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Development and Evaluation of a Drip Irrigation System in Southeastern Nigeria

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Authors' contributions

This work was carried out in collaboration among all authors. Author CPN designed the study, wrote the protocol and wrote the first draft of the manuscript. Author LCO did the statistical analyses of the study. Author NMO managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Extreme climatic factors (temperature, precipitation etc) which at times lead to drought and flooding affect crop yield negatively. In this study, a PVC drip irrigation was developed and the irrigation parameters were evaluated in a farmland with three tillage methods (conventional tillage, conservative tillage and no tillage). The irrigation treatments comprised of three levels of irrigation (50% Management allowable depletion, 30% management allowable depletion and 10% management allowable depletion). Different irrigation parameters were evaluated for different crop growth stages, different soil treatments and different soil depths (0-25 cm, 25-50, 50-75 and 75-100 cm depths).

The field capacity was determined at -0.01MPa, from the result, the field capacity was minimum at no tillage (0.07 cm^3/cm^3, 0.11 cm^3/cm^3, 0.12 cm^3/cm^3, and 0.14 cm^3/cm^3) for soil depths 0-25 cm, 25-50 cm, 50-75 cm and 75-100 cm respectively, for conservative tillage (0.11 cm^3/cm^3, 0.11 cm^3/cm^3, 0.11 cm^3/cm^3, 0.14 cm^3/cm^3) for 0-25 cm, 25-50 cm, 50-75 cm and 75-100 cm soil depths respectively and conventional tillage (0.09 cm^3/cm^3, 0.13 cm^3/cm^3, 0.15 cm^3/cm^3, 0.17 cm^3/cm^3) for 0-25 cm, 25-50 cm, 50-75 cm and 75-100 cm soil depths respectively.

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The permanent wilting point was determined at -1.5MPa, from the result, permanent wilting point increased with increase in soil depth in conventional tillage and no tillage with PWP of 0.01 cm^3/cm^3, 0.05 cm^3/cm^3, 0.09 cm^3/cm^3 and 0.11 cm^3/cm^3 at 0-25 cm, 25-50 cm, 50-75 cm and 75-100 cm soil depths respectively for conventional tillage and PWP of 0.02 cm^3/cm^3, 0.05 cm^3cm^3, 0.05 cm^3/cm^3 and 0.08 cm^3/cm^3 at 0-25 cm, 25-50 cm, 50-75 cm and 75-100 cm soil depths respectively for no tillage.

The average net irrigation was found to be 1.2 cm, 1.56 cm and 1.95 cm for conventional tillage, conservative tillage and no tillage respectively, while the average gross irrigation was found to be 1.7 cm, 1.7 cm and 2.1 cm for conventional tillage, conservative tillage and no tillage respectively. Statistical analysis of net and gross irrigation gave a coefficient of determination of 0.99 and p-value at 0.05 was significant with a value of 0.00007.

Keywords: Climatic factors; drought; crop yield; drip irrigation.

1. INTRODUCTION

Irrigation is the application of water to the land to provide adequate moisture for crop production. Irrigation as the application of water, supplementary to that supplied by precipitation for the production of crops [1]. Man cannot depend solely on rainfed Agriculture for his activities without supplementary application of water hence the need of artificial application of water cannot be underestimated in achieving a sustainable agriculture. Agriculture is the greatest user of water resources in the world totalling 70% of total withdrawals and over 80% of the consumptive use of water [2]. Notably, there are large regional variations from 88% in Africa to less than 50% in Europe. In dry areas, rainfall is not enough for most crops hence irrigation makes up for the shortage. Crops suffer from moisture shortage even in areas of high seasonal rainfall for short period [3]. These brings the importance of irrigation for great yield in crop production. Irrigation has its limitations hence there is need for calibration and irrigation scheduling for proper use of water. According to [1], there are two basic types of irrigation systems, namely open canal systems and pressurised piped systems. There are four basic methods of applying water, they are subsurface irrigation, surface irrigation, drip irrigation and sprinkler irrigation [4].

