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Simulating Effects of Drainage Design Parameters on Optimum Crop Yield Using Drainmod

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ABSTRACT

Agricultural water management system aims to provide crop water requirements to sustain optimum yield. Some of the factors influencing optimum crop yield are drainage design parameters in water logged soils. Hence, the impact of drainage design parameters on optimum crop yield was examined. Field experimentation was for 12 weeks which includes land preparation, planting to maturity of Corchorus olitorius ('Ewedu') on a poorly drained sandy loam topsoil of National Horticultural Research Institute Ibadan 'fadama' field. Hourly rainfall and daily minimum and maximum temperature data for 32 years (1963- 1994) for Ibadan was obtained from Nigerian Meteorological Station as DRAINMOD input data. Aluminum drainage pipes at 110 cm drain spacing, 60 cm drain depth and effective radius of 5.08 cm was installed. Depth from drain to restrictive layer was 204.3 cm while drainage coefficient was 1.3 cm/day. Drainage system parameters, such as drain spacing, drain depth, effective drain pipe radius were varied and effects on crop yield observed. Field evaluation was conducted at 60 cm and 110 cm drain depth and spacing respectively, and relative crop yield of 35.60% was observed. Predicted results showed that peak values of simulated relative yield of 36.39% was attained at 40 cm, 45 cm, and 55 cm drain depth, corresponding to 120 cm, 115 cm and 105 cm spacing respectively when drain depth was varied with drain spacing at constant drain pipe effective radius. It was concluded that if land availability is limiting and there is availability of cheap labour typical of developing countries, drain depth of 55 cm, and drain spacing of 105 cm and drainage pipe effective radius of 2.54 cm (i.e. 1 inch pipe) corresponds with the optimum yield of Corchorus olitorius. However, shorter drain spacing requires more drainage pipes and land reformation; hence increase in production cost.

KEYWORDS: Water management, Drainage design, 'Fadama' soils, Relative yield, DRAINMOD

INTRODUCTION

Drainage in agricultural land is needed to remove excess water from, in or on the soil. The design and management of drainage systems to achieve both crop yield production and water quality goals will be a challenging task in the coming years (Luo *et al.*, 2010). Methods for evaluating the efficacy of various drainage design and management practices generally include field experimentation and computer modeling. Both of these approaches are critical to improve our understanding of which practices are most efficient under different conditions. The need to have guidelines for drainage design and water management for different soils and climates has driven both the experimental field research and computer modeling (Wang *et al.*, 2006). Previous studies emphasize the importance of drainage system layout and management in reducing water quality impacts while satisfying agricultural production requirements (Skaggs, 2007). Soil, being the medium for water and solute movement and crop yield, being the target of irrigation and drainage, makes both plant and soil determinant factors in water management (Oosterbaan, 1997).

Few models are available for evaluation of drainage water management systems for soils with natural or induced high water tables. DRAINMOD, a hydrologic model which simulates the performance of drainage systems, is one of the most widely used models developed specially for drainage applications (Singh *et al.*, 2007; Ale *et al.*, 2009). Comparative studies have shown that DRAINMOD has equal or better accuracy with greater efficiency than similar models, such as the Agricultural Drainage and Pesticide Transport (ADAPT) and Soil Water Infiltration and Movement (SWIM) models (Barkle *et al.*, 1998; Sands *et al.*, 2002; Randall and Goss, 2008).

Surface and subsurface drainage improvements along with controlled drainage and sub-irrigation can be considered by DRAINMOD. Simulations of 20 years or more enable system comparisons over a range of weather scenarios.

