

EVALUATION OF HYDRAULIC PERFORMANCE OF DRIP IRRIGATION SYSTEM AND YIELD RESPONSE OF TOMATO (*Solanum lycopersicon* L.) TO DEFICIT IRRIGATION AND FERTIGATION USING BUCKET DRIP IRRIGATION KITS

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ABSTRACT

The challenge of irrigation agriculture in the present day realities is how to guarantee more crop produce from limited fresh water and nutrient supplied. One way of overcoming this challenge is through adoption of deficit irrigation (DI) and fertigation (FT) technologies both at micro and macro scale. This experiment was therefore primarily to test the efficacies and performances of DI and FT for enhanced tomato yield and profitability using fabricated drip irrigation setup. The experiment was conducted during the 2016/2017 dry season at Indafare, Kano. Effects of twelve treatment combinations, namely; four levels of water application depths (40, 60, 80, and 100% ET_o) and three levels of FT (60, 80 and 100% N) were studied. Each treatment was replicated three times and laid in a randomized complete block design. Experimental setup consisted of 20 ltr bucket hanged onto a wooden stand, filters, flow meters, and drip lateral lines of 5m with emitter spacing of 0.33m. The research assessed moisture stress-tolerance of Roma VF Tomato variety by developing its yield response factor (ky). The system performance was measured using Darcy-weisbach's equation and production profitability determined using cost-benefit analysis. Final yield increased with increased irrigation and fertigation levels. Yield response factor (Ky) were 0.3, 1.6, 0.4 and 0.9. Thus, all the values are less than unity except the second which indicated high moisture stress. Cost-benefit ratio showed that, I₁₀₀F₁₀₀ treatment recorded the highest profit of ₦1,629,535.1 and ₦2.23 gains per naira invested for Roma VF. Based on these, Chapin Bucket drip system of irrigation and fertigation (I₁₀₀F₁₀₀; I₈₀F₈₀) could be recommended for adoption in the study area.

Keywords: Drip irrigation, Tomato, Deficit irrigation, Fertigation, Yield

INTRODUCTION

Optimum use of irrigation water and nitrogen (N) nutrient is one of the most important agricultural management practices for enhancing crop yield and water use efficiency in arid region, owing to insufficient and erratic rainfall behavior and exhaustive nutrient reserve (Idris, et al. 2019). Moreover, water shortage and escalating irrigation and fertilizer costs require more attention to practices which improve water and N use efficiencies (Badr, et al., 2016). Currently, one of the challenges of irrigated agriculture has been how to produce diverse crop options and high quantity produce from limited water supply. One important way of tackling this challenge is adopting water-saving management practices at both large and small scale farming. The combined practice of regulated deficit irrigation (DI) and fertigation (FT) appears to be very promising in achieving this goal (Kirda, 2002).

Regulated DI is the practice of irrigating below actual crop water requirement. This can be carried out by either withholding or skipping irrigation event or reducing the amount of water applied per irrigation at some growth stages of the crop which are less critical (Igbadun, et al., 2006). This practice, although leads to reduction in crop yields in many instances but most often insignificantly especially if percent ETo reduction is not high (Ibrahim, et al., 2020). Deficit irrigation saves water; labor cost; and in some cases energy (Ibrahim, et al., 2020), thus, justifies further its superior advantages. Research evidences showed that higher crop water productivities are sometimes recorded with DI practice, especially if the moisture stress resulting from the deficit is not so severe (Sammis, et al., 2000; Kirda, 2002; Igbadun, et al., 2006). Diverse ways (volatilization, leaching

and fixation) through which applied nitrogen is lost is worrisome (Brady and Weil, 2014) thus begs for testing more efficient application methods and approaches such as granulation, deep placement, micro dosing and fertigation (Girei, 2021). In connection to that, the research aimed to evaluate the hydraulic performance of locally designed Drip Irrigation System and yield and growth responses of tomato crop as influenced by DI and fertigation treatments.

MATERIALS AND METHODS

The research was conducted during the 2016/2017 dry season (October to February) at Bayero University Kano, which lies on Longitude 11°58'30''N, Latitude 8°25'30''E, and altitude 481m above mean sea level, in the Guinea Savanna ecological zone, Nigeria. The area was characterized by hot-dry season from March to May; rainy season from June to October, and cool dry (Harmattan) season from November to February. The annual relative humidity is 23.5% and the minimum and maximum temperatures are 15.9°C and 32.3°C respectively (CDA, 2017, (Table 1).

Table 1: Monthly growing season climatic data of the experimental area

Month	Min. Temp (°C)	Max. Temp (°C)	Wind speed (km/day)	Sunshine (hours/day)	Precipitation (mm/month)	Radiation (Mj/m ² /day)
December	13.9	31.0	328.32	8.11	0.0	19.3
January	13.2	32.0	311.04	7.01	0.0	19.3
February	15.9	33.0	320.32	8.12	0.3	20.9
March	20.4	33.1	311.04	7.78	1.6	21.4

Source: CDA, BUK (2016)

Soil of the Experimental Site

Soil in the experimental site was sampled through random method using bucket auger and cores

for disturbed and undisturbed samples respectively. Disturbed samples were air-dried, gently crushed and sub-sampled for standard laboratory procedures as prescribed in Okalebo, et al. (2002).

Table 2: Selected properties of the soil of the experimental site

Parameter	Unit	Value
Sand	%	63
Silt	%	20
Clay	%	17
Textural Class	Sandy loam	
Bulk density	Mg m ⁻³	1.64
Field capacity	%	6.2
Permanent Wilting Point	%	5.0
Plant Available Water	%	1.2
Electric conductivity	dS m ⁻¹	1.13
Organic matter	%	0.38
Organic carbon	%	0.22
Total nitrogen	%	0.16

Description of the experimental treatments

The experimental treatments consisted of four levels of irrigation water application depth (100, 80, 60 and 40% ET_o) and three levels of fertigation applications (100, 80 and 60%) %, replicated three times to make a total of 36 treatment combinations laid in a Randomized Complete Block Design (RCBD), (Table 3).

The area of the gross plot was 18 x 11.5m. The experimental area was divided into three equal parts,

representing the three replicates with a buffer strip of 1.5m between replicates to minimize lateral interference as well as 0.5m leeway between plots. Each experimental plot was 5m long by 1m wide (5m²). Inter and intra row planting spacing was 12 cm and 33 cm respectively, giving a population of fifteen plants per row and total number of plant stands of 540.

Table 3: Description of the Treatment Combinations

Treatment No.	Treatment Combination	Description of Treatment Combination
1	I ₁₀₀ F ₁₀₀	100% Water application 100% Fertigation
2	I ₁₀₀ F ₈₀	100% Water application 80% Fertigation
3	I ₁₀₀ F ₆₀	100% Water application 60% Fertigation
4	I ₈₀ F ₁₀₀	80% Water application 100% Fertigation
5	I ₈₀ F ₈₀	80% Water application 80% Fertigation
6	I ₈₀ F ₆₀	80% Water application 60% Fertigation
7	I ₆₀ F ₁₀₀	60% Water application 100% Fertigation
8	I ₆₀ F ₈₀	60% Water application 80% Fertigation
9	I ₆₀ F ₆₀	60% Water application 60% Fertigation
10	I ₄₀ F ₁₀₀	40% Water application 100% Fertigation
11	I ₄₀ F ₈₀	40% Water application 80% Fertigation
12	I ₄₀ F ₆₀	40% Water application 60% Fertigation

I=Irrigation, F=Fertigation

Agronomic Operations

Roma VF tomato seeds were sown and raised on nursery prepared seedbed. A land area of 18 x 11.5m² was earmarked and prepared into rows of 2 x 5m and transplanted with the tomato seedlings on 4th November at after seven weeks of emergence (four leaf stage) in accordance with FAO (2013) recommendation. Nitrogen fertilizer (NPK 15:15:15) was applied as ammonium nitrate in water soluble form at 10 days interval through drip irrigation system via sieve membrane in the bucket (Plate 1). Fertigation started two weeks after planting.

Irrigation Water Application

Measured volume of water was supplied into a 20Ltr bucket and then delivered automatically to the

Chapin drip system at once (no pump is included in this design). Drip laterals were adjusted such that the water was directed into the roots zone of the plant. Weekly crop water requirement was applied at 100, 80, 60 and 40%. For full irrigation (0% deficit, (I₁₀₀) water quantity amounted to 1,7014Ltr (1.7014 m³) and 782.6mm depth per the 5m² area with wetted area of 45.6%. The 20% deficit (I₈₀) water application amounted to 1,360.8 Ltr, (1.3608 m³). Moreover, the 40% water application deficit (I₆₀) amounted to 1,0206Ltr (1.2060 m³). The 60% water application deficit (I₄₀) was 680.4Ltr (0.6084 m³). Crop water applied increased at initial and developmental stages and decrease at maturity/ senescence stage.

**Plate 1: Bucket Drip Irrigation System in the Experimental Set up**

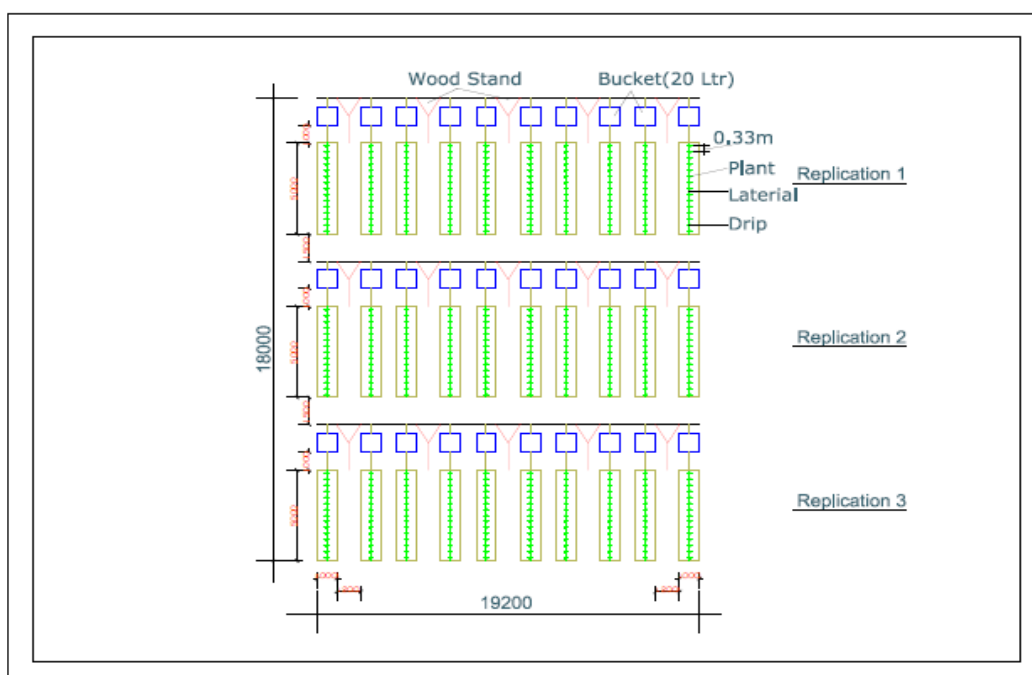


Fig. 2: Experiment Field Design

Fertigation application

Table 4 shows crop stages and Nitrogen (g/l) and fertigation applied at 100, 80 and 60%. Amount of

fertilizer dissolved per Litter of water at development stage was 2.51g l^{-1} , the mid-stage received the highest fertilizer of 7.5g l^{-1} because the stage requires more N-fertilizer than other growth phases.

Table 4: Fertigation Treatment Applied

Fertigation Application period (10days ⁻¹)	Crop Growth Stage	Nitrogen (g/l)	Fertigation Application 100% (g)	Fertigation Application 80% (g)	Fertigation Application 60% (g)
1	Development	2.51	304.6	243.68	182.76
2	Development	2.51	304.6	243.68	182.76
3	Development	2.51	304.6	243.68	182.76
4	Mid	7.5	1312.5	1050.00	787.50
5	Mid	7.5	1312.5	1050.00	787.50
6	Mid	7.5	1312.5	1050.00	787.50
7	Mid	7.5	1312.5	1050.00	787.50
Total			6163.8	4931.04	3698.28

Soil Moisture Measurement

Soil moisture status of each plot was monitored throughout the crop growing season using soil moisture resistance blocks. Three soil moisture resistance blocks (gypsum blocks) were installed in each plot at 0-20cm, 0-40cm and 0-60cm depths to monitor the electrical resistance of soil moisture. The gypsum blocks were locally fabricated and calibrated on the field to relate electrical resistance measured to gravimetric moisture content for the soil of the experimental site using the method of Ejieji and Fasasi (2003). The calibration curve was defined by the power function obtained as:

$$GMC = 536.17 \times RS^{-0.394} \dots\dots\dots(1)$$

Where:

GMC = gravimetric soil moisture content (%) and RS = soil moisture resistance in ohms (Ω). Reading was converted to gravimetric moisture content (% dry weight basis).

Hydraulic Characteristics of the Drip irrigation Determination of water application efficiency of bucket drip system

The volume of water added into the 20 litter capacity bucket was measured as V_2 and the volume of water collected from each individual emitter was measured and recorded as V_1 . The equation for application efficiency was given by (Barragan, *et al.*, 2006)

$$Ea = \frac{V_1}{V_2} \times 100\% \quad (1)$$

Where:

V1= water delivered to the farm (Ltr)

V2= water added into the bucket (Ltr)

Coefficient of Variation Uniformity

The Coefficient of Variation Uniformity (CVU) of the individual emitter discharge from the field test data which was very relevant to the measure of performance for a small drip system was obtained using equation 2 (Keller & Keller, 2003)

$$CVU = (1 - sd|qa) \times 100 \quad (2)$$

Where:

Sd = estimated standard deviation of the emitter flow rate (l/min)

qa = average rate of emitter flow rate (l/min)

Estimation of Friction Loss

Darcy–Weisbach equation was used to calculate friction losses in a length of lateral as adopted by Provenzano *et al.* (2005).

$$hf = (6.377 fL Q^2)/D^5 \quad (3)$$

Where:

Hf = friction losses along lateral (m),

L = lateral length (5m),

Q = total lateral flow rate (0.0985l/min),

D = lateral diameter (16mm) and

F = Darcy Weisbach friction factor (0.15)

Determination of Energy Slope

Energy slope was computed using the equation below as adopted by Juana, *et al.* (2002).

$$\Delta H/\Delta L = (14.03 \times Q^{1.852})/D^{4.871} \quad (4)$$

Where:

Q = total lateral flow rate (0.0985l/min),

D = lateral diameter (16mm)

Yield Response Factor of Tomato under Deficit Irrigation and Fertigation

$$\left(1 - \frac{Y_a}{Y_m}\right) = K y \left(1 - \frac{SCWU_{deficit}}{SCWU}\right) \quad (5)$$

Where:

Y_a = tomato yield of deficit irrigated treatments,

Y_m = tomato yield of the fully irrigated (I_{100}) treatments,

$SCWU_{deficit}$ = seasonal consumptive water use of the deficit irrigated treatments and

$SCWU$ = seasonal crop water use of the fully irrigated treatment (Igbadun & Oiganji, 2012).

Cost-Benefit Analysis

The economic analysis was evaluated using partial budget procedure to determine the treatment combinations that gave acceptable return at low risk to farmer (CIMMYT, 1988). Economic analysis of the

data was done based on prevailing farm gate prices of inputs, operations and outputs. The concepts used in the partial budget analysis are defined as follows:

$$GR = \text{Average price of tomato} \times \text{Total Yield..} \quad (6)$$

$$TVC = CL + S + F + C \dots\dots\dots (7)$$

Where:

TVC=Total variable cost

CL= Cost of labour

S = Seeds

F = Fertilizer

C = Chemical

$$GM = GR - TVC \dots\dots\dots (8)$$

Where:

GM =Gross Margin

GR= Gross revenue

TVC=total variable cost

$$\text{Gross Margin per Naira (₦) invested} = GM \div TVC \dots \quad (9)$$

GM = Gross margin

TVC=Total variable cost

RESULTS AND DISCUSSION

Hydraulic performance of drip irrigation

Table 5 presents results obtained from the evaluation of performance of drip irrigation system (inline non pressure compensating drip emitters). The system was tested for its uniformity coefficient, emission uniformity, manufacturing coefficient of variation and energy head lost. The average discharge rate of the emitter was 0.006 Lmin^{-1} , while the emitter discharge exponent and discharge coefficient (empirical factor) of the emitter were obtained as 0.94 and 0.98 respectively. Manufacturer Coefficient variance (Cv) was 0.06 which falls within the average range category $0.05 < CV < 0.07$. The application efficiency for drip line was 98% and emission uniformity was 80% which fall within the range of good according to Merriam and Keller (1978). General values for emitter uniformity factor (EUF) for systems as follows: greater than 90% (excellent), between 80% and 90% (good), 70 to 80 (fair) and less than 70% (poor). Coefficient of Variation Uniformity (CvU) was 94% which was excellent in accordance with a Keller and Keller (2003). Energy slope was 1.4kJ. The head losses was 0.04m. From the above hydraulic performance of the bucket drip irrigation show that the system had high water application efficiency.

Table 5: Hydraulic Performance Of Bucket Drip Irrigation

HC :	X	K	Cv	Ea	Euf	CvU	Es	Dw
Values:	0.94	0.98	0.06	98	80	94	1.4	0.05

Where: X = Emitter discharge exponent, K = Discharge coefficient (empirical factor), Cv = Manufacturer Coefficient variance,

Ea = Application efficiency for drip line, Euf = Emitter Uniformity, CvU = Coefficient of Variation Uniformity,

Es = Energy slope, ED = Energy drop and D.W = Darcy–Weisbach

Seasonal Crop Water Use (SCWU)

Table 6 shows the seasonal crop water use (SCWU) which ranged from 183.5 to 542.6 mm/season across the treatments. The SCWU was observed to decrease with decrease in fertigation and irrigation. The SCWU observed in I_{100} and F_{100} was 542.6mm/season. However, the trend of the daily crop water use revealed that the daily crop water use was more pronounced in the development and fruit formation (Mid) growth phase, most especially in the I_{100} . Seasonal crop water use for I_{100} ranged from 452.1 to 514.2mm while for deficit irrigation regimes they ranged as follows: 417.0 to 445.5, 279.5 to 356.2 and

183.5 to 224.1 mm/seasonal for 20% (I_{80}), 40% (I_{60}) and 60% (I_{40}) deficits respectively. The SCWU depicted a progressive trend with increase in fertigation which may be due to increase in growth which results in more water demand and intake.

The least value was obtained in the treatment combination ($I_{40}F_{60}$), while the highest value was obtained in the treatment ($I_{100}F_{100}$). Analyses of the percentage reduction showed that treatment $I_{100}F_{100}$ was 64% higher than treatments $I_{40}F_{60}$. This implied that treatment $I_{100}F_{100}$ had a better water utilization efficiency.

Table 6: Seasonal Crop Water Use (SCWU) mm/season

Treatment No.	Treatment Combinations	SCWU(mm)
1	$I_{100}F_{100}$	514.6
2	$I_{100}F_{80}$	465.0
3	$I_{100}F_{60}$	452.5
4	$I_{80}F_{100}$	445.5
5	$I_{80}F_{80}$	428.0
6	$I_{80}F_{60}$	417.0
7	$I_{60}F_{100}$	356.2
8	$I_{60}F_{80}$	287.9
9	$I_{60}F_{60}$	279.5
10	$I_{40}F_{100}$	224.1
11	$I_{40}F_{80}$	201.9
12	$I_{40}F_{60}$	183.5

I = Irrigation, F= Fertigation, SCWU = seasonal crop water use

Tomato Yield

Statistical analysis showed that the yield obtained varied significantly (**) at 1% probability level ($p < 0.01$) (see Table 7). Fruit yield of tomato

ranged from 6.0 to 14.8ton ha⁻¹ and the least yield was obtained from I_{40} treatment, while the highest yield was obtained from I_{100} .

Table 7: Statistical Analysis of Yield Obtained from ANOVA

Treatment	Yield (ton ha ⁻¹)
Irrigation Levels	
I_{100}	14.38a
I_{80}	12.62b
I_{60}	9.02c
I_{40}	6.53d
Significance	**
DMRT@5%	0.0956
Fertigation Levels	
F_{100}	11.23a
F_{80}	10.57b
F_{60}	10.12c
Significance	**
DMRT@5%	0.0828
Interaction	
I * F	*

** = Highly significance NS = not significance, @ 5%, (P ≤ 0.05). Means with the same letter are not significantly different using DMRT at 5% probability level.

Further, the interaction between irrigation and fertigation was significant. The research outcome showed that irrigating tomato at 40%

evapotranspiration (ET_o) reduced tomato yield by 52.3%. More so irrigating tomato at 60% of ET_o caused a yield reduction of 35.1%. Nonetheless,

irrigating at 80% of ETo only reduced yield by 9.0%. This agreed with FAO (2013) who reported that tomato yield decreased with increase in water deficit. This suggests that water application per irrigation may be reduced to 80% ETo without causing significant lost in the yield of tomato crop.

Yield Response factor of Tomato

Table 8 presents the relative seasonal crop water use and relative tomato yield response factor (ky). The ky and relative SCWU deficit also increases with increase in irrigation deficit and fertigation practices.

The Ky obtained were 0.3, 1.6, 0.4 and 0.9 for the combined treatment 1 to 4 respectively (Table 9). Lovelli, *et al.* (2007) advanced that Ky usually indicates a linear relationship of the relative reduction in water that was consumed with a relative reduction in yield. The coefficient of determination (r^2) values were obtained as 0.83, 0.94, 0.83 and 0.99 respectively. Yield response factors (Ky) for the combine treatments 1 to 4 respectively was obtained using regression analysis.

Table 8: Yield Responses of Tomato under Full and Deficit Irrigation

S/No.	Treatment	Relative Yield	Relative SCWU	Ky
1	I ₁₀₀ F ₁₀₀ × I ₁₀₀ F ₁₀₀	0.00	0.00	0.39
	I ₁₀₀ F ₁₀₀ × I ₁₀₀ F ₈₀	0.03	0.09	
	I ₁₀₀ F ₁₀₀ × I ₁₀₀ F ₆₀	0.05	0.12	
2	I ₁₀₀ F ₁₀₀ × I ₈₀ F ₁₀₀	0.09	0.13	1.68
	I ₁₀₀ F ₁₀₀ × I ₈₀ F ₈₀	0.16	0.17	
	I ₁₀₀ F ₁₀₀ × I ₈₀ F ₆₀	0.19	0.19	
3	I ₁₀₀ F ₁₀₀ × I ₆₀ F ₁₀₀	0.35	0.31	0.45
	I ₁₀₀ F ₁₀₀ × I ₆₀ F ₈₀	0.39	0.44	
	I ₁₀₀ F ₁₀₀ × I ₆₀ F ₆₀	0.43	0.46	
4	I ₁₀₀ F ₁₀₀ × I ₄₀ F ₁₀₀	0.53	0.57	0.99
	I ₁₀₀ F ₁₀₀ × I ₄₀ F ₈₀	0.56	0.61	
	I ₁₀₀ F ₁₀₀ × I ₄₀ F ₆₀	0.60	0.64	

Ky= Yield response factors, SCWU=seasonal crop water used

The Ky value obtained from combined treatment 2 was higher than unity, which indicated that the moisture stress imposed on the crop due to withholding irrigation every other week at in multiple growth stages was severe to cause yield declination. When crops have Ky values lower than unity they are considered to be tolerant to water deficiency as noted by Ayas and Domirtas (2009). On the other hand, all the treatments were less than unity except combine

treatment 2 which is greater than unity. This finding indicated that tomatoes grown under drip irrigation approach could be considered to be moisture stress-tolerant as reported by Patane, *et al.* (2010).

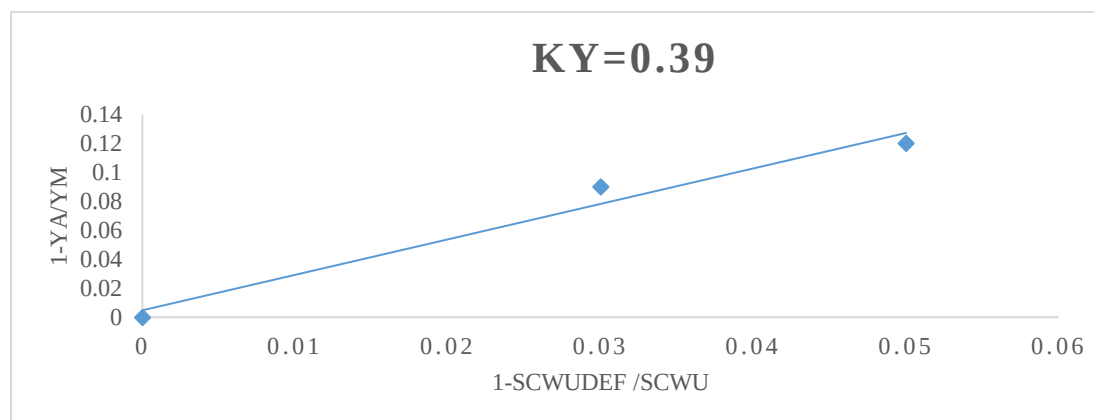


Fig. 3: Combined treatment 1

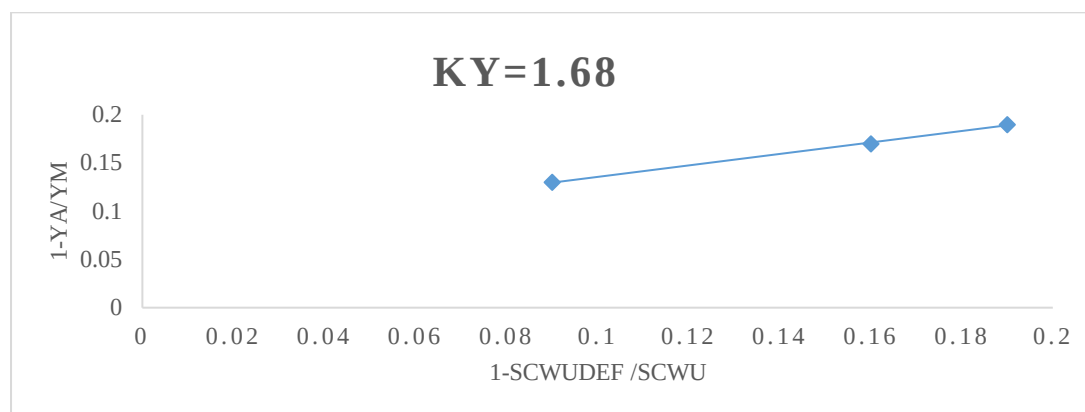


Fig. 4: Combine treatment 2



Fig. 5: Combine treatment 3