There is need to create technology for efficient water usage to improve water management as nature cannot be controlled. Drip irrigation system is one type of technology for improvement of water supply management and food crisis. These systems use low flow rates and low pressures at the emitters and are typically designed to only wet the root zone and maintain this zone at or near an optimum level. This conserves water by not irrigating the whole area of land. Some advantages of the drip irrigation system are smaller wetted surface area, minimal evaporation and weed growth, and potentially improved water application uniformity within the crop root zone by better control over the location and volume of water application.

2. MATERIALS AND METHODS

2.1 The Study Area

Field experiment was conducted at the Department of Agricultural and Bioresources Engineering Experimental Site/ Farm Workshop, Nnamdi Azikiwe University, Awka. The site lies between latitudes 6°15'11.8N to 6°15'5.3E and longitudes 7°7'118N to 7°7'183N and altitude of 142 m during the dry season, previous studies carried out in the area shows that the soil in the area is sandy loam. It is a typical of savanna covered with grass. The geologic formation of Nnamdi Azikiwe University, Awka is Imo shale [5]. The Anambra River and its tributaries are the major Rivers that drain the area. There are two major climatic seasons, dry season (November to March) and rainy season (April to October) with reduced rain (August break) in August. Dry season temperature ranges from 20°C to 38°C which increases evapotranspiration, while rainy season temperature ranges from 16 to 28°C, with lower evapotranspiration. The experiment was conducted from 27th November 2017 to 22th February 2018.

2.2 Materials and Equipments

The materials used for the experiment were as follows:

- 25 mm PVC pipe for the main line
- 12.5 mm PVC for the submain

- 19 mm PVC for the laterals
- 19 mm end cap
- 25 mm by 12.5 bend
- 12.5 mm by 19 mm inch bend
- 25 mm ball gauge
- 12.5 mm ball gauge
- 25 mm by 12.5 mm Tee
- 12.5 mm by 19 mm Tee
- 2 mm drill machine

The equipments include:

- Pressure gauge
- Moisture meter
- Storage tank
- Block stand
- Double ring infiltrometer
- Measuring tape
- Levelling instrument
- Measuring cylinder
- Tractor
- Collection cans
- Pressure plate apparatus

2.3 Field Preparation

The field is a level ground and field preparation was done by dividing the plot into three major plots/sections A, B and C. Conventional tillage was done in the plot A by thoroughly tilling with plough and harrow, conservative tillage was applied in plot B by ploughing with one tractor pass. Plot C received no tillage. The tillage factor was also used in combination with three irrigation deficit levels (50% MAD, 30 MAD and 10% MAD).

25 mm PVC pipes were used as the main line, 19 mm PVC pipes served as the submain while 12.5 mm PVC pipes were used as the lateral. Laterals were laid at 0.5 m spacing while holes were perforated in the laterals at 0.45 m spacing to serve as emitter, with these, crop spacing was 0.5 m X 0.45 m.

All other necessary operations such as pest and weed controls were performed according to general local practices and recommendations.

2.4 The Test Crop

The crop for the experiment was *Zea mays* hybrid OBA SUPER 13.

2.5 Field Capacity Determination

This was done for the three tillage methods (conventional tillage, conservative tillage and no tillage) at different soil depths (0-25 cm, 25-50 cm, 50-75 cm and 75-100 cm) using the pressure plate apparatus, it was determined at -0.01MPa matric potential.

2.6 Permanent Wilting Point Determination

This was done for the three tillage methods (conventional tillage, conservative tillage and no tillage) at different soil depths (0-25 cm, 25-50 cm, 50-75 cm and 75-100 cm) using the pressure plate apparatus, it was determined at -1.5MPa matric potential.