DRAINMOD model has been updated a number of times to extend its capabilities (Skaggs *et al.*, 1988; Fernandez *et al.*, 1998; Vepraskas and Calwell, 2008; Kwon and Hudson, 2010). The model conducts a water balance on a day-by-day, hour-by-hour basis for a soil column extending from the impermeable layer to the surface as observed in He *et al.* (2002). However, it was evident from these preliminary analyses of DRAINMOD results that the model is very sensitive to timing during the day in which the rainfall event occurs (Konyha *et al.*, 1988). Several objective functions such as Working Days, Sum of Excess Water (SEW), Dry Days and Relative Yield are calculated in DRAINMOD to quantify the performance of the system that was simulated (Skaggs, 1992). Three of these objective functions were used in this study. Stress due to high water tables was quantified by the SEW30 value. It is the summation of the depth of water table encroachment to within 30 cm of the surface expressed in cm day. The most direct and meaningful way of testing the reliability of DRAINMOD is to compare model predictions with results measured in field situations (Cizikci *et al.*, 2004). Hence, this study was carried out to simulate the effects of varying drainage system design parameters to provide optimum crop yield in tropical 'Fadama' soils in south-western Nigeria.

MATERIALS AND METHODS

The field experiment was carried out at National Horticultural Research Institute (NIHORT), Ibadan, Nigeria. A 12 m × 6 m plot water-logged through irrigation was used. The poorly-drained sandy loam soil field had a 2% slope and the field was ploughed using a disc plough. The field was then prepared into ten beds, each of 5m × 1m × 0.2m dimensions, with 20 cm spacing between each bed. Subsequently, about 65 cm deep troughs were dug in the 20 cm spacing between the beds, in order for the 11 drainage pipes to be laid. Afterwards, ditches of area 60 cm × 45 cm ×30 cm were dug at the tail end of each trough to collect the drainage water as shown in Figure 1.

Holes of 5mm diameter were drilled along the length of the pipe at approximately 61 cm intervals, making a total of 9 holes along the lengths of each pipe. At each of the nine points along each pipe, four holes were also drilled across the circumference at approximately 8mm spacing using a hand drill. *Cochorous olitorius*, 'Ewedu', was selected as the grown crop due to its ability to survive on waterlogged soils such as the 'Fadama' field; and also because of its short maturity duration period.

The saturated hydraulic conductivity was measured in the field using the auger holes method (Boast and Kirkham, 1971) and using small undisturbed core samples in a constant head permeameter in the laboratory. Saturated conductivity measurement and values used in DRAINMOD are summarized in Table 1. Soil water characteristic data are tabulated in Table 2 for the soils considered in this study. Drainage system input includes drain depth, spacing, depth of impermeable layer, depth of surface depression storage, effective pipe radius, drainage rate of ponded surface conditions and depth of water in the outlet as a function of time. The water management system consists of underground drainage pipes spaced 110 cm and buried 60 cm deep. Drainage system parameters are given in Table 3.

RESULTS AND DISCUSSION

Results from simulations at drain depth of 60 cm and drain spacing of 150 cm but at varying effective pipe radii are given in Table 4. The results predicted maximum relative yield of 36.39% for pipe radius of 2.54 cm and 5.08 cm, while there was no significant difference in the value predicted for other pipes of effective radius greater than 5.08 cm as shown in Table 4. However, it would be of economic benefit to select a pipe of 2.54 cm radius because it is cheaper when compared to a 5.08 cm radius pipe. Also, a 2.54 cm pipe will gradually remove drainage water at a non erosive velocity when compared to a 5.08 cm pipe, since the volume of drain flow increases linearly with pipe effective radius. In conclusion, the 2.54 cm pipe will be appropriate size in terms of cost and power requirement for frequent irrigation applications.

Figure 1a: Gravel Envelope material and Pipe Discharge End

Figure 1b: Prepared Field before Planting.

Simulation results at 110 cm drain spacing and 5.08 cm effective drain pipe radius were used in the field evaluation but at varying drain depths (Table 5). DRAINMOD predicted closely the yield when compared to the measured yield. At 60 cm drain depth; and relative crop yield of 35.6% was obtained by summing the average percentages of yield for the number of beds cultivated.

