PERFORMANCE EVALUATION OF DRIP IRRIGATION SYSTEM USING SWEET CORN UNDER VARIABLE WATER APPLICATION

[1]*Ewemoje T. A., [1]Lateef, S. A. and S. O. Afolayan [2]

[1] Department of Agricultural and Environmental Engineering, University of Ibadan, Nigeria.
[2] National Horticultural Research Institute (NIHORT) Idi-isin GRA, Ibadan, Nigeria.

ABSTRACT

Gravitational drip irrigation system was developed using available materials. The system consisting of 4.0 l/hr Netafim pressure-compensating emitters was used to irrigate 0.0015 ha of land where sweet corn was planted under variable water applications in a randomised complete block design with three treatments. Treatment one (W_1) received water once per week, treatment two (W_2) received water twice per week, while third treatment (W_3) received water thrice per week. W_1 received 229mm per emitter; W_2 received 437mm per emitter, while 653mm per emitter was applied to W_3 throughout the experimentation period. Total biomass yield including bulk weight, stem weight, root weight and cob yield were determined using top loading digital weighing balance. Results obtained which were subjected to statistical analysis at 5% significant level show that there were significant differences in the crop growth, biomass and cob yield. Watering thrice per week resulted in the highest leaf area, plant height, root depth and weight. However, watering twice per week provided the highest fresh weight and cob yield. The trend in biomass yield showed that W_2 performed better. Watering twice per week appeared optimum for cultivation of sweet corn during water scarce season in Ibadan, Nigeria.

Keywords: Drip Irrigation, Agronomic parameters, Corn, Evaluation.
* Author for correspondence

INTRODUCTION

Irrigation assists in stabilizing food production in a number of countries by either supplementary or replacing the need for natural precipitation. It serves as crop insurance against drought and increases crop yield and quality when rainfall is insufficient.

In Africa, an estimated 88% of all freshwater use is for agriculture, 7% for domestic purposes, and 5% for industry. In Europe, however, 54% is for industry, while agriculture accounts for 33%, and domestic use, 13% (Hinrichsen *et al.*, 1998). The higher the level of development, the more water is used for domestic and industrial purposes and the less for agriculture. Irrigation contributed substantially to increase food production worldwide. Statistics show that irrigated land in the world rose from 8 million ha in 1800 through 48million ha in 1900 to 94 million ha in 1950. Irrigated land has tripled to 260 million ha today of which two-third are in developing countries. Averaged globally, about 65% of all freshwater withdrawn each year is used to irrigate 16% of the world's cropland, some 60-80% of this water either evaporates or seeps into the ground before reaching crops (Miller, 1999). During the mid-1960s to mid-1980s, the Food and Agriculture Organization (FAO) estimated that the expansion of irrigation accounted for over 50 % of the increase in global food production (Dina, 1993).

Despite the advances in irrigation practices and their attendant contributions in agricultural production, human population is increasing at an alarming rate. World population is expected to reach 7.8 billion by 2025 with 80 percent expected from developing countries (Mark *et al.*, 2002). This will put greater pressure on world food security. The 1996 World Food Summit set a goal of halving the number of food insecure people from 800 million in 1995 to 400 million in 2015. However, according to projections by the International Food Policy Research Institute (IFPRI), it is unlikely that this goal will be achieved before 2030 at best. South Asia and Sub-Saharan Africa are the regions worst affected by food insecurity and malnutrition, being home to 60% of the world's food-insecure people and 75% of its malnourished children (Inocencio *et al.* 2003). Subsequently, more water will be withdrawn to satisfy domestic needs, coupled with this is the irregular distribution of rainfall in the semi-humid region of the tropics. Thus, an efficient method of irrigation that applies right quantity of water needed must be adopted if this goal is to be achieved.

