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PERFORMANCE EVALUATION OF A PLASTIC BOTTLE-BASED SUBSURFACE IRRIGATION SYSTEM

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ABSTRACT

Several attempts have been made by researchers for an efficient and cost-effective means of applying irrigation water, since traditional Surface irrigation system is becoming unsustainable due to water shortage. Adoption of most of these systems have failed because sophistication in design and complexity in setup. The use of recycled plastic bottles (PB) is another attempt at achieving a less complex system, yet promoting reuse of spent PB. Experimental Plot was set up in Samaru-Zaria, for a Subsurface irrigation system using recycled PB perforated at the base and connected to network of pipes. Evaluation of the system was carried out to determine the orifice size, orifice depth and the type of fertilizer application with the best agronomic yield parameters in RCBD design with sixteen (16) treatments replicated three (3) times. The results show the treatment with 3mm orifice size buried to 10mm depth with inorganic fertilizer performs best. The use of PB is therefore recommended for use in subsurface system to promote low-cost, less complex yet very effective water saving irrigation system.

Keywords: Recycled Plastic bottle, Subsurface irrigation, Orifice size

INTRODUCTION

Several attempts have been made by researchers for an efficient and effective means of applying irrigation water. Oiganji *et al.*, (2016) recommended the adoption of Medi-emitters (medical infusion set) drip system by farmers in Northern Nigeria; this is in line with Mofoke (2006) who affirm its potential as a continuous flow, point source drip system. However, the economic realities of the present-day Nigeria may have impeded its adoption. A medical infusion set (Medi-emitter) of #25/set (Mofoke, 2006) is now as high as #250/set (2023). The cost implication coupled with complexity of re-modifying the Medi-emitter necessitated the search for an alternative that could perform the same way if not better with low initial cost and less complexity in set up. One of such potential alternatives is the plastic bottle Subsurface irrigation method as recommended by XiShui et al., (2013); Kadhane & Manekar, (2016); Dlamini & Khumalo (2019); Alrubaye et al., (2020); Alrubaye et al., (2021) and Alrubaye et al., (2022), have reported the potentials of a spent plastic bottles as a low-cost alternative to conventional system.
While Dlamini and Khumalo (2019); XiShui et al., (2013); recommends the use of plastic bottles as viable alternatives to conventional emitters for rural farmers in the growing of vegetables, limited literature exists in terms of research findings, as to the performance of the system and its adaptability to different soil types, climates and crops. This research seeks to test the performance of a plastic bottle based subsurface irrigation system in the production of lettuce.

MATERIALS AND METHODS

Description of the Study Area

This research was carried out at Samaru – Zaria, Nigeria. Located within the Northern Guinea Savannah ecological zone of Nigeria with a Semi -arid climate. The location lies on latitude 11°11' N and longitude 7° 38' E at an altitude of 686 meters above the sea level. Information about the research area has been provided in details by many researchers (e.g., Igbadun et al., 2012).

Installation of the System

The subsurface system was set up on the field using the materials and methods stated below.

Materials

PVC tank (2000 litres), PVC pipes, Pipe fittings (elbows, Tees, end caps, control valves), PVC Gum, Used Plastic bottles (0.75L), Rubber hose.

Methods

Land preparation

The land was pulverized and levelled manually using hoe.

Experimental design

Randomized Complete Block Design (RCBD) was used with treatment factors being four different orifice sizes H_2, H_3, H_4, H_5 (2,3,4, and 5mm diameter), two levels of depth of the orifice D_{10}, D_{15} (10cm and 15cm) and two types of fertilizer application O & I (Organic and Inorganic). The selection of orifice sizes was informed by the findings of Xishi et al., (2013), and that of depth of orifice installation, informed by the effective rooting depth of lettuce (15cm). Hence, the study comprised of sixteen (16) treatments (4x2x2), replicated three times to give a total of forty-eight (48) number of observations.

