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SOIL WETTING PATTERN OF SANDY LOAM SOIL IN RESPONSE TO DRIP IRRIGATION RUNNING TIME

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ABSTRACT
The wetting pattern of in-situ soil of sandy loam texture was evaluated under drip irrigation system with respect to the wetted diameter and depth in two locations. The drippers were run at the system's predetermined maximum emitter discharge rate of 6.994×10^{-4} ls^{-1}, with emission uniformity and optimum operating pressure of 95% and 172 KPa, respectively. The observed wetted diameter ranged between 19.2 cm and 22.8 cm at the National livestock project site, and 15.3 cm to 22.7 cm at the College of Forestry Mechanization research field within 15 to 75 minutes of irrigation. The observed values were compared with predicted values obtained from an existing model by means of correlation coefficient, agreement index and confidence index. The correlation coefficients showed a very high correlation ($r = 0.70 – 0.90$) for the observed and predicted wetted diameters and wetted depths at both sites. However, further analysis using the confidence index showed that there was bad correlation ($c < 0.51$) between the observed and predicted wetted diameters at both sites. The correlation between observed and predicted wetted depths at both sites showed excellent performance based on confidence index ($c > 0.85$). The study serves as a guide for irrigation scheduling under drip irrigation system as the root depth of the crop must at least be within the wetted volume (depth and area) of the soil. The study can be repeated with agricultural soils of other textures.

Keywords: Soil wetting pattern, sandy loam, drip irrigation, irrigation running time

INTRODUCTION

Irrigation can be defined as the artificial application of water to plants for the purpose of plant growth. It is meant to be a way of applying water to plants during periods of drought. A plant requires a certain amount of water to aid its growth and production at certain fixed interval throughout its growing and production period (Sharma and Sharma, 2004). Drip irrigation, also known as trickle irrigation system, is one of the most efficient water application methods wherein precise amount of water is applied to the root zone of plants. It is planned to deliver frequent light applications of water to wet portions of the soil (Al-Qinna and Abu-Awwad, 2001).

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 patterns which develop from dripping water onto the soil depend on discharge and soil type (Brouwer *et al.*, 1986). Although only part of the root zone is wetted it is still important to meet the full water needs of the crop. While it has been thought that drip irrigation saves water by reducing the amount of water used by crops, the crop water use is not changed by the irrigation method. Rather, drip irrigation simply reduces the losses due to deep percolation, surface runoff and evaporation from the soil. Rather than being a substitute for other proven methods of irrigation, drip irrigation is just another way of applying water and it is best suited to areas with limiting water supply and quality, land with steep slopes or undulations and or where high value crops require frequent water applications (Brouwer *et al.*, 1986). A major prerequisite in drip irrigation system design is adequate data about the moisture distribution patterns under a drip emitter source (Moncef *et al.*, 2002). The wetting pattern from emitters is an important consideration in the design and management drip irrigation systems. The design of drip irrigation system requires that the volume of soil wetted by single emitter be determined so that the total number of emitters required to wet a large enough soil volume can also be determined and plant water requirement can be met. Fundamentally, the volume of wetted soil from a point source is a function of the texture and structure of the soil as well as the water application rate and the total volume of water applied.

The restricted volume of wetted soil under drip irrigation and the depth-width dimensions of this volume are of practical significance (Zur, 1996). The wetted soil volume represents the amount of soil water stored within the soil root zone in terms of depth and width dimensions, and these should coincide with the plant root depth and the spacing between emitters and lines, respectively (Zur, 1996; Revol *et al.*, 1991). In trickle irrigation both soil type and application or emission rate of water influence the pattern of water movement in the soil and it is essential to determine these patterns so that crops could be provided with adequate wetted soil volume that can meet their water requirements (Al-Qinna and Abu-Awwad, 2001; Thabet and Zayani, 2008).

