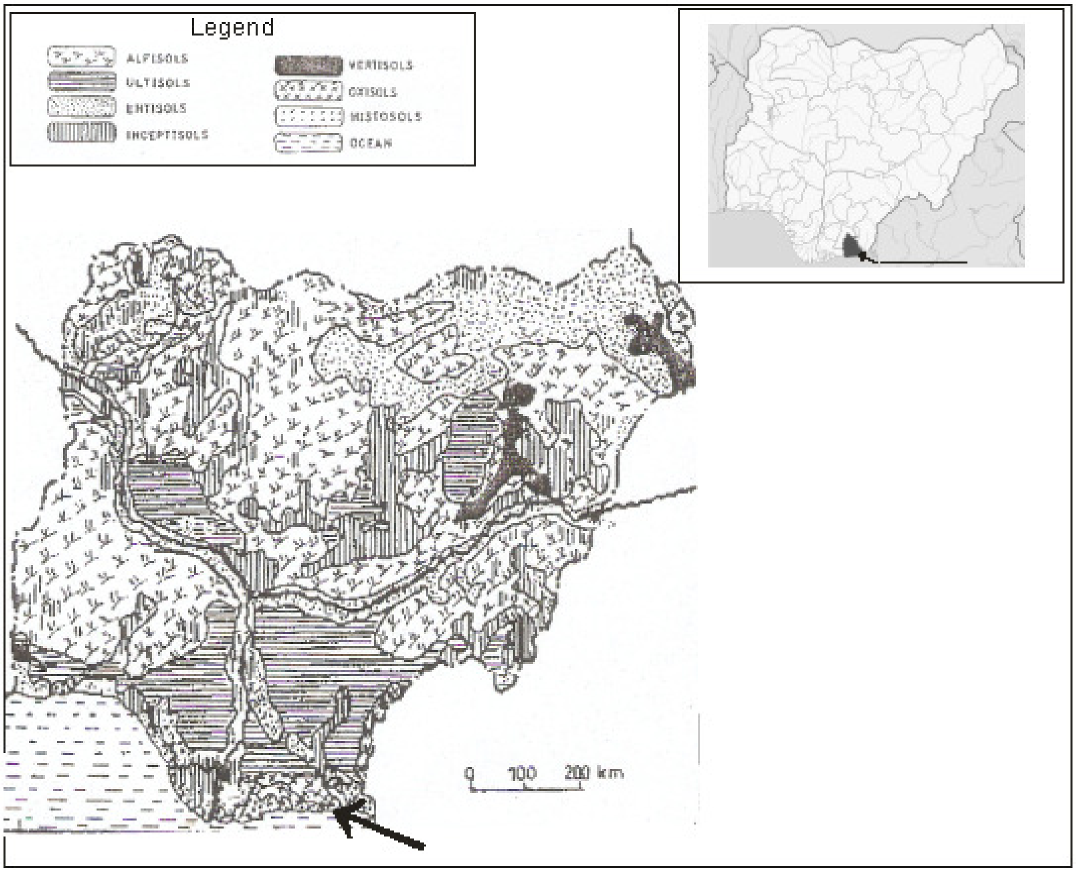

Figure 1: Soil map of Nigeria showing location of oxisol in South-South Nigeria [3]