Experimental Field Layout

Water flows by gravity from the tank (2000liters capacity, sitting on 2m height platform). PVC pipes were used as mains and laterals to supply water to the field (See figure 1). The plastic bottles which were sourced from waste materials serve as a sub-storage as well as the discharge point. A rubber hose (8mm diameter) was used to divert the water from the laterals to each plastic bottle spaced at 0.3m. An end cap was used to close the ends of the laterals. The lateral spacing was 0.5m. The main line was a PVC pipe of 25.4mm diameter (1 inch). The sub-main 19mm (3/4 inch), and the laterals 12.7mm (1/2 inch) in diameter. An 8mm siphon was cut to about 15cm length and used to divert water from the lateral to the bottles through the PB cap. The plastic bottles were punctured on the side to required diameters (2, 3, 4 & 5mm) close to the base.
Aggregate material bigger than the orifice sizes was used as envelope material around the orifice to prevent clogging of the orifice.

Table 1: Description of Experimental Treatment Combination.

Number of Treatments	Treatments Combination	Description of Treatment Combination
T1	D_{10} H_2 I	Orifice of 2mm diameter buried 10cm below soil surface with inorganic fertilizer application
T2	D_{10} H_3 I	Orifice of 3mm diameter buried 10cm below soil surface with inorganic fertilizer application
T3	D_{10} H_4 I	Orifice of 4mm diameter buried 10cm below soil surface with inorganic fertilizer application
T4	D_{10} H_5 I	Orifice of 5mm diameter buried 10cm below soil surface with inorganic fertilizer application
T5	D_{15} H_2 I	Orifice of 2mm diameter buried 15cm below soil surface with inorganic fertilizer application
T6	D_{15} H_3 I	Orifice of 3mm diameter buried 15cm below soil surface with inorganic fertilizer application
T7	D_{15} H_4 I	Orifice of 4mm diameter buried 15cm below soil surface with inorganic fertilizer application
T8	D_{15} H_5 I	Orifice of 5mm diameter buried 15cm below soil surface with inorganic fertilizer application
T9	D_{10} H_2 O	Orifice of 2mm diameter buried 10cm below soil surface with organic manure (cow dung) application
T10	D_{10} H_3 O	Orifice of 3mm diameter buried 10cm below soil surface with organic manure (cow dung) application
T11	D_{10} H_4 O	Orifice of 4mm diameter buried 10cm below soil surface with organic manure (cow dung) application
T12	D_{10} H_5 O	Orifice of 5mm diameter buried 10cm below soil surface with organic manure (cow dung) application
T13	D_{15} H_2 O	Orifice of 2mm diameter buried 15cm below soil surface with organic manure (cow dung) application
T14	D_{15} H_3 O	Orifice of 3mm diameter buried 15cm below soil surface with organic manure (cow dung) application
T15	D_{15} H_4 O	Orifice of 4mm diameter buried 15cm below soil surface with organic manure (cow dung) application
T16	D_{15} H_5 O	Orifice of 5mm diameter buried 15cm below soil surface with organic manure (cow dung) application