By the year 2025, approximately 1.4 billion people or one-third of the population of developing countries will be living in areas of chronic water scarcity. People living in these areas will not have sufficient water resources to

maintain even their 1990 average levels of per capita water consumption in the agricultural, industrial and environmental sectors, and much less avenue to increase these levels to acceptable standards (Sakthivadivel *et al.* 2001). Since agriculture consumes over 80% of all the water in developing countries, there will be intense pressure to transfer water out of agriculture to meet the needs of the other sectors and to increase the efficiencies of irrigation water use at both system and field levels.

In order to reduce water use in agriculture, drip irrigation is often preferred over other irrigation methods because of high water application efficiency on the account of reduced losses, limited surface evaporation and reduction in losses due to percolation (Rajput and Patel, 2005). The optimal use of irrigation according to Yuan et al. (2005) is the supply of sufficient water according to plant needs in the rooting area and, high-frequency water management by drip irrigation minimises soil as a storage reservoir for water, provides at least daily requirements of water to a portion of the root zone of each plant, and maintains a high soil matric potential in the rhizosphere to reduce plant water stress.

Hence, the objectives of the study are to design and construct an improvised gravity drip irrigation system for developing countries and experimentally determine the effect of irrigation frequency on growth parameters of sweet corn on a demonstration plot.

Comparative advantages of drip irrigation system over other methods have been observed over the years with sweet corn. When effluent from domestic waste was used, the contact between the effluent and the crop was less in drip irrigation compared to other methods and this reduces the possible contamination by pathogens (Pescod *et al.*, 1984). It was observed that trickle irrigated plots received less than 45% of pan evaporation in all season resulting in increased in water use efficiency. Marketable tomato (*Lycoperscon esculentum*) planted with trickle irrigation showed a yield of 22% increase more than with furrow irrigation. No significant change was observed in soluble salts concentration in the soil (Bogle *et al.*, 1989).

Sweet corn is a high moisture commodity and sold on the basis of high quality alone. It is very succulents, has a rather shallow root system and does not yield well if adequate soil water is not readily available (Vittum *et al.*, 1963). Irrigating sweet corn with micro-drip (emitter discharge of less than 0.5l/h) irrigation

may improve yield, reduce drainage flux (excess water removal) and affect the water content distribution within the root zone especially within $0.6 - 0.9$ m soil layer when compared with the conventional drip irrigation (Assouline, 2002)

MATERIALS AND METHODS

Improved gravity drip irrigation was designed and constructed. The system consists of two tanks (100 l and 120 l), sub-mainline, mainline, laterals, and emitters (Fig.1). Use of the refill tank together with the constant head tank and pressure compensating emitters eliminated problem of pressure variation commonly experienced in conventional family drip irrigation system. Head losses in lateral pipe and mainline were determined by (Larry, 1998):

$$H = (K)(C)(L)(Q^m)/D^{2m + n} \qquad (1)$$

In which K is friction factor that depends on pipe material, L is Length of pipe (m), Q is Flow rate (l/min), D is diameter (cm) and C, M, n are constants based on the method of computation.

$$K = 0.811 \ F/g, \qquad (2)$$

F is a friction factor from the Moody diagram which depends on the magnitude of Reynolds Number (N_R); and acceleration due to gravity (g). N_R is given by:

$$N_R = DV/ \nu \qquad (3)$$

D is diameter of pipe (cm), V is average velocity (cm/s), and ν is kinematic viscosity.
For laminar flow,

$$F = 16 / N_R \qquad (4)$$

Pressure variation in lateral and mainline was determined using

$$P_d = P_u - y (h_1, \pm \Delta Z) \qquad (5)$$

Where; P_d, P_u are Pressures at down and upstream positions respectively (KP$_a$), h_1 is energy loss in pipe between up and down stream position (m), ΔZ is difference in elevation between up and down stream positions (m) and y is unit constant (y = 9.81 for P_d and P_u in (KP$_a$) and h_1, ΔZ in meters). Thus total loss h_1 is calculated from

$$h_1 = fH_1 + M_1 \qquad (6)$$

Where f is constant that depends on method of estimation of H_1 and number of emitter outlets. H_1 is friction loss in pipe between up and down stream locations (m) and M_1 is Minor loss through the fittings (m). The total head loss (h_1) computed from equations 1 to 6 was 0.96m, but the recommended minimum pressure head from the manufacturer chart (Larry, 1998) for flow rate

against pressure head for pressure compensating emitters using 4l/hr emitter to deliver 1.4 l/hr average value (to compensate for the head loss in pipes) was 2 m. Hence, the refill tank was placed 2 m above the datum.