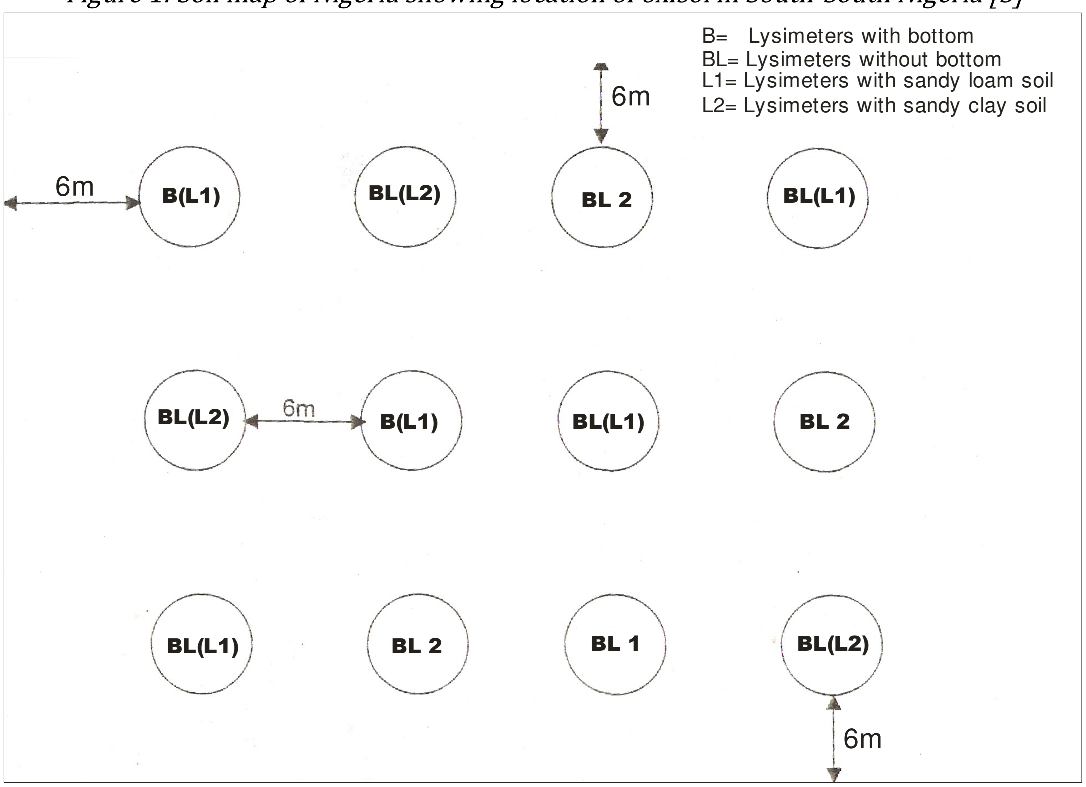

Figure 2: Experimental setup of Lysimeters in the field

The standard method [16] was used to determine bulk density of the lysimeter soils as 1.51g/cm^3 and 1.33g/cm^3 for the sandy loam and sandy clay soils respectively. The entire experimental area both in between and around the lysimeters was cropped with waterleaf (Talinum triangulare) . In the drums with bottom and those without bottom, the plants were grown in identical conditions and it was presumed that the total crop water requirement in both cases was similar in each soil type. The difference in moisture use between the drums with bottom and drums without bottom represented the amount of water contributed by the ground water table through capillary rise.

Crop water requirement was determined by studying the soil moisture depletion in the crop root zone of the drums with bottom B(L1) and drums without bottom BL(L1). The difference between the recent and previous sampled values accounted for moisture lost to the atmosphere during the interval between the two samplings. By considering the mean measured soil moisture (mm) in the root zone, the crop water requirement was calculated according to guidelines presented by FAO [4]. Groundwater contribution to crop water requirement of waterleaf was estimated for two separate 10-day periods of deficient rainfall and no irrigation during the growing cycle of the crop. Percolation loss from the root zone was disregarded.

3. Results and Discussion

Groundwater contribution to water need of waterleaf in South-South Nigeria was studied with oxisols of Obio Akpa river floodplain in twelve drum lysimeters. Six drums had their bottom removed while six drums had their bottom intact. The results which were summarized using tables and graphs are presented in tables 3-6 and figures 3-4

Table 1 presents data on the hydraulic properties of the lysimeter soils. These properties are important in quantifying the physical processes active in the unsaturated zone of soils. They are also important for the characterization of many aspects of unsaturated soil water flow processes. They regulate the movement and retention of water in the soil. The higher values of the data for sandy clay compared to sandy loam soil are indicative of the high tenacity which the soil holds onto water. The low saturated hydraulic conductivity of the sandy clay soil describes the difficulty water encounters in passing through the soil pore spaces. This property is more favorable in the sandy loam soil. These differences are explained by the increase in permeability of soils as water content decreases and, permeability increases with the amount and size of soil pores.

Table 2, presents data on the water table drawdown during the experimental period. The depth varied from 0.66 m, when the study commenced, to 0.88 m towards the end of December, in the first stage of the study. Again, the depth increased from 1.05 to 1.14 m between January 5 and 18. The depth to water table was influenced by the stage of growth and the evaporative demand of the crop [17][18] Soil moisture extraction rates for waterleaf in the two types of soil and water table depths are presented in tables 3-6.