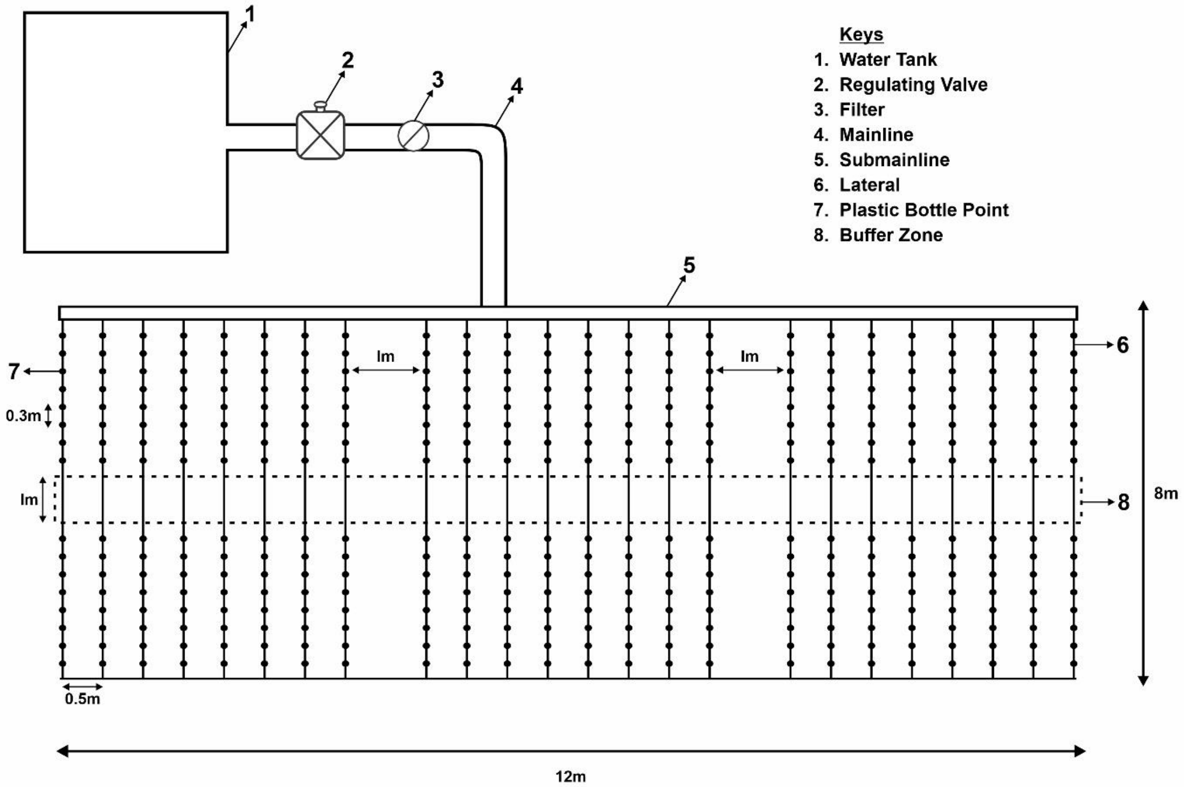

Figure 1: Experimental field layout.

Plate 1: The Set up (a) immediately after transplanting (b) at maturity.

Agronomic practice

Lettuce seedlings were transplanted 10cm away from the bottles on the same side where the hole was punctured (Dlamini & Khumalo, 2019). The spacing between bottles were 30cm, to give a spacing of 30cm between lettuce plants (Gashaw and Haile, 2020).

The fertilizer application (organic and inorganic) was done 2 weeks after transplanting with the organic applied through surface dressing at the rate of 1.2kg/m^2. The inorganic fertilizer was applied through incorporation at the rate of 50g/m^2.

Data Collection

Measurement of plant height (cm), number of leaves, leave width (cm), leave length (cm), root length (cm) and fresh weight of lettuce (g) were taken at maturity. The harvesting and measurement of the above agronomic data was done on the 15th March, 2023.

Leaf Area Index (LAI): The leaf area (LA) and leaf area index (LAI) were determined by measuring the length and width of the leaf as described by Ibrahim & Mahgoub (2014) and expressed in equation 6 and 7 respectively.

$$LA = cLW \ldots\ldots \quad (1)$$

$$LAI = \frac{LA\ x\ NLxNP}{GA} \ldots\ldots \quad (2)$$

Where; LA and LAI are leaf area and leaf area index respectively. c is the shape factor for the crop, L and W area length and width of the crop. NL, NP and GA are the number of leaves per plant, number of plants per m^2 and ground area in m^2.

Computation of Water Use Efficiency, WUE.

The WUE is expressed as the weight of crop produced per amount of water used, that is, Kg/m^3. The WUE was calculated as using equation 3;

$$\text{WUE} = \frac{Y}{IR} \ldots \quad (3)$$

Where; WUE = Water use efficiency (Kg/m$^{3)}$, Y = crop yield (Kg), IR = Amount of irrigation water used (m^3)

Analysis of Data

A multi-factor Duncan Multiple Range Test (DMRT) was used to determine if there is significant difference in the yield and growth parameters of the lettuce under the different treatments, using the SAS Software.

RESULTS AND DISCUSSION

Yield Performance

The performance of the crop (Lettuce) was determined on the basis of the growth in plant height, number of leaves, leave width, leave length, root length and fresh weight of lettuce.