Lateral pipe of 16mm diameter and mainline of 25 mm diameter were selected. Field experimentation was conducted at the National Horticultural Research Institute (NIHORT), Idi-isin, GRA, Ibadan, Oyo State, Nigeria. A plot of 6 m x 2.5 m was demarcated. Randomised complete block design was used. The block consisted of three replications each of 1.5 m x 2.5 m and a spacing of 0.75 m in between two replications. Each replication had fifteen plant stands at spacing of 0.75 m x 0.5 m. Ten plants were analysed in each replication.
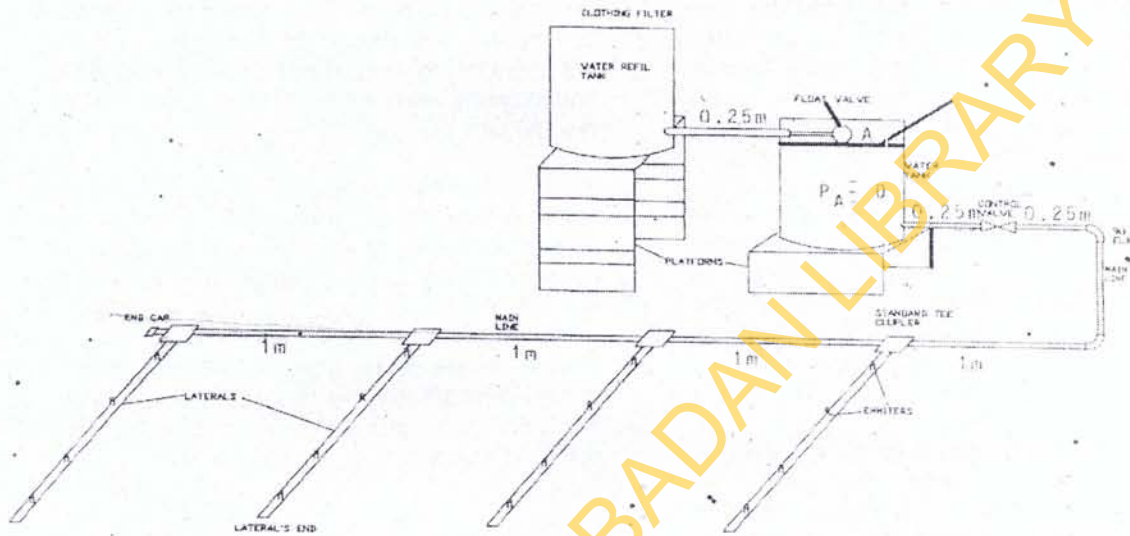

Figure 1:   Gravitational Drip Irrigation Model.

Sweet corn seeds were planted at three seeds per hole and at spacing of 0.7 m x 0.5 m as recommended by Doorenbos and Kassam, (1979). The planting was done around 10.00 h of 22 November 2004. Live mulch, *Chromolinea odorata* at the rate of 3000 kg/ha was applied. The whole plot was irrigated on Tuesday 22 November 2004 and Friday 25 November 2004 to cushion the effect of the sun prior to experimentation. Irrigation water treatment started on Monday 29 November 2004. Irrigation water from the constant head tank was applied using 4.0 l/hr Netafim pressure-compensating emitters designed for irrigation of vineyards, orchards, nurseries and greenhouses. Water application was done on Mondays, Wednesdays and Fridays. All treatments received water on Mondays; W_2 and W_3 treatments received water on Wednesdays while only W_3 treatment alone received water on Fridays. In other words, W_1 received water once per week, W_2 received water twice per week, while W_3 received water three times in a week. Total depth of water applied in the three treatments for the whole period of experimentation was 19.78×10^3mm. W_1 received 229.10mm per plant; W_2 received 436.60mm per plant, while 652.73mm was applied per plant to W_3 respectively. Depth of water applied per plant to W_3 fall within the 500mm and 800mm depth of water suggested by Doorenbos and Kassam (1979), for maximum production of a medium maturity grain crop. W_1 and W_2 were chosen to evaluate induced effects of water stress.

