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RESEARCH ARTICLE

STUDY OF WETTING PATTERN AND DEPTH FOR DIFFERENT SOIL TYPES USING DRIP IRRIGATION IN THE LOWER BENUE RIVER FLOODPLAIN NIGERIA

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ABSTRACT

A field experiment was conducted in the University of Agriculture, Makurdi Nigeria to study the wetting pattern and depth of three different soil types (clay, loamy and sandy) at different flow rates of 0.5, 1.0, 1.5, and 2.0 litres per hour (l/h). Drip irrigation was used as water application method to the soil. The results obtained indicated that different soil types have different wetting pattern and wetting depth because of different textural composition. Surface wetted width increased with flow rates across soil types, while wetted depth decreased with increasing flow rates across the soil types. Moisture content afer wetting (irrigation) increased with increase in flow rates and followed the order clay > loam > sand while the wetted width followed the order sand > loam > clay. Analysis of variance also compared the wetted widths or diameters and wetted depths with different soil types and it revealed a significant difference at $P<0.05$, which indicate that soil type has effect on wetting pattern and depth.

INTRODUCTION

Irrigation for increasing food production is very important for food security due to the demographic pressure, combined with increased competition for water and climate change. The increasing pressure on natural resource, particularly on land and water, stemming from complex water-food-energy linkages, makes it clear that the increase in food production cannot be achieved through only rainfed crop production. Excessive application of water generally entails losses because of surface run-off from the field and deep percolation below the root zone within the field. An alternative water application method such as the drip irrigation method allow for much more uniform distribution as well as more precise control of the amount of water applied and also decreases nutrient leaching (Phene et al., 1994, Smeal, 2007). Drip irrigation is an efficient method for minimizing the water used in agricultural and horticultural crop production.

Drip irrigation system have proven to increase water productivity (Mailhol et al.,2011) that meets the water use and uniform water requirement of crops, to improve yield and production. This system is effective in determining the soil wetting patterns from emitters which in turn are important for the design and management of drip irrigation systems. The significance of this study is to enlighten farmers, especially those in arid and semi-arid regions where water scarcity is a major problem, on a more effective method of irrigating their crops and conserving this scarce water. The method increases crop yield and reduces evaporative losses. The information on the wetting pattern from emitters will help in the design and management of drip irrigation systems (Garg, 2013). It is essential that the water is applied at a rate that will allow uniform wetting of the root zone. The water flowing from an emitter is distributed in the soil downward by gravity and horizontally by capillary action. The shape of wetting pattern is dependent upon soil type but can be influenced by tillage and soil amendments. Unlike surface and sprinkler irrigation, drip irrigation only wets part of the soil root zone. This may be as low as 30% of the volume of soil wetted by the other methods. The wetting pattern which develop from dripping water onto the soil depending on discharge and soil type.

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The water use efficiency can be affected by the water application rate and system design parameters such as the size, depth, and spacing of pipes, which determine the extent of deep percolation, water losses and soil saturation problems. The ability to predict the geometry and moisture distribution of the wetted zone for different soils, pipe compositions, and system designs can be very useful for developing guidelines and criteria to optimize the performance of irrigation systems. Investigations into the effect of the application rate on the water distribution pattern showed that increasing the water application rate allows water to move in the horizontal directions, while decreasing the application rate leads to greater water movement in the vertical direction for a given volume applied. Changes in the wetted surface radius and the vertical wetted depth were monitored during irrigation and the results showed that the increase in the wetted surface radius and the vertical wetted depth with increasing volume applied can be represented by a power function with power values of about 0.3 and 0.45, respectively. Soil wetting patterns under surface and subsurface micro-irrigation have been measured and analyzed theoretically by a number of authors (Assouline, 2002; Cote et al., 2003; Skaggs et al., 2004; Gardenas et al., 2005., Singh et al., 2006; Wang et al., 2006; Lazarovitch et al., 2007). It is assumed that the geometry of wetted soil, the wetted soil width and wetted soil depth depend on soil type, water application rate, duration of water application and total amount of water to the soil mass.