2.7 Evapotranspiration

This was determined daily using the Hargreaves equation [6].

$$ET_o = a + b.(0.408).0.0023.\left(\frac{T_{max}+T_{min}}{2} + 17.8.Tmax - Tmin\,.\,Ra \right. \qquad (2.1)$$

ET_o = Reference evapotranspiration
Tmax(°C) is the maximum daily air temperature
Tmin(°C) is the minimum daily air temperature
Ra ($MJm^{-2}d^{-1}$) is the extra terrestrial solar radiation converted to equivalent evaporation in mm day^{-1} with a factor of 0.408.

The parameters a(mm d^{-1}) and b are calibrated coefficients, determined on a monthly basis by regression analysis or visual fitting. An adjusted version of Hargreaves equation is with a=0, b = 1.

Table 1. Duration and period with in the various growth stages

Growth stages	Duration (days)	Period
Initial stage	14	November 27 to December 11
Crop development stage	24	December 12 to January 4
Mild stage	27	January 5 to February 1
Late stage	20	February 2 to February 22

2.8 Consumptive Use (CU)

Consumptive use (CU) is computed as the product of crop factor and potential evapotranspiration [7]. This is expressed mathematically in equation 2.2

$$CU = KET_p \tag{2.2}$$

Where: K = crop factor; ET_P = Potential evapotranspiration.

The equation will be used to determine monthly consumptive use for the growing months.

2.9 Net Irrigation Requirement

The net irrigation requirement is the depth of irrigation water, exclusive of precipitation, carry-over soil moisture or groundwater contribution in soil that is required consumptively for crop production [7]. The maximum net depth to be applied per irrigation can be calculated using [8] in equation 2.3:

$$d = \sum_{i=1}^{n} \frac{(M_{fci} - M_{bi})}{100} . A_i . D_i \tag{2.3}$$

Where:

d = net depth of water application per irrigation for selected crop (cm)
M_{fci} = field capacity moisture content in the i_{th} layer of the soil (%)
M_{bi} = moisture content before irrigation in the ith layer of the soil (%)
A_i = bulk density of the soil in the ith layer
D_i = depth of the ith layer of soil within the root zone (cm)
n = number of soil layers in the root zone D.

2.10 Gross Irrigation Requirement

This is the net irrigation of the crop plus losses in water application and any other possible losses and will be calculated using equation 2.4.

$$GIR = \frac{dn}{AE} \tag{2.4}$$

Where

GIR = Gross Irrigation Requirement (cm)
dn = Net Irrigation
AE = Application Efficiency

2.11 Irrigation Frequency (IF)

This refers to the number of days between irrigations during periods without rainfall. It was determined using the equation in equation 2.5.

$$IF = \frac{AWC.R_z.MAD}{ET_c} \tag{2.5}$$

Where,

IF = Irrigation frequency (days)
AWC =Available water holding capacity (inch/ft)
R_z = Root zone depth (ft)
MAD = management allowable depletion
ET_c = crop water use rate

This was done for different stages of crop growth considering different depths of soil.

2.12 Head Loss on Main Line

The head loss on mainline was determined by William and Hazen Equation n equation 2.6

$$\Delta H = \frac{Q^{1.852}}{D^{4.87}}\Big) L \tag{2.6}$$

Where

ΔH = energy drop by friction (m)
Q = total discharge in the pipe (lit/sec)

2.13 Total Energy Drop for Lateral

This was determined by introducing an F-value as a reduction coefficient or determined by the integration

$$\Delta H = 5.35 \left(\frac{Q^{1.852}}{D^{4.87\ 2}}\right) L$$

2.14 Uniformity Coefficient

Uniformity coefficient (UC) was calculated using [6] in equation 2.7:

$$UC = 100\, X \left[1 - \left(\frac{\frac{1}{n}\sum_{i=1}^{n}\{q_i - q_{ii}\}}{q_{ii}}\right)\right] \tag{2.7}$$

Where,

q = discharge
q_{ii} = mean of discharge (q)
n = number of drip holes evaluated

2.15 Statistical Analysis

The statistical analysis Gross and Net Irrigation was done using the excel solver.