Sprouting began on the 29th November 2004 and water was applied for 15minutes from 1 to 26 days after emergence (DAE). Also 29 to 46 DAE, water application duration was 25minutes, while between 48 to 53 DAE the application time was increased to 30minutes. For the period 55 to 62 DAE, the time of water application was 35minutes and finally, water application duration was 40minutes 65 to 70 DAE. The increase in duration of water

application was necessitated due to observed water stress the on planted crop. The experiment was carried out at the peak of the dry season in Ibadan when the field was at the permanent wilting point (PWP) and observed water stress leading to drying of vegetation was noticed on the experimental field before land clearing and preparation. The soil on the experimental field is sandy loam (54% sand, 28% silt and 18% clay), having 6% moisture content at the PWP.

Growth parameters such as plant heights were measured using a metre rule from the soil surface to the tip of the terminal bud, while the number of leaves was counted manually at 7-day intervals and stem diameter measured using vernier calliper. Leaf area was measured empirically by the relationship 0.75 x length x breadth given by Saxena and Singh (1965). Cobs were harvested fresh on 8 February 2005 and their masses (root weight and total biomass) were evaluated. Scientific Application Software (SAS) was used for the analysis of variance (ANOVA).

RESULT AND DISCUSSION

Average discharge per emitter was found to be 1.32 l/h. It was observed that plants under treatments W_2 and W_3 tasselled earlier than other plants under W_1 due to the fact that the most sensitive stage of crop development when water is inevitable is between flowering (tasselling) and fruit set. Hence, the quantity of water required to simulate tasselling in plants under W_1 was less than the required. This was similarly reported by Slatyer (1969) that a frequently observed effect of water stress in the pre-flowering stage is a delay in date of flowering, although some observations of advanced flowering have also been made.

Effects of water application on cob growth, cob yield, biomass and weekly observation are presented in Tables 1, 2 and 3. Results obtained indicated significant differences in the crop growth; biomass and cob yield at 5% significant level for the three treatments.

Average leaf area was best under W_3, followed by W_2 and W_1 the least in Table 1. This result is expected in view of the fact that the amount of water utilized by a plant is assumed to be proportional to its canopy development under similar weather conditions. This is also in agreement with the work of Ines et al. (2001). Plants under W_3 performed more luxuriantly than those under W_2 and W_1. Similarly, root depth performed best under W_3. However bulk weight

was best under W_2. This trend is expected because sweet corn being a shallow rooted crop with few days of gestation could survive under minimum application of water. However, in order to forestall any imminent drought, a little above the minimum for as long as it does not necessarily affect the farmer's expenditure could be applied.

Table 2 shows the effect of drip irrigation on biomass. Results indicate that W_3 was more preferred. Compared with the results of Table 1 there seems to be contradictory output. This outcome is unexpected because crop handling and metering of water differ from one farmer to the other which is considered to be the end user of the drip irrigation system. Table 3 presents the result of weekly observation. This shows that W_2 and W_3 performed better.