MATERIALS AND METHODS

Study Area

The study was carried out at the Federal University of Agriculture Makurdi, Nigeria. It lies between Latitude 7º 44æ North and Longitude 8º 54′ East and is located within the floodplain of the Lower Benue River valley. The physiographic span of Makurdi is between 73 – 167 metres (m) above sea level. Due to the general low relief, sizeable portions of Makurdi is waterlogged and flooded during heavy rainstorms. Makurdi town is drained principally by River Benue which divides it into North and South banks which are connected by two bridges (Ocheri, et.al, 2010). The climatic condition in Makurdi town is influenced by two air masses: the warm moist southwesterly and the warm dry northeasterly. The southwesterly air mass is a rain bearing wind that brings about rainfall from the months of May to October. The dry northeasterly air mass blows over the region from November to April, thereby bringing about seasonal drought (Ologunorisa and Tersoo, 2006). The mean annual rainfall is 1190 mm and ranges from 775-1792 mm. The mean monthly relative humidity varies from 43% in January to 81% in July-August. Temperatures are generally high throughout the year, with February and March occurring as the hottest months. Temperature in Makurdi varies from 40ºC (celcius) and a minimum of 22.5º C (Ologunorisa and Tersoo, 2006).

Experimental setup and procedure

The field was cleared and disposed of the vegetation. Soil samples were collected and taken to the laboratory for analysis. The soil was tilled and leveled to enable maximum soil wetting depth and width. PVC tank serving as a source of water was placed at a height of 1 m to provide the flow head. The components of set up are main line (3 m long, diameter 32 mm), sub-main line (6 m long, diameter 16 mm), two laterals (6 m long, (diameter) 12 mm). All the components were coupled together using appropriate fittings. The laterals were laid with caution to ensure a uniform flow and distribution of water from each drip hole. Four drip holes of diameter of 1.2 mm (numbered 1-4) were made on the two laterals with a hand drill at a spacing of 1.5 m apart. End caps were used to cover the ends of the lateral pipes to prevent water from flowing out. Valve was used to control the flow of water from the drip holes. The experiment was conducted on selected three soil types namely; sand, loam and clay. The experimental set up is as shown in Figure 1. It was in such a way that it will be easily dismantled and carried to various locations where the soil types have been identified.

The locations of the various soil types (sand, loam, and clay) were identified by soil analysis using particle size distribution. Four collector cans were used to collect water from the drip holes. The collector cans were placed on a level surface beneath the emitters. The collected water at a time interval (one hour) was measured using a measuring cylinder to obtain the volume of water that each dripper emitted and also to check for uniformity of water flow rate. After the soil was allowed to wet at the specified time (1hr) of water application, the horizontal section of the wetted bulb was measured and then the soil profile was excavated to measure the vertical section of the wetted bulb. Both vertical and horizontal sections were measured with a measuring rule. Four flow rates (0.5 l/h, 1.0 l/h, 1.5 l/h, and 2.0 l/h) were arbitrarily chosen for the experiment. These flow rates were achieved by adjusting the control valve. Analysis of variance (ANOVA) was carried out to analyze the data statistically.

RESULTS

Tables 1- 3 show the values of surface wetted widths (diameter) and the vertical wetted depths according to various flow rates. Table 4 shows average values of soil monitored parameters. Analysis of Variance (ANOVA) was further used to analyze the measured parameters (wetted surface width and vertical depth) across the different soil types with different flow rate as shown in Tables 5 and 6.