Effects of the Treatments on Yield Parameters

Table 2 shows the average yield parameters of the lettuce plant at maturity. The plant height, fresh lettuce mass and water use efficiency has their highest average value of 22.20cm, 1492.67g and 5.4kg/m3 respectively under the treatment D10H3I (3mm orifice diameter buried at 10cm below the surface with inorganic fertilizer application). The highest value for root length (14.07cm), and Leaf area index (4.88) were obtained under D15H2I and D10H4I respectively.

Table 2: Average yield parameters of Lettuce at Maturity

Treatments	Plant Height (cm)	Root Length (cm)	Leaf Area Index	Fresh Lettuce Mass (g)	WUE (kg/m^3)
D10 H2 I	15.30	10.43	3.65	1102.67	3.99
D10 H3 I	22.20	9.17	4.39	1492.67	5.40
D10 H4 I	19.30	8.60	4.88	1084.00	3.92
D10 H5 I	18.20	12.17	4.26	964.00	3.50
D15 H2 I	17.90	14.07	3.65	859.33	3.11
D15 H3 I	18.37	11.33	4.00	1079.33	3.94
D15 H4 I	17.17	10.33	3.15	866.67	3.14
D15 H5 I	16.87	11.83	4.18	1082.67	3.92

D10 H2 O	15.23	10.57	2.68	693.33	2.51
D10 H3 O	14.33	10.37	3.60	746.00	2.70
D10 H4 O	14.30	9.70	2.97	830.00	3.00
D10 H5 O	15.53	7.67	3.26	834.00	3.02
D15 H2 O	12.73	10.67	2.57	466.00	1.69
D15 H3 O	14.60	12.03	3.21	709.33	2.57
D15 H4 O	12.83	10.53	3.29	518.33	1.87
D15 H5 O	14.83	9.70	3.33	797.00	2.88

Table 3 is the results of the statistical analysis showing the effects of treatment factors on the yield of lettuce using DMRT to separate the mean.

Table 3: Effects of Treatments on yield.

Treatment	PH (cm)	RL (cm)	LAI	FLW (g)	WUE (kg/m^3)
Orifice Size (H)					
2mm	15.33b	11.43a	3.14a	780.4a	2.82a
3mm	17.38a	10.73a	3.80a	1006.8a	3.64a
4mm	15.90ab	9.79a	3.57a	824.80a	2.98a
5mm	16.36ab	10.34a	3.76a	919.6a	3.32a
SE±	1.75	2.10	0.79	245.3	0.89
Depth of Orifice (D)					
10cm	16.82a	9.83b	3.71a	968.42a	3.50a
15cm	15.66b	11.31a	3.42a	797.38b	2.89b
SE±	1.14	1.37	0.52	160	0.58
Fertilizer Application (F)					
Inorganic	18.18a	10.99a	4.02a	1066.42a	3.86a
Organic	14.30b	10.15a	3.11b	699.38b	2.53b
SE±	1.14	1.37	0.52	160	0.58
Interaction					
D*H	NS	NS	NS	NS	NS
D*F	NS	NS	NS	NS	NS
H*F	NS	NS	NS	NS	NS
D*H*F	*	NS	NS	NS	NS

PH= Plant Height, RL= Root Length, LAI= Leaf Area Index, FLW= Fresh Lettuce Weight, WUE= Water Use Efficiency. Means followed by same letter(s) in the same column are not different statistically at $P = 0.05$ using DMRT. * = Significant, NS = not significant.

Discussion

The plant height shows significant difference due to orifice size, depth of the orifice and type of fertilizer applied. The highest value was recorded under the 3mm orifice, 10cm depth of orifice and inorganic fertilizer application. The interactions between the factors are insignificant except for that among the tree factors combined.

For the root length, there was no significant difference due to orifice size and fertilizer applications, but there exists a significance due to depth of orifice, with 10cm depth having the highest. Interactions between and among the factors are not significant under root length.

There is no significance difference for the values obtained for the leaf area index due to orifice size and depth, there was however a significant difference due to fertilizer application with inorganic having a higher value than organic. For the interactions, the observation is the same as that under root length.