Soil water distribution in drip irrigation is normally in the form of a bulb shape under each emitter. Keller and Karmeli (1974) and Peries *et al.* (2007) have shown that the percentage of wetted area is a proportion of the irrigated area and depends on the emitter discharge rate, spacing and soil type. Different methods have been proposed for the estimation of wetted volume of soils under a drip. Battam *et al,* (2003) and Barreto *et al.* (2008) described a field method to derive drip irrigation design factors and this involved monitoring of wetting front over time from a subsurface emitter adjacent to an excavated pit. Empirical equations for computing the maximum width and depth of the wetted soil volume for surface drip irrigation system have been developed in studies carried out by Schwartzman and Zur (1986) and Singh *et al.* (2006). The models developed can be used to compute soil water distribution under a drip irrigation system. However, due to soil heterogeneity, in-situ determinations of the wetted volume may be necessary for accuracy to avoid irrigation surpluses or deficits. Many of the researches carried out on soil wetting pattern were done in the laboratory, such as the ones carried out by Keller and Bliesner (1990), Shwartzman and Zur (1986) and Zur (1996) and attention needs to be paid to soil water distribution pattern under actual field conditions (Nafchi *et al.* (2011). Lanini *et al.,* (2004) has stated that further investigations into the wetting patterns from a surface point source can be useful in refining general design criteria because direct wetting measurements are site specific.

The in-situ soil of the study area has been evaluated to be dominantly sandy loam, which is ideal for crop production (Barbour *et al,* 2002). The objectives of the study are to evaluate the site-specific horizontal (wetting diameter) and vertical (wetting depth) spread of water in sandy loam soil irrigated under point source pressure-compensating drip emitters, and comparing the results with calculated values.

MATERIALS AND METHODS

Description of the experiment

The study was carried out at the teaching and research farm of the Federal College of Forestry Mechanization (FCFM), Afaka (Location 1) and the National Livestock Project (NLP) site, Mando (Location 2), both in Kaduna, Nigeria (latitude 10º 34′ - 10º 35′N and longitude 7º 20′ - 7º 21′E. The soil of the area is classified as sandy loam, the vegetation is open woodland with tall broad leaf trees (Barbour *et al.,* 2002).

The experiment is a single factor experiment comprising five irrigation running time (IRT): IRT_{15}, IRT_{30}, IRT_{45}, IRT_{60} and IRT_{75}, implying 15, 30, 45, 60 and 75 minutes irrigation running time at the system's predetermined maximum emitter discharge rate. The experiment was laid out in a randomized complete block design (RBD) and replicated three times. Hence, there were fifteen experimental plots. Each plot was a 5m long row spaced 1.2 m between each other. Drip tubings of 1.27 cm (1/2 inch) diameter with in-line pressure compensating emitters designed to emit water at 6.994 x 10^{-4} l/s (2.5 lh^{-1}) (Drip Depot, 2013) were laid on the rows and connected to a water source (a 2000 litres capacity water tank). Water was run through the tubings by means of a 3 hp gasoline powered centrifugal pump at the pre-determined optimum system operating pressure (172.37 KPa) that gave the best emission uniformity (95%) for the drip kit used (Onwuegbunam *et al.*, 2019). A view of the experimental set-up is shown in Figure 1.

Water was delivered in trickles the moment the pump was operated to wet the soil for the time allocated. A stop watch was used in timing the flow according to the treatments and a valve was connected to each lateral (tubing) at the junction with the system submains to cut off inflow when the determined time is reached. The water spread in the soil (wetting pattern) and moisture content were measured using a meter rule and moisture meter, respectively. The vertical moisture spread was measured by the insertion of a long probe moisture meter.

Fig. 1: Drip lines with wetted areas

Some physical properties of the soils of the experimental sites are described in Tables 1(a) and (b).

Table 1a: Some physical properties of the in-situ test soil (National Livestock Project site)

Depth, cm	Clay, %	Silt, %	Sand, %	Texture	D_b, g/cm^3	k_s, = ms^{-1}
0-15	9.51	29.21	61.28	SL	1.46	0.000315
15-30	15.40	29.37	55.23	SL	1.46	0.000315
30-45	17.50	26.90	55.60	SL	1.47	0.000314
45-60	21.73	24.03	54.24	SCL	1.49	0.000314

Table 1b: Some physical properties of the in-situ test soil (FCFM Research farm)

Depth, cm	Clay, %	Silt, %	Sand, %	Texture	D_b, g/cm^3	k_s, = ms^{-1}
0-15	9.79	30.59	59.62	SL	1.45	0.000245
15-30	16.47	28.72	54.81	SL	1.46	0.000246
30-45	16.10	29.00	54.90	SL	1.46	0.000246
45-60	29.30	21.03	49.65	SCL	1.47	0.000244

The predicted wetting depth (z) and wetting diameter (w) were computed using the model equations presented by Schwartzman and Zur (1986):

$$z = 2.54 * V_w^{\ 0.63} * (\frac{k_s}{q})^{0.45} \quad (1)$$

$$w = 1.82 * V_w^{\ 0.22} * (\frac{k_s}{q})^{-0.17} \quad (2)$$

where, z is wetting depth (m), w is wetting diameter (m), V_w is volume of water applied (m^3), k_s is saturated hydraulic conductivity of sandy loam and q is emitter discharge rate (m^{3}s^{-1}).