3. RESULTS AND DISCUSSION

3.1 Field Capacity

From the result, the field capacity was minimum at no tillage (0.07 cm^3/cm^3, 0.11 cm^3/cm^3, 0.12 cm^3/cm^3, and 0.14 cm^3/cm^3) for soil depths 0-25 cm, 25-50 cm, 50-75 cm and 75-100 cm respectively, for conservative tillage (0.11 cm^3/cm^3, 0.11 cm^3/cm^3, 0.11 cm^3/cm^3, 0.14 cm^3/cm^3) for 0-25 cm, 25-50 cm, 50-75 cm and 75-100 cm soil depths respectively and conventional tillage (0.09 cm^3/cm^3, 0.13 cm^3/cm^3, 0.15 cm^3/cm^3, 0.17 cm^3/cm^3) for 0-25 cm, 25-50 cm, 50-75 cm and 75-100 cm soil depths respectively. At 0-25 cm soil depth, there was a bigger value of field capacity in conservative tillage than conventional tillage, this could be because of runoff which occurred in the top soil in conventional tillage as there was maximum disturbance of soil. This is because the soil type is clay loam where highest FC was observed in no tillage (0.14 cm^3/cm^3), followed by conservative tillage (0.08 cm^3/cm^3).

3.2 Permanent Wilting Point (PWP)

From the result, permanent wilting point increased with increase in soil depth in conventional tillage and no tillage with PWP of 0.01 cm^3/cm^3, 0.05 cm^3/cm^3, 0.09 cm^3/cm^3 and 0.11 cm^3/cm^3 at 0-25 cm, 25-50 cm, 50-75 cm and 75-100 cm soil depths respectively for conventional tillage and PWP of 0.02 cm^3/cm^3, 0.05 cm^3cm^3, 0.05 cm^3/cm^3 and 0.08 cm^3/cm^3 at 0-25 cm, 25-50 cm, 50-75 cm and 75-100 cm soil depths respectively for no tillage. For conservative tillage PWP of 0.05 cm^3/cm^3, 0.04 cm^3/cm^3, 0.09 cm^3/cm^3, and 0.07 cm^3/cm^3 were recorded for 0-25 cm, 25-50 cm, 50-75 cm and 75-100 cm soil depths respectively. There was variation in permanent wilting point for conservative tillage which could be as a result of the bulk density of the soil.

3.3 Irrigation Frequency

The soil depths are the stages in soil growth as presented in Fig. 1 where, 0-25 cm represents the initial stage, 25-50 cm represents the crop development stage, 50-75 cm represents the mild stage and 75-100 cm represents the late stage.

3.3.1 Irrigation frequency for conventional tillage

At 10% MAD, irrigation frequency was 3 days, 4 days, 1 day and 4 days for 0-25 cm, 25-50 cm, 50-75 cm and 75-100 cm respectively.

At 30% MAD, irrigation frequency was 4 days, 4 days, 3 days and 4 days for 0-25 cm, 25-50 cm, 50-75 cm and 75-100 cm soil depths respectively.

At 50% MAD, irrigation frequency was 4 days, 10 days, 6 days and 5 days for 0-25 cm, 25-50 cm, 50-75 cm and 75-100 cm respectively.

Irrigation frequency is higher in 50% MAD because a lot of water was allowed to deplete from field capacity hence more days before irrigation.

3.3.2 Irrigation frequency for conservative tillage

At 10% MAD, irrigation frequency was 3 days, 3 days, 4 day and 3 days for 0-25 cm, 25-50 cm, 50-75 cm and 75-100 cm respectively.

At 30% MAD, irrigation frequency was 4 days, 4 days, 5 days and 3 days for 0-25 cm, 25-50 cm, 50-75 cm and 75-100 cm soil depths respectively.

At 50% MAD, irrigation frequency was 6 days, 7 days, 10 days and 5 days for 0-25 cm, 25-50 cm, 50-75 cm and 75-100 cm respectively.

3.3.3 Irrigation frequency for no tillage

At 10% MAD, irrigation frequency was 5 days, 4 days, 4 day and 3 days for 0-25 cm, 25-50 cm, 50-75 cm and 75-100 cm respectively.