Analysis showed tremendous vegetable crop yield reductions upon simultaneous increase in drain depth and drain spacing as shown in Table 5. DRAINMOD predicted its yield at 60 cm to be 33.10%, indicating a prediction error of 2.3%. However, reductions in relative yield were recorded at higher drain depth values than 60 cm, and no yield was predicted at values of 90 cm and above. This is an indication that water table would have reduced below the cultivated vegetable crop root zone.

Table 1: Hydraulic conductivity (K) measurement and input values for DRAINMOD

Soil Profile Depth (cm)	K (cm/hr)
0 – 25	1.85
25 – 62.5	0.10
62.5 – 120	0.16

Table 2: Soil water characteristics (values in volumetric water content)

Soil Water Pressure Head (cm of water)	Depth		
	0 – 25	25 – 62.5	62.5 – 120
0	0.413	0.314	0.334
-3.8	0.411	0.299	0.331
6.8	0.409	0.296	0.309
-8.8	0.404	0.296	--
13.8	0.404	0.295	0.308
-23.8	0.400	0.292	--
33.8	0.392	0.289	0.290
-48.8	0.376	0.284	--
63.8	0.368	0.280	0.263
78.8	0.360	0.279	--
-103.8	0.351	0.275	0.235
153.8	0.343	0.267	--
203.8	0.334	0.260	0.211
303.8	0.326	0.253	0.200
-1500	0.120	0.120	0.084

Table 3: Drainage System Parameters

Parameter	Values
Drain Tube	Aluminum draining tube
Drain Spacing	110cm
Drain depth	60cm
Drain diameter	5cm
Effective drain radius	5.08cm
Depth from drain to restrictive layer	204.3cm
Drainage coefficient	1.3cm/day

If availability of land is limited, it is advisable to use smaller drain spacing. A drain spacing range of 80 cm to 90 cm and drain depth range of 40 cm to 50 cm can be used as optimum drainage design (Table 6). Using a drain depth of 40 cm, which corresponds to a spacing of 80 cm will reduce the cost of human labour (man hours) needed in digging the depth, also increase in the farm land area and ultimately requiring more drainage pipes and hence, increase the material cost. Hence, land and labour availability should be considered in selecting optimum drainage spacing to be used, while the drain depth is related to the cost and energy expended in digging.

Also, shorter drain spacing requires more drainage pipes; hence the number of pipes used increases the project cost. Both drain spacing and depth also affect the height of water table.

CONCLUSION

From the analysis; it can be concluded that in tropical environment with similar water-logged 'Fadama' field soil where this experiment was conducted, the drainage design engineer can go for the 50 cm drain depth which implies more labour requirement for land excavation at the expense of shorter drain spacing.

requiring more drainage pipes for the same hectare of land. This is due to the availability of cheap human labour in developing countries.

From the above analysis, it can be deduced that in developing countries such as Nigeria with availability of cheap human labour, 50 cm drain depth and 90 cm drain spacing can be recommended for use.

Table 4: Simulations of Effective Pipe Radius and Corresponding Yield

Effective Radius (cm)	Relative Yield (%)
0.64	12.6
1.27	12.6
2.54	36.39
5.08	36.39
7.62	15.35
10.16	15.35
12.7	15.35
15.24	15.35
17.78	15.35
20.32	15.35
22.86	15.35
25.4	15.35

Table 5: Simulations of drain depth and the corresponding yield

Drain Depth (cm)	Relative Yield (%)
40	36.39
45	36.39
50	36.35
55	36.39
60	33.10
65	27.08
70	7.63
75	5.45
80	5.66
85	1.06×10
90	0.00

Table 6: Response of Yield to increase in both drain depth and spacing

Drain Depth (cm)	Drain Spacing (cm)	Relative Yield (%)
30	70	33.10
35	75	36.35
40	80	36.39
45	85	36.35
50	90	36.39
55	95	33.10
60	100	33.10
65	105	27.08
70	110	7.63
75	115	5.45
80	120	1.11

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