Analysis of Experimental Results

The wetted diameter and depth obtained from the two study locations were compared with each other using t-test. The predicted and observed results were statistically analyzed by means of correlation coefficient, agreement (concordance) index (d), and confidence (performance) index (c) as stated in equation (3) (OCDE, 2015).

$$d = 1 - \left[\frac{\sum_{i=1}^{N}(P_i - O_i)^2}{\sum_{i=1}^{N}\left(|P_i - \bar{O}| + |O_i - \bar{O}|\right)^2}\right] \quad (3)$$

where, d is the agreement index, P_i is the predicted wetted diameter or depth as computed from the model equation used, O_i is the observed wetted diameter or depth from the field experiment; $\bar{O}$ is the mean of the observed values.

$$c = r\,.\,d \quad (4)$$

where, c is the confidence index and d is the agreement index.

The performance of the model equation used for predicting the wetted diameter and depth is presented in Table 2.

Table 2: Criteria for interpreting the wetted diameter and depth estimation method by the confidence index, c and correlation coefficient, r

Confidence index, c	Performance rating
> 0.85	Excellent
0.76 – 0.85	Very good
0.66 – 0.75	Good
0.61 – 0.65	Median
0.51 – 0.60	Affordable
0.41 – 0.50	Bad
< 0.4	Terrible
Correlation coefficient, r	Precision
0.9 – 1.0	Almost perfect
0.7 – 0.9	Very high
0.5 – 0.7	High
0.3 – 0.5	Moderate
0.1 – 0.3	Low

Source: Camargo and Sentelhas (1997).

RESULTS AND DISCUSSION

The wetted diameter for the National Livestock Project (NLP) site was consistently higher than that of the FCFM research farm (Figure 2). The difference is attributable to the aggregate difference between the soils of both sites. Though both are sandy loam site analysis showed that NLP site has coarser particles and higher saturated conductivity, k_s, than the FCFM site. Wetted diameter is known to increase with k_s based on the model proposed by Schwartzman and Zur (1986). This is also applicable to the wetted depths observed from the two sites.

There is a significant difference in the means of the wetted diameter between the two study sites [t_{stat} (= 1.9820) > $t_{crit.}$(= 1.8595] and p = 0.0414 (<0.05). Figure 3 shows the relationship between the wetted depth and irrigation running time at the two sandy loam sites. There is no significant difference in the wetted depth between the two sites [t_{stat} (= 0.1923) < $t_{crit.}$(= 1.8595] and p = 0.4262 (>0.05). The higher consistency in the vertical spread of water can be related to the higher k_s of the NLP soil. Higher saturated conductivity has been found to aid vertical downward water movement as evidenced in much more rapid rate of vertical water movement in sandy loam soil as compared with clay loam under furrow irrigation system wherein wetted depth of 60 cm was attained in 40 minutes and 4 hours for sandy loam and clay loam, respectively (Brady and Weil, 2010).