DISCUSSION

Comparing the wetted width and wetted depth of different soil types

From Tables (1 – 3) of measured values wetted width (wetted diameter) and depth for the various soils under consideration with different flow rates, it was observed that the wetted width across the different soil types increases with increase in flow rate while the wetted depth decreases with increasing flow rate. With respect to all the flow rates, the wetted widths (diameters) for clay were greater compared to loamy soil while the values of wetted depths for loamy were greater than those of clay soil. This is attributable to the fact that clay soil has finer particles as compared to loam. The pore spaces are greater in loam than clay soil. For sandy soil, the values of wetted depth were higher and the values of wetted width were smaller than the loam and clay soils.

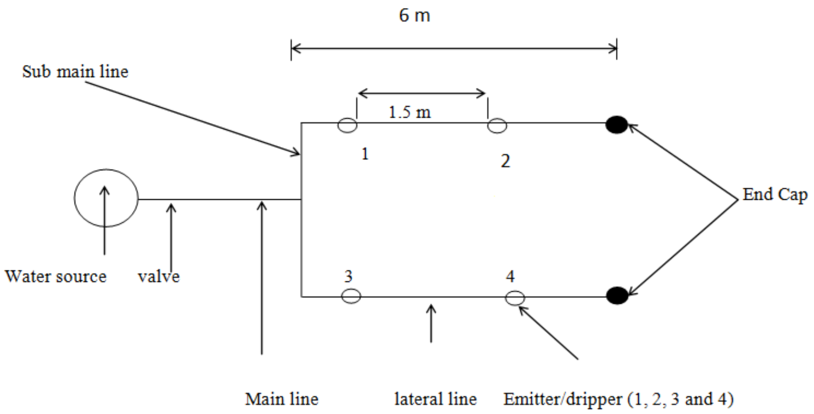

Figure 1. The experimental set up

Table 1. Measured values for clay soil

Drip No.	Wetted Soil (cm)	Flow rates (L/h)			
		0.5	1.0	1.5	2.0
Replications 1	Width	20.00	25.00	29.00	34.00
	Depth	16.80	14.20	11.80	8.90
2	Width	21.00	24.50	27.50	33.50
	Depth	15.50	13.80	12.00	10.00
3	Width	20.50	24.00	28.50	36.00
	Depth	16.50	14.00	12.30	9.00
4	Width	19.50	25.40	28.00	35.00
	Depth	17.00	13.40	12.50	9.50

Table 2. Measured values for loamy soil

Drip No.	Wetted Soil (cm)	Flow rates (L/h)			
		0.5	1.0	1.3	2.0
Replications 1	Width	16.00	22.00	25.00	28.50
	Depth	25.00	21.00	16.00	14.80
2	Width	16.50	21.50	24.70	27.40
	Depth	24.00	20.00	17.60	15.00
3	Width	15.50	22.00	25.00	27.60
	Depth	23.00	19.00	16.50	15.00
4	Width	17.00	20.80	23.80	28.00
	Depth	23.60	18.50	17.00	14.50

Table 3. Measured values for sandy soil

Drip No.	Wetted Soil (cm)	Flow rates (L/h)			
		0.5	1.0	1.3	2.0
Replications 1	Width	12.50	17.00	21.50	24.00
	Depth	31.00	25.00	20.00	17.00
2	Width	12.30	17.60	21.00	26.00
	Depth	30.00	24.00	20.50	18.00
3	Width	11.80	18.00	22.00	25.00
	Depth	29.50	23.00	19.50	16.50
4	Width	11.50	17.50	22.00	24.80
	Depth	28.00	23.60	20.00	17.00

Table 4. Average values of the monitored soil parameters

Soil Type (Textural classification)	Flow rate (l/h)	Wetted Width (cm)	Wetted Depth (cm)	Initial moisture content (%)	Moisture content after wetting (%)
Clay (clay loam)	0.5	20.25	16.44	12.83	14.42
	1.0	24.48	13.85	12.83	18.04
	1.5	28.25	12.15	12.83	21.16
	2.0	34.63	9.35	12.83	26.38
Loamy (loam sand)	0.5	16.25	23.90	6.87	12.68
	1.0	21.58	19.63	6.87	14.83
	1.5	24.63	16.78	6.87	18.64
	2.0	27.88	14.83	6.87	22.25
Sandy (sandy clay)	0.5	12.03	29.63	2.83	9.28
	1.0	17.63	18.90	2.83	11.77
	1.5	21.63	20.00	2.83	14.47
	2.0	24.95	17.13	2.83	19.04