At 30% MAD, irrigation frequency was 5 days, 5 days, 5 days and 4 days for 0-25 cm, 25-50 cm, 50-75 cm and 75-100 cm soil depths respectively.

At 50% MAD, irrigation frequency was 5 days, 6 days, 4 days and 4 days for 0-25 cm, 25-50 cm, 50-75 cm and 75-100 cm respectively.

Irrigation frequency is higher in 50% MAD for conventional tillage, conservative tillage and no tillage because a lot of water was allowed to deplete from field capacity hence more days before irrigation. The mean number of days is less in no tillage because runoff is more likely to occur in tilled soil than undisturbed soil.

3.4 Evapotranspiration

The Daily Evapotranspiration for the growing period was obtained from climatic data and calculated using Hargreaves equation. The maximum evapotranspiration is 7.3 mm/day and this was obtained in the 38th day of the growing period. This is because the average temperature calculated from the minimum and maximum temperature is high in this periods. The least evapotranspiration is 1 mm/day at 83rd day because the average temperature from the minimum and maximum temperature of the period is low.

3.5 Consumptive Use (CU)

The highest consumptive use was 6.3 mm/day obtained in 38th day and minimum was 0.86 mm/day at 83rd day. These correspond to the days of highest and lowest evapotraspiration because consumptive use increases as evapotranspiration increases.

3.6 Basic Hydraulics of Drip Irrigation

The results of energy drop by friction for the mainline and total energy drop for the lateral are presented in Table 2.

Table 2. Basic hydraulics of the drip irrigation system

Energy Drop by Friction for mainline (m)	$1.29X\ 10^{-6}$
Total Energy Drop by the friction at the end of the Lateral (m)	$3.6\ X\ 10^{-9}$

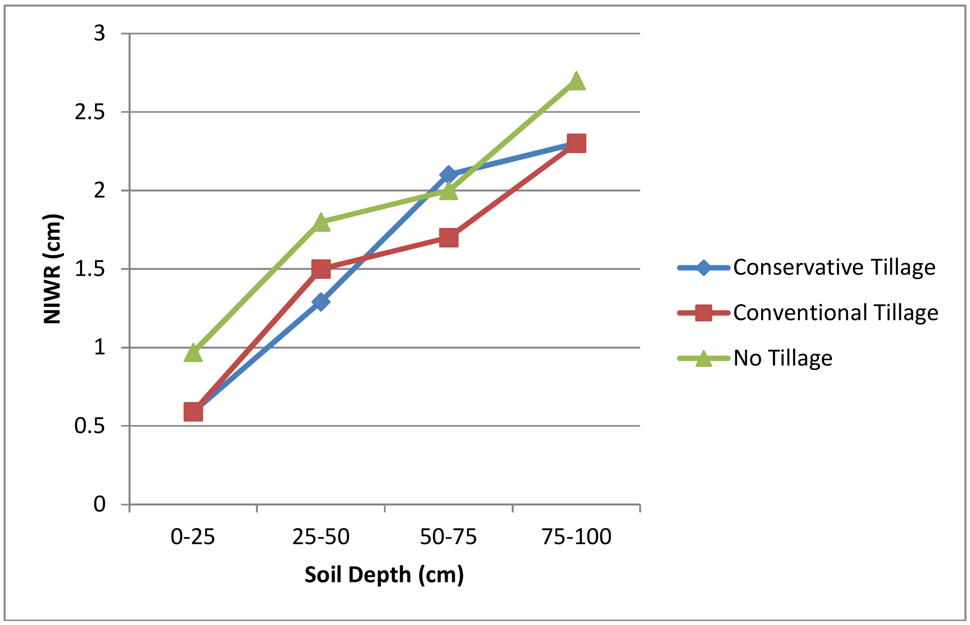

Fig. 1. Effect of soil depth on net irrigation water requirement

Table 3.1. Net irrigation requirement for the three tillage methods at 0-25 cm soil depth