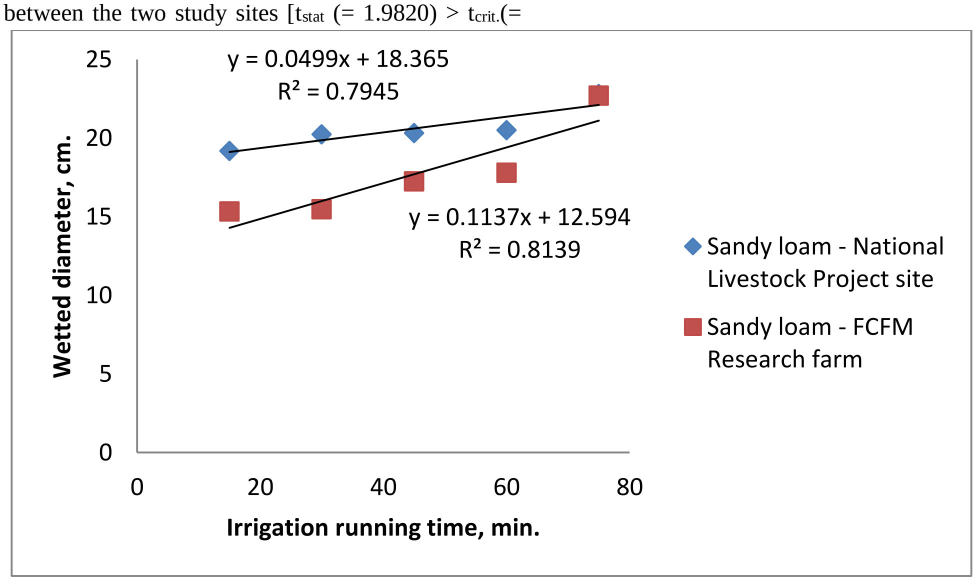

Fig. 2: Wetted diameter variation with irrigation running time

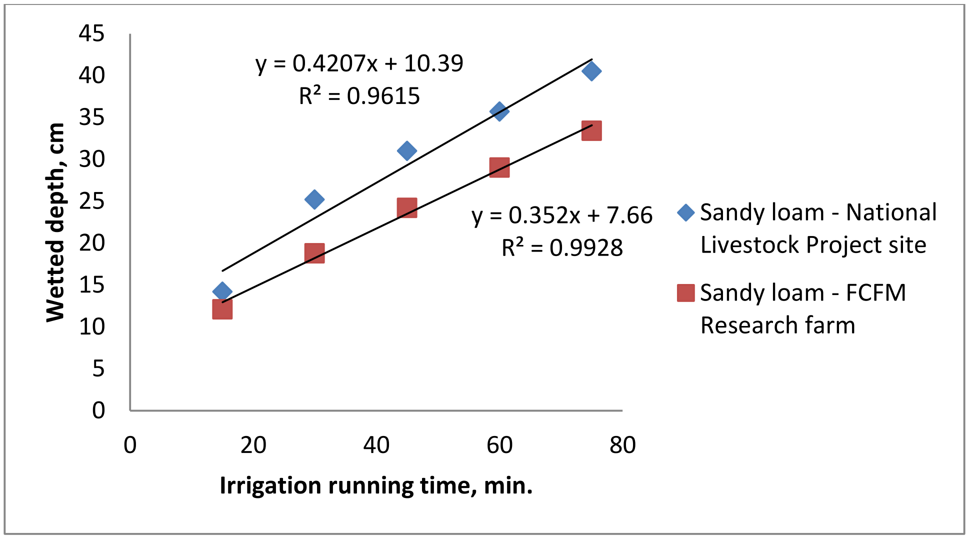

Fig. 3: Wetted depth variation with irrigation running time

The relationship between the observed and predicted wetted diameter and wetted depth are presented in Figures (4) and (5), respectively. The parameters for the relationships in terms of regression equations, coefficient of determination and correlation coefficients are presented in Table 3.