The total cost of the drip irrigation system (materials of construction and labour) as at October 2004 when it was constructed was ₦ 19 520 .00k (USD 139.5). Maintenance and repair cost of the reservoirs and pipes were estimated to cost 2% of the initial cost of purchase while emitters were estimated at 6.5% of initial cost. Reservoirs (Refill tank and Constant head tank) and pipes (Lateral and Main) costs ₦ 2300.00k and ₦ 3385.00k, while Netafim emitters purchased from Dizengoff Agric (a division of Dizengoff W.A. Nig. Ltd., Iwo Road, Ibadan) cost ₦ 11250.00k. Raw water used for irrigation costs ₦ 16.78 at the rate of ₦ 05.00 per litre. Hence total operating, repair and maintenance cost including raw water supply cost to the nearest Naira was ₦ 862.00. From the cost analysis, only the cost of raw water supply vary for each of the treatments due to variable volume of water applied. Similarly, cost of labour is also variable as a result of different number of days of water applications per week. The cost of procuring sweet maize (hybrid) was ₦ 100/Kg as at 2004 at the National Horticultural Research Institute where the experimentation was carried out. The cob yield per hectare for W_1, W_2 and W_3 were 5 889kg, 11 272kg and 11 070kg respectively. Highest cost was incurred in W_3, while cost incurred on W_2 and W_1 were lower. Highest cost in W_3 was as a result of cost of water. Obviously from yield, W_2 was most profitable followed by W_3 and W_1. This shows that frequency of water application seems non-commensurate with revenue generation.

CONCLUSION

Gravity drip irrigation system has been designed and constructed using available materials. The problem of pressure fluctuation

common in family drip irrigation system has been eliminated by the use of pressure compensating emitters. It is recommended that if sweet corn is to be planted during dry season in humid tropical environment such as Ibadan, gravitational drip irrigation system of average discharge of 1.32 l/h per emitter watered twice weekly is to be employed.

Table 1: Effect of Drip Irrigation on Crop Growth and Cob Yield.

Trt	Leaf Area (cm^2)	Plant Height (cm)	Root Depth (cm)	Bulk Weight (g)	Cob Yield (g)	Stem Diameter (cm)	Stem Weight (g)	Root Weight (g)
W_1	1133.1[b]	79.18[a]	9.52[b]	61.40[b]	14.72[b]	3.70[a]	39.89[b]	2.95[b]
W_2	1308.8[d]	109.76[d]	12.21[d]	113.00[d]	28.18[d]	8.06[d]	71.13[d]	5.10[d]
W_3	1628.5[f]	121.40[e]	13.71[f]	111.30[f]	27.67[f]	7.15[e]	62.19[f]	7.05[f]
LSD (5%)	1305.4	26.72	4.42	55.28	20.26	2.96	37.23	6.27

Table 2: Effect of Drip Irrigation on Biomass.

Trt	Cob Weight (g)	Root Weight (g)	Stem Weight (g)
W_1	1.36[a]	5.46[a]	14.37[a]
W_2	2.79[d]	13.44[d]	21.54[c]
W_3	3.11[e]	12.14[e]	24.74[e]
LSD (5%)	1.06	2.59	2.06

Table 3: Effect of Drip Irrigation on Weekly Observation

Trt	Plant Height (cm)	Number of Leaves
W_1	48.60[a]	7[a]
W_2	66.58[c]	8[d]
W_3	59.23[e]	8[e]
LSD (5%)	10.15	0.76

Trt – Treatment
W_1- Receives water only on Mondays
W_2 - Receives water on Mondays and Wednesdays
W_3 - Receives water on Mondays, Wednesdays, and Fridays
LSD – Least Significant Difference

Treatments comparison between;
W_1 and W_2:   [a] Significantly Different   [b] Not Significantly Different
W_2 and W_3:   [c] Significantly Different   [d] Not Significantly Different
W_3 and W_1:   [e] Significantly Different   [f] Not Significantly Different

LIST OF REFERENCES

Assouline, S. (2002). The Effect of Micro drip and Conventional Drip Irrigation on Water Distribution and Uptake. Soil Science Society of America Journal. 66(5): 1630-1636.