Tillage method	Soil depth (cm)	MAD (%)	NIWR (cm)
Conservative	0-25	10	0.19
		30	0.6
		50	1
Conventional	0-25	10	0.19
		30	0.6
		50	1
No Tillage	0-25	10	0.317
		30	1
		50	1.6

Table 3.2. Net Irrigation Requirement for the three methods at 25-50 cm soil depth

Tillage method	Soil depth (cm)	MAD (%)	NIWR (cm)
Conservative	25-50	10	0.43
		30	1.29
		50	2.15
Conventional	25-50	10	0.51
		30	1.5
		50	2.5
No Tillage	25-50	10	0.605
		30	1.81
		50	3.0

Table 3.3. Net irrigation requirement for the three tillage methods at 50-75 cm soil depth

Tillage method	Soil depth (cm)	MAD (%)	NIWR (%)
Conservative	50-75	10	0.7
		30	2.1
		50	3.5
Conventional	50-75	10	0.234
		30	0.70
		50	1.17
No Tillage	50-75	10	0.79
		30	2.4
		50	3.0

Table 3.4. Net irrigation requirement for the three methods at 75-100 cm soil depth

Tillage method	Soil depth (cm)	MAD (%)	NIWR (%)
Conservative	75-100	10	0.77
		30	2.31
		50	3.9
Conventional	75-100	10	0.77
		30	2.31
		50	3.9
No Tillage	75-100	10	0.924
		30	2.77
		50	4.6

3.7 Net Irrigation Water Requirement (NIWR)

This is the actual amount of water necessary for cop growth, it was determined using equation.

For the three tillage treatments, net irrigation increased with increase in management allowable depletion, this is because more water is removed at higher management allowable depletion. The average net irrigation for conservative tillage at 0-25 cm, 25-50 cm, 50-75 cm and 75-100 cm soil depth were found to be 0.59 cm, 1.26 cm, 2.1 cm and 2.3 cm respectively. For conventional tillage at 0-25 cm, 25-50 cm 50-75 cm and 75-100 cm soil depth, the average net irrigation obtained was 0.59 cm, 1.5 cm, 1.70 cm and 2.3 cm respectively, while for no tillage at 0-25 cm, 25-50 cm, 50-75 cm and 75-100 cm soil depths an average net irrigation of 0.97 cm, 1.8 cm, 2.3 cm and 2.7 cm respectively were obtained. From the results, net irrigation increased with increase in soil depth for all the tillage methods.

3.8 Gross Irrigation Water Requirement (GIWR)

This is the quantity of water to be applied in realty, taking into consideration water losses.

There was increase in gross irrigation with increase in soil depth, this is because of the net irrigation which increased with increase in soil depth. For conservative tillage at 0-25 cm, 25-50 cm, 50-75 cm and 75-100 cm soil depths, there were average gross irrigations of 0.67 cm, 1.56 cm, 2.33 cm and 2.61 cm respectively. For conventional tillage at 0-25 cm, 25-50 cm, 50-75 cm and 75-100 cm soil depths, average gross irrigations recorded are 0.67 cm, 1.69 cm, 1.97 cm and 2.6 cm respectively while for no tillage at 0-25 cm, 25-50 cm, 50-75 cm and 75-100 cm, gross irrigations of 1.07 cm, 2.00 cm, 2.64 cm and 3.04 cm respectively was obtained.