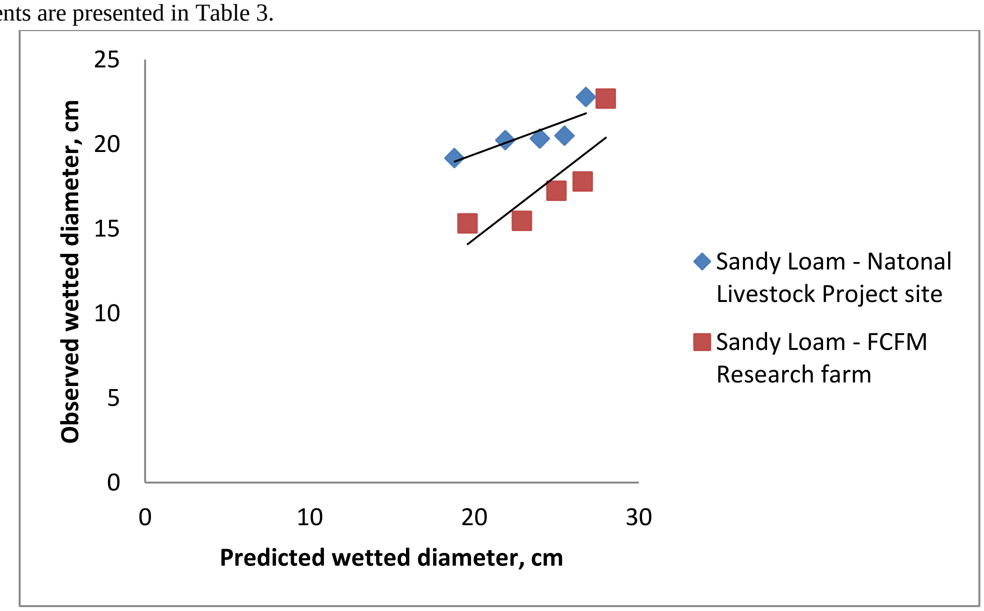

Fig. 4: Observed and predicted *wetted diameter* for sandy loam sites

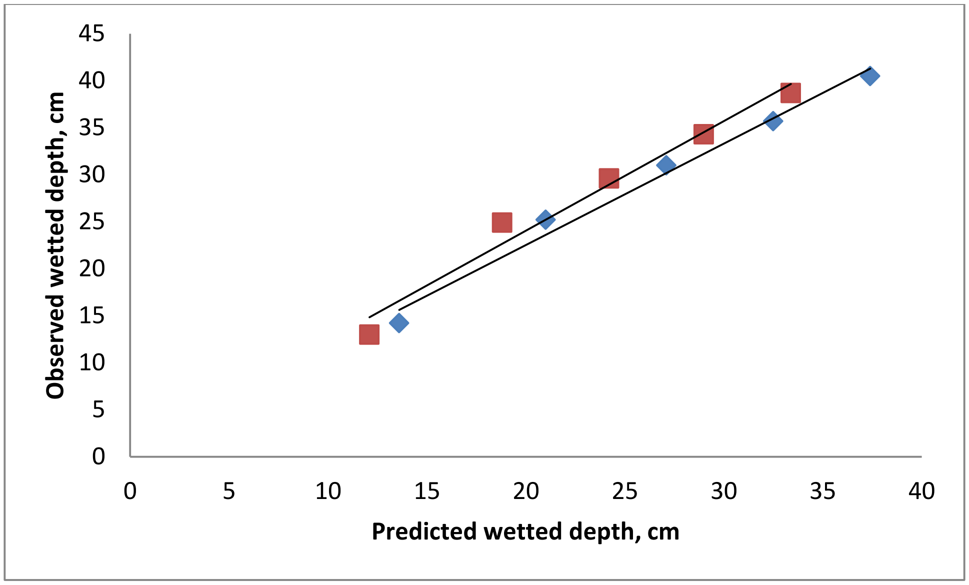

Fig. 5: Observed and predicted *wetted depth* for sandy loam sites

Table 3: Parameters for the relationships between predicted and observed wetted diameter and depth of sandy loam soil

Parameter	Wetted diameter		Wetted depth	
	NLP Site	FCFM Res. farm	NLP Site	FCFM Res. farm
Regr. Eqn.	$y = 0.36x + 12.27$	$y = 0.75x - 0.64$	$y = 1.17x + 0.71$	$y = 1.08x + 0.96$
r^2	0.72	0.69	0.97	0.99
r	0.85	0.83	0.99	0.99
d	0.53	0.47	0.97	0.92
c	0.45	0.39	0.96	0.91

The correlation coefficients show a very high correlation (r = 0.70 – 0.90) for the observed and predicted wetted diameters and wetted depths at both sites. However, further analysis using the confidence index show that there is bad correlation ($c < 0.51$) between the observed and predicted wetted diameters at both sites. The correlation between the observed and predicted wetted depths at both sites showed excellent performance based on confidence index ($c > 0.85$). The bad correlation in wetted diameter can be attributed to the loose state of the in-situ soil due to tillage. Loose soils have large air spaces among aggregates, and hence reduced cohesion, and so retard the capillary movement of water in the lateral direction. The excellent correlation in wetted depth was aided by downward gravitational pull of water, sandy loam soil being a medium coarse soil.

CONCLUSION

The wetted diameter and depth of sandy loam soil at two locations were evaluated. The downward movement of the water was more pronounced than the lateral spread. The gravitational pull of water in addition to capillary movement aided the vertical movement. The predicted values of the wetted diameter were higher than those of the observed values. This was not the case in the wetted depth; the predicted values were lower than the observed values. The correlation between the predicted wetted depth with the observed wetted depth was excellent; that of the wetted diameter was poor. It was suggested that the lateral movement of water was slowed down because of the loose state of the in-situ soil due to tillage. It is recommended that wetting pattern studies be carried out on agricultural soils of other texture, at different drip emission rates and with emphasis on the compactive state of the in-situ soil. The study serves as a guide for irrigation scheduling under drip irrigation system as the root depth of the crop must at least be within the wetted volume (depth and area) of the soil. The study can be repeated in other areas with agricultural soils of different texture.

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