Table 1: Hydraulic properties of lysimeter soils

Soil type	Soil water content			Saturated hydraulic conductivity $K_{sat.}$ m/day
	Saturation θ_{sat} m^3/m^3	Field capacity cm^3/cm^3	Wilting point m^3/m^3	
Sandy loam	0.42	0.21	0.10	0.380
Sandy clay	0.50	0.32	0.23	0.115

Table 2 : Water Table Drawdown

Days	Date	Depth		Days	Date	Depth
1	December 18	0.66		11	January 5	1.05
2	December19	0.68		12	January 8	1.08
3	December 20	0.70		13	January 9	1.09
4	December 21	0.70		14	January 10	1.09
5	December 22	0.73		15	January 11	1.08
6	December27	0.75		16	January 12	1.09
7	December 28	0.76		17	January 15	1.0
8	December 29	0.80		18	January 16	1.0
9	January 3	0.82		19	January 17	1.12
10	January 4	0.84		20	January 18	1.14

Table 3: Soil moisture extraction rate for sandy loam soil at 0.74m water table depth

Days	Treatments	Soil Moisture Extraction Top (0 - 300mm)	Middle (300 - 600mm)	Bottom 600 - 900mm	Total (mm)	Capillary rise (mm/day)
1	BL	1.40	2.36	0.95	4.71	4.10
	B	0.17	0.29	0.15	0.61	
2	BL	1.54	2.58	1.00	5.12	4.41
	B	0.21	0.34	0.16	0.71	
3	BL	1.54	2.63	1.00	5.17	4.53
	B	0.18	0.32	0.14	0.64	
4	BL	1.68	2.81	1.04	5.53	4.77
	B	0.23	0.39	0.14	0.76	
5	BL	1.68	2.76	1.04	5.48	4.64
	B	0.25	0.42	0.17	0.84	
6	BL	1.77	2.90	1.09	5.76	4.94
	B	0.28	0.41	0.13	0.82	
7	BL	1.72	2.86	1.04	5.62	4.87
	B	0.24	0.40	0.11	0.75	
8	BL	1.77	2.90	1.09	5.76	4.95
	B	0.27	0.41	0.13	0.81	
9	BL	1.77	2.94	1.13	5.84	5.07
	B	0.22	0.41	0.14	0.77	
10	BL	1.90	3.17	1.22	6.29	5.33
	B	0.28	0.47	0.21	0.96	
Total		**16.74**	**29.91**	**10.6**	**57.25**	**47.61**
%		**29**	**52**	**19**		**83**

Table 4: Water extraction rate for sandy loam soil at 1.0m water table depth

Days	Treatments	Soil Moisture Extraction Top (0 - 300mm)	Middle (300 - 600mm)	Bottom 600 - 900mm	Total (mm)	Capillary rise (mm/day)
1	BL	1.00	1.77	0.72	3.49	2.55
	B	0.28	0.44	0.22	0.94	
2	BL	1.54	1.90	0.72	4.16	2.92
	B	0.39	0.59	0.26	1.24	
3	BL	1.04	1.90	0.68	3.62	2.45
	B	0.37	0.58	0.22	1.17	
4	BL	1.09	1.90	0.68	3.67	2.47
	B	0.41	0.57	0.22	1.20	
5	BL	1.18	2.04	0.72	3.94	2.79
	B	0.40	0.57	0.18	1.15	
6	BL	1.17	2.04	0.72	3.93	2.69
	B	0.41	0.61	0.21	1.24	
7	BL	1.13	2.04	0.68	3.85	2.58
	B	0.42	0.65	0.20	1.27	
8	BL	1.18	2.04	0.72	3.94	2.74
	B	0.41	0.59	0.20	1.20	
9	BL	1.18	2.13	0.77	4.08	2.56
	B	0.47	0.77	0.28	1.52	
10	BL	1.22	2.22	0.82	4.26	2.71
	B	0.47	0.77	0.31	1.55	
Total		**11.73**	**19.98**	**7.23**	**38.94**	**26.46**
%		**30**	**51**	**19**		**68**

Table 5: Soil moisture extraction rate for sandy clay soil at 0.74m water table depth

Days	Treatments	Soil Moisture Extraction Top (0 - 300mm)	Middle (300 - 600mm)	Bottom 600 - 900mm	Total (mm)	Capillary rise (mm/day)
1	BL	1.53	2.59	1.30	5.42	1.27
	B	1.18	1.99	0.98	4.15	
2	BL	1.61	2.67	1.34	5.62	1.26
	B	1.30	2.04	1.02	4.36	
3	BL	1.65	2.79	1.34	5.78	1.27
	B	1.30	2.19	1.02	4.51	
4	BL	1.73	2.85	1.35	5.93	1.19
	B	1.58	1.89	1.27	4.74	
5	BL	1.81	2.99	1.41	6.21	1.39
	B	1.39	2.35	1.08	4.82	
6	BL	1.87	3.10	1.41	6.38	1.39
	B	1.47	2.46	1.08	5.01	
7	BL	1.93	3.14	1.45	6.52	1.45
	B	1.48	2.47	1.12	5.07	
8	BL	1.89	3.10	1.45	6.44	1.43
	B	1.46	2.45	1.10	5.01	
9	BL	1.93	3.18	1.53	6.64	1.30
	B	1.54	2.58	1.22	5.34	
10	BL	2.97	3.26	1.61	7.84	1.28
	B	1.60	2.68	1.28	5.56	
Total		**17.94**	**29.69**	**14.22**	**61.85**	**13.23**
%		**29**	**48**	**23**		**21**

Table 6: Water extraction rate for sandy clay soil at 1.0m water table depth

Days	Treatments	Soil Moisture Extraction Top (0 - 300mm)	Middle (300 - 600mm)	Bottom 600 - 900mm	Total (mm)	Capillary rise (mm/day)
1	BL	1.10	1.82	0.93	3.85	0.41
	B	0.97	1.63	0.84	3.44	
2	BL	1.40	1.86	1.03	4.31	0.64
	B	1.26	.163	0.78	3.67	
3	BL	1.21	1.92	0.97	4.13	0.54
	B	1.06	1.68	0.85	3.59	
4	BL	1.21	2.09	0.96	4.24	0.35
	B	1.17	1.86	0.86	3.89	
5	BL	1.30	2.13	0.01	4.44	0.51
	B	1.14	1.89	0.90	3.93	
6	BL	1.34	2.25	1.01	4.60	0.55
	B	1.17	1.99	0.89	4.05	
7	BL	1.29	2.10	1.00	4.36	0.41
	B	1.17	1.91	0.89	3.95	
8	BL	1.29	2.17	1.00	4.44	0.48
	B	1.14	1.13	0.89	3.96	
9	BL	1.32	2.21	1.05	4.60	0.52
	B	1.17	1.97	0.94	4.08	
10	BL	1.40	2.29	1.13	4.83	0.49
	B	1.26	2.06	1.02	4.34	
Total		**12.86**	**20.84**	**10.09**	**43.79**	**4.9**
%		**29**	**48**	**23**		**11**

Table 3 presents the amount of water extracted at a depth of 0.74 m from sandy loam soil to meet the water needs of waterleaf. A total of 16.74 mm or 29% of moisture was contributed by the top 300 mm layer of soil. The middle layer (300-600 mm) contributed 29.91 mm or 52% moisture while the deeper layer (600-900 mm) contributed 10.6 mm or 19%. Total moisture uptake during this 10- day period was 57.25 mm. 83% of this amount was groundwater contribution to the water need of waterleaf

Similarly, table 4 presents soil moisture extraction data for the same sandy loam soil but, at a water table depth of 1.0 m. 11.73 mm or 30% of moisture was contributed by the upper 300 mm layer of soil. 19.98 mm or 51% of moisture was contributed by the middle 300-600 mm of soil. 7.23 mm or 19% was contributed from the deeper 600-900 mm layer of soil. Capillary rise contribution to water needs of waterleaf was 24.46 mm. This represented 68% of total water uptake of 38.94 mm during the period of study

Table 5 shows soil moisture extraction rate for sandy clay soil at 0.74 m depth to water table. Total amount of moisture extracted by waterleaf during the period of study was 61.85 mm. 17.94mm or 29% was extracted from the upper 300 mm layer of soil. 29.69 mm or 48% was extracted from the 300-600 mm soil layer and 14.22 mm or 23% was extracted from the deeper 600-900 mm layer of soil. Capillary rise contribution to extracted soil moisture was 13.23 mm or 21mm

Table 6 presents the extracted moisture from sandy clay soil at 1.0 m depth to water table. Total amount of moisture extracted from all the depths was 43.79 mm. Top 300 mm soil layer contributed 12.86 mm or 29%. 300-600 mm soil layer contributed 20.84 mm or 48% while the 600-900 mm soil layer contributed 10.09 mm or 23%. Capillary rise contribution to total amount of water extracted from all the depths was 4.9 mm or 11%. Comparing data in tables 3-6 reveals that crop water extraction was higher in the middle depths (300-600mm) than the upper and lower depths in the different soils and depths to water table. It is likely that the waterleaf roots proliferated in the 300-600mm soil depth to meet its water requirement from the capillary fringe of the soil. This proves that the water table holds a great promise for reducing the irrigation requirement of crops when scheduling irrigation. Luo [19] had reported 75% contribution of groundwater to crop requirement of winter wheat in sandy loam soil at 1.0 m depth to water table and 3% at 3.0 m depth to water table of the same soil. He noted 0.60 -0.65 m as the depth at which groundwater may evaporate at potential rate. Similarly, Richard [20] reported up to 30% groundwater contribution to crop water requirement for cotton in sandy clay soil at 1.5 m depth to water table. Egharevba [21] also reported that 37% of total corn crop water requirement was derived from groundwater at 1.0 m depth to water table in sandy clay soil.

By considering the mean of the 10-day capillary rise in tables 3-6, it can be seen that 4.76 mm was the contribution in table 3, 2.65 in table 4, 1.32 in table 5 and 0.49 in table 6. Also since there was no other import of water during the simulation period, groundwater extraction (capillary rise) is equated to crop water requirement. Udom and Idike [22] had determined the crop water requirement of waterleaf as 4.28mm/day at Nsukka, Nigeria. By comparing this value of crop water requirement with those in tables 3-6, we discover that the groundwater holds great promise for reducing the irrigation requirement of the crop when scheduling irrigation. The results of capillary rise variation with depth to water table in the two soils studied are presented in tables 7-8. Table 7 shows that in sandy loam soil a total of 47.61 mm was contributed to waterleaf water need from the 0.74 m depth to water table while the 1.0 m depth to water table supplied 24.46 mm to waterleaf crop water need during the period of study.

Table 7: Capillary rise for sandy loam soil at different depth to water table

Days	Depth to water table	
	0.74 m	1.0 m
1	4.10	2.55
2	4.41	2.92
3	4.53	2.45
4	4.77	2.47
5	4.64	2.79
6	4.94	2.69
7	4.87	2.58
8	4.95	2.74
9	5.07	2.50
10	5.33	2.71
Sum X	47.61 4.76	24.46 2.45

Table 8 presents the capillary rise contributions from sandy clay soil. The 0.74 m depth to water table contributed 13.23 mm while the 1.0 m depth to water table supplied 4.9 mm during the experimental period. Tables 7 and 8 were analyzed to establish the relationship between capillary rise and depth to water table. Application of Student t-test at 5% level of significance showed that there was significant difference of capillary rise at different depths to water table irrespective of soil type.

Table 8: Capillary rise for sandy clay soil at different depth to water table

Days	Depth to water table	
	0.74 m	1.0 m
1	1.27	0.41
2	1.26	0.64
3	1.27	0.54
4	1.19	0.35
5	1.39	0.51
6	1.39	0.55
7	1.45	0.41
8	1.43	0.48
9	1.30	0.52
10	1.28	0.49
Sum X	13.23 1.32	4.9 0.49

The average daily capillary rise contributions to waterleaf crop water requirement in the 300-600 mm soil depth (rooting depth) of sandy loam and sandy clay soil lysimeters without bottom were 51% and 48% respectively. The observed trend in these values is explained by the fact that permeability of soil to water is controlled partly by the chemistry of the soil matrix and pore water, but mainly by the pore size and geometry [23].

4. Conclusion

A study on groundwater contribution to crop water requirement of water leaf in oxisols of South-South Nigeria was carried out. Estimated mean daily capillary rise contribution to crop water requirement of waterleaf from the 0.74 m depth to water table was 4.76 mm and 1.32 mm for sandy loam and sandy clay soils respectively. Small pores give much hydraulic resistance to flow than large pores. Thus, although the porosity of sandy loam is less than that of sandy clay soil, the much greater bonding in the sandy clay soil makes the amount of water held in the soil at a given pressure to be more in sandy clay than in sandy loam soil. Thus, at the same pressure and field condition, less amount of water is transmitted through sandy clay soil than through sandy loam soil. Therefore, sandy loam soil supplies more capillary water than sandy clay soil at the same pressure. There was significant relationship between capillary rise and depth to water table for the soils studied. In other words, capillary rise varies with depth to water table. It is concluded that soils with shallow water table may need no irrigation or the need for irrigation water may be reduced considerably due to the ability of plant roots to draw sufficient moisture directly from the water table. Furthermore, the adaptation of irrigation scheduling approach as presented in this study will potentially reduce the impact of over irrigation within the study area.

References

1. Hillel, D. H., Tepaz, H and Kielen, Van. "A Macroscopic scale model of water uptake by a non uniform root system and of water and salt movement in the soil profile. *Soil Science*, vol. 1, Number 2, 1975, pp 242-255.

2. Tanji, K. K. and Kielen N. C. " Agricultural drainage water management in arid and semi-arid areas". FAO irrigation and drainage paper 61. 2002. http://www.fao.org/docrep. Accessed on October 20,2011

3. Kumar, C. P. "Estimation of groundwater recharge using soil moisture balance approach". National Institute of Hydrology. http://www.academia.edu. Accessed on January18, 2012

4. FAO. Crop evapotranspiration: Guide for computing crop water requirement. *FAO Irrigation and Drainage* paper 56. Rome. 1998

5. Udeh, N.C. "Lysimeter determination of consumptive use of swamp rice." *Third Nigerian Society of Agricultural Engineers Conference*, pp120-134. 1979

6. Andales, A. A., Chavez, J. L. and Bander, T. A. "Irrigation scheduling : the water balance approach." http://www.ext.colostate.edu. Accessed on November 23, 2011

7. Harris, G. "Water balance scheduling." Agriculture, Fisheries and Forestry Department. Queensland Govt., http://www.daff.qld.gov. Accessed on November 9, 2011.

8. Ekpo, T. U. U. "Gender participation in vegetable production in Akwa Ibom State." *Journal of science, education and technology*, vol. 2, Number 2, 2009, pp 123-13

9. Enete, A. A and Okon, U. E. "Economics of waterleaf production in Akwa Ibom State. Field Action Science Report, vol. 4, 2010. http://www.factsreport.revues.org. Accessed on May 20, 2012.

10. Esu, I. E. "Characterization, Classification and Management Problems of the Major Soil Orders in Nigeria". 26TH *Inaugural Lecture of the University of Calabar*. 2005

11. Davison, L. "Soil mechanics." University of the West of England. 2000. http://www.environment.uwe.ac.uk. Accessed on October 28,2012

12. Mackay, R. and Younger, P. L. "Groundwater levels, aquifer properties and sampling". In Hydroinformatics and Management Systems University of Newcastle. 2000 pp 238-264

13. Evans, R., Cassel, D. K., Sneed, R. E "Calibrating soil water measuring devices". North Carolina Cooperative Extension Service. http://www.bae. ncsu.edu. Accessed on January 18, 2008

14. Gee, G. W., Bauder, J. W. "*Particle size analysis*." In Klade A. (ed.) Methods of soil analysis. Madison.1986. pp 342- 358.

15. Saxton, K. E : "Estimating generalized soil-water characteristics from texture". *Soil Science Society of America Journal*, vol. 50, Number 4, 1986, pp1031-1036.

16. ASTM D7263-09, "Standard test methods for laboratory determination of density of soil specimens". http://www.astm.org/standards. accessed on July 28,2010.

17. Bouwer, H. *Groundwater Hydrology*. McGraw Hill Book Company. New York.

18. Mazur ,C., Wiley, M. J., Wiilcox, D. A. "Estimating evapotranspiration and groundwater flow from water table fluctuations for a general wetland scenario". *Ecohydrology*, vol. 10. Number 1. 2013, pp1342-1356.

19. Luo, Y. "Seasonal groundwater contribution to crop water use assessed with lysimeter observation and model simulations*." Journal of Hydrology*, vol. 4. 2010, pp325-335.

20. Richard, S., Ayars, J. "Characterizing groundwater use by cotton using weighing lysimeter." National Irrigation Symposium. http://www.usda.gov. Accessed on November 18, 2011.

21. Egharevba, N. A. "*Groundwater contribution to corn water use in inland valley of Badeggi, Nigeria*". PhD dissertation. Ahmadu Bello University, Nigeria. 2000

22. Udom,I. J., Idike, F. I. Comparison of consumptive use of dry season waterleaf as determined by irrigation water dripper and soil moisture cells. *Nigerian Journal of Agicultural Technology*., vol. 10. 2002, pp 43-50.

23. Brady, N. C., Neil, R. R. *The Nature and Properties of Soils.* Prentice-Hall. New Jersey. 1993.