Bogle, C. R., T. K. Hartz, C. Nunez, and V. Alexandra (1989). Comparison of Subsurface Trickle and Furrow Irrigation on Plastic-mulched and Bare Soil for Tomato Production. Journal of America Society for Horticultural Science. 114(1): 40-43.

Dina, U. (1993). Irrigation Induced Salinity; A Growing Problem for Development and the Environment. World Bank Technical Paper. No 215.

Doorenbos, J. and A. H. Kassam. (1979). Yield Response to Water. FAO Irrigation and Drainage Paper 33. FAO Rome.

Hinrichsen, D., B. Robey, and U. D. Upadhyay (1998). Solutions for a Water-Short World. Population Reports Series M, No 14. Johns Hopkins School of Public Health, Population Information Program, Baltimore USA. Retrieved May 26 2005 from http://www.infoforhealth.org/pr/m14.shtml

Ines, A. V. M., P. Droogers, I. W. Makin, and A. D. Gupta (2001). Crop Growth and Soil Water Balance Modelling to Explore Water Management Options. IWMI Working Paper 22. Colombo, Sri Lanka. International Water Management Institute.

Inocencio, A., H. Sally, and D. J. Merrey (2003). Innovative Approaches to Agricultural Water Use for improving food Security in Sub-Saharan Africa. IWMI Working Paper 55. Colombo, Sri Lanka. International Water Management Institute.

Larry, G. J. (1998). Principle of Farm Irrigation System Design. John Wiley and Sons, Inc. USA.

Mark, R., C. Ximing, C. Sarah, and N. Naoko. (2002). The Role of Rain fed Agriculture in the Future of Global Food Production. Environment and Production Technology Division Discussion Paper No 90; International Food Policy Research Institute, Washington D. C. USA.

Miller, T. G. Jr. (1999). Environmental Science: Working with the Earth. 7th Edition Wadsworth Publishing Company A Division of International Thomson Publishing Inc. South Africa.

Pescod, M. B., U. Alka, and D. J. Elliot (1984). Urban Effluent Reuse in Arid Region. Proceedings of the International Seminar on Water Resources Management Practices, Ilorin, Nigeria. p.347-359.

Rajput, T. B. S. and N. Patel. (2005). Water and Nitrate Movement in Drip-irrigated Onion under Fertigation and Irrigation Treatments. Agricultural Water Management. Article in Press, Corrected Proof. Retrieved from https://www.aginternetwork.net/http://dx.doi.org/10.1016/j.agwat.2005.03.009 on August 15, 2005

Sakthivadivel, R., N. Aloysius, and Y. Matsuno (2001). Assessment of Performance and Impact of Irrigation and Water Resource Systems in Taiwan and Sri Lanka. IWMI Working Paper 31. Colombo, Sri Lanka. International Water Management Institute.

Saxena, M. C. and Singh, Y. (1965). A Note on Leaf Area Estimation of Intact Maize Leaves. Indian Journal of Agronomy. 10: 437 – 439.

Slatyer, R. O. (1969). Physiological Significance of Internal Water Relations to Crop Yield. In Physiological Aspects of Crop Yield. (J. D. Easting, F. A. Haskins, C. Y. Sullivan and C. H. N. Van Bavel, eds.) Amer. Soc. Of Agronomy, Crop Sci. Soc. Of America, Madison, Wisconsin. Pages 53-79.

Vittum, M.T. and W. J. Flocker. (1963). Vegetable Crop. America Society of Agronomy Monograph Series 11, 682-683, America Society of Agronomy, Madison Wisconsin, USA.

Yuan, B., J. Sun, Y. Kang, and S. Nishiyama. (2005). Response of Cucumber to Drip Irrigation Water under a Rain shelter. Agricultural Water Management. Article in Press, Corrected Proof. Retrieved 15 August 2005 from https://www.aginternetwork.net/http://dx.doi.org/10.1016/j.agwat.2005.03.003

Acknowledgements