Table 5. Comparing wetted width and wetted depth across different soil types and different flow rates

Source of Variation	Dependent Variable	Sum of Squares	Degree of Freedom	Mean Square	F	Sig
Flow Rate	Width	1087.915	3	362.638	868.017	.000
	Depth	604.022	3	201.341	389.326	.000
Soil Type	Width	505.080	2	252.540	604.485	.000
	Depth	764.801	2	382.401	739.435	.000
Flow Rate * Soil Type	Width	19.481	6	3.247	7.772	.000
	Depth	40.022	6	6.670	12.898	.000
Error	Width	15.040	36	.418		
	Depth	18.618	36	.517		
Total	Width	26707.680	48			
	Depth	17207.090	48			

Table 6. Comparing wetted depth and moisture content for different flow rates and different soil types

Source of Variation	Dependent Variable	Sum of Squares	Degree of Freedom	Mean Square	F	Sig
Flow Rate	Depth	630.772	3	210.257	269.681	.000
	Moisture Content	721.243	3	240.414	1335.253	.000
Soil Type	Depth	796.264	2	398.132	510.653	.000
	Moisture Content	320.108	2	160.054	888.936	.000
Flow Rate * Soil Type	Depth	36.560	6	6.093	7.815	.000
	Moisture Content	8.567	6	1.428	7.930	.000
Error	Depth	28.067	36	.780		
	Moisture Content	6.482	36	.180		
Total	Depth	17162.690	48			
	Moisture Content	14769.736	48			

This is because sandy soil has large particle size and bigger pores which encourage faster vertical movement of water than the horizontal movement which is peculiar to clay. The analysis of variance ANOVA (Table 5) revealed that the wetted width (diameter) and wetted depth measured for the four drippers across the different flow rates is significantly different at $P < 0.05$. ANOVA also compared the wetted width and wetted depth with the different soil types and it was observed that there is a significant difference at $P < 0.05$, which indicates that soil type has effect on wetting pattern and depth. Flow rate and soil type were combined to check the relationship between the wetted width and depth and it was still observed that there was variation (significant difference at $P < 0.05$) as shown from the ANOVA table above.

Relationship between moisture content of soil and wetting depth

Moisture content after wetting was compared to flow rates, it revealed that the moisture content increases as flow rate increases for the various soil types and it followed the order clay > loamy > sandy (Table 4). ANOVA in Table 6 above analyzed relationship between the wetted depth and moisture content after wetting with flow rate and it is observed that there is significant difference ($P < 0.05$) for all the dependent variables across different flow rates. This means that different flow rates have effect on wetted depth and moisture content. Similar observation was made when flow rate and soil type were combined, which still showed significant difference for all the dependent variables.

Flow rate with the best wetting pattern and wetting depth

From the experimental values, it was observed that flow rates of 0.5 L/h and 1.0 L/h yielded better wetted width and had high wetting depths compared to flow rates of 1.5 L/h and 2.0 L/h for all soil types. Hence the choice of flow rate will be based on soil type, consumptive use and the rooting depth of crop to be planted.

Conclusion

Surface drip irrigation system was used as water application method to three different soil types (sand, loam and clay) to compare their surface wetting pattern and wetted depth with different flow rates of 0.5, 1.0, 1.5 and 2.0 l/h. Results revealed that the wetted width increased as flow rate increased while the wetted depth decreased with increase in flow rate for all the soil types. This shows that the values of wetted width and depth depend on soil type and flow rate. The flow rates of 0.5 and 1.0 l/h were judged better than 1.5 and 2.0 l/h. However, choice of flow rate will depend on crop and soil parameters.

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