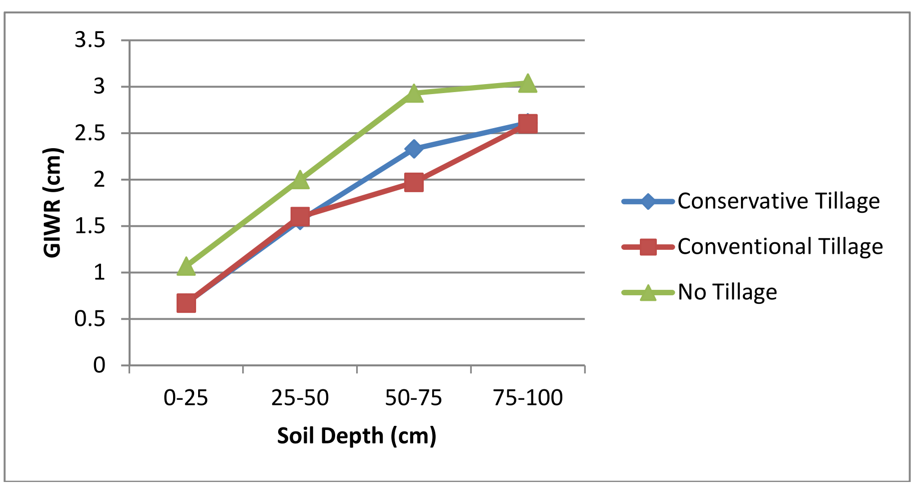

Fig. 2. Effect of different tillage practices on gross irrigation water requirement

Table 3.5. Gross irrigation requirement for the three tillage methods at 0-25 cm soil depth

Tillage method	Soil depth (cm)	MAD (%)	NIWR (%)
Conservative	0-25	10	0.21
		30	0.7
		50	1.1
Conventional	0-25	10	0.21
		30	0.7
		50	1.1
No Tillage	0-25	10	0.35
		30	1.11
		50	1.77

Table 3.6. Gross irrigation requirement for the three methods at 25-50 cm soil depth

Tillage method	Soil depth (cm)	MAD (%)	NIWR (%)
Conservative	25-50	10	0.5
		30	1.43
		50	2.77
Conventional	25-50	10	0.6
		30	1.7
		50	2.7
No Tillage	25-50	10	0.67
		30	2.01
		50	3.34

Table 3.7. Gross irrigation requirement for the three tillage methods at 50-75 cm soil depth

Tillage method	Soil depth (cm)	MAD (%)	NIWR (%)
Conservative	50-75	10	0.77
		30	2.33
		50	3.9
Conventional	50-75	10	0.26
		30	0.77
		50	1.9
No Tillage	50-75	10	0.87
		30	2.67
		50	4.4

Table 3.8. Gross irrigation requirement for the tillage methods at 75-100 cm soil depth

Tillage method	Soil depth (cm)	MAD (%)	NIWR (%)
Conservative	75-100	10	0.9
		30	2.6
		50	4.33
Conventional	75-100	10	0.9
		30	2.6
		50	4.3
No Tillage	75-100	10	1.03
		30	3
		50	5.1

3.9 Uniformity Coefficient

This was also calculated using equation 3.16 and shown in Table 3.9.

Table 3.9. Result of uniformity coefficient

Uniformity coefficient @10%MAD (%)	Uniformity coefficient @ 30%MAD (%)	Uniformity coefficient @ 50%MAD (%)
96	99	99

There was uniformity coefficient of 96% for 10% MAD, 99% for 30% MAD and, 99% for 50% MAD. Uniformity coefficient up to 90% is acceptable. The uniformity coefficients in Table 3.9 are within the acceptable range.

3.10 Statistical Analysis

Table 3.10. R^2, multiple R, standard error and observation table for bulk density and least limiting water range

Multiple R	R square	Standard error	Observation
0.99	0.99	0.104	11

Table 3.11. ANOVA for gross and net irrigation

	Df	SS	MS	F	P -Value @ 0.05
Regression	1	35.4	35.34	3248	0.00007 Significant
Residual	10	0.108	0.010		
Total	**11**	**35.4567**			

4. CONCLUSION

A PVC drip irrigation was developed and evaluated on the basis of irrigation parameters and performance evaluation. The values obtained for the parameters were in acceptable range coefficient of determination R^2 value obtained for gross and net irrigation was 0.99, the p-values of <0.05 shows that the terms for gross and net irrigation are significant.

Based on the outcome of the study, the developed drip irrigation systems performance is adequate for the study area.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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