The fresh lettuce average obtained from the experiment shows no significant difference due to orifice sizes as a factor. However, there is significant difference due to depth of the orifice and the fertilizer application, with the 10cm orifice depth and inorganic fertilizer application having the highest. For interactions, the observation is the same as in root length and leaf area index.

Average values of water use efficiency obtained follows the exact pattern for the fresh lettuce mass, with significant difference due to depth of orifice and fertilizer application but not orifice sizes. The level of the factor with highest value were also observed to be 10cm and inorganic for depth of orifice and fertilizer application respectively.

The significant difference due to orifice sizes is attributable to the flow rate from the different orifice sizes when compared to the infiltration rate of the soil. The higher the orifice sizes, the more the flow rate. When the flow rate becomes higher than the infiltration rate of the soil, surface ponding will take place. This will enhance surface evaporation, thereby reducing water use efficiency. Another factor responsible for the significant difference is the effective rooting depth of the plant as against the depth of orifice. When the root is surrounded by the wetting front created at the depth of orifice installation, uptake of water becomes more effective. The rate of decomposition/dissolution of the fertilizer applied also determine the effectiveness of the fertilizer applied. Inorganic fertilizer is known for quick action compared to organic which require more time for decomposition.

It can be inferred from the forgoing, that the depth of the orifice in a plastic bottle subsurface irrigation as well as the type of fertilizer applied affects significantly the yield of the lettuce crop.

CONCLUSION

Based on the results of the investigation, it is can be concluded that;

i. The discharge orifice orientation of the Plastic bottle and the organic matter application affects the effectiveness of the Subsurface system.
ii. A sustainable subsurface system of irrigation using spent plastic bottles can be designed for effective water management.

REFERENCES

Alrubaye, Y.L., Yusuf B., Mohammad, T.A., Nahazanan, H., & Zahawi, M.A.M., (2022). Experimental and Numerical Prediction of Wetting Fronts Size Created by Subsurface Bubble Irrigation system. Sustainability. 14:11492

Alrubaye Y.L., Yusuf B., (2021), Former and Current Trend in Subsurface irrigation Systems. Pertanika Journal of Sci. & Tech. 29:1-30

Alrubaye, Y.L., Yusuf B., & Hamad, S.N., (2020). Development of a self-regulated bubble irrigation system to control size & shape of wetting fronts. Pertanika Journal of Sci. & Tech. 28(28):1297-1313

Dlamini M. V. and Khumalo T., (2019), Comparing the performance of a home-made bottle drip to a commercial drip system in the production of lettuce (Lactuca sativa L.) International Journal of Environmental & Agriculture Research (IJOEAR) Vol-5, Issue-9.

Gashaw, B. and Hailer, S., (2020) Effect of Different Rates of N and Intrarow Spacing on Growth Performance of Lettuce (Lactuca sativa L.) in Gurage Zone, Wolkite University, Ethiopia. Hindawi Advances in Agriculture, volume 2020.

Igbadun, H.E., Ramalan, A.A. and Oiganji, E. (2012). Effects of Regulated Deficit Irrigation and Mulch on Yield, Water Use and Crop Water Productivity of Onions in Samaru, Nigeria. Agricultural Water Management 109: 162-169.

Ibrahim, Y. M., & Mahgoub, S. A. G. (2014). Evaluation of Wheat Growth Under Different Fertilizer Type, Application and doses at Northern State of Sudan. *Journal of Agriculture and Environmental Sciences*, *3*(1), 173–180. www.aripd.org/jaes

Mofoke A.L.E (2006). Design, Construction and Evaluation of a Continuous-Flow Drip Irrigation System. Unpublished PhD Thesis in Department of Agricultural Engineering, ABU Zaria.

Oiganji E., Ibrahim I. I., Abubakar A.M., and Bayo D. (2016), Hydraulic Characteristics of Medi-Emitter Drip Irrigation System in Jos, Nigeria PAT June, 2016; 12 (2): 126-134

XiShui Y., Oladipo I.O., YunCheng L. and BeiBei Z., (2013) Development of very low-cost drip irrigation system using spent plastic bottle for sustainable farming in poor countries. Journal of Food, Agriculture and Environment vol. 11 no.2, part 2 pp 691-695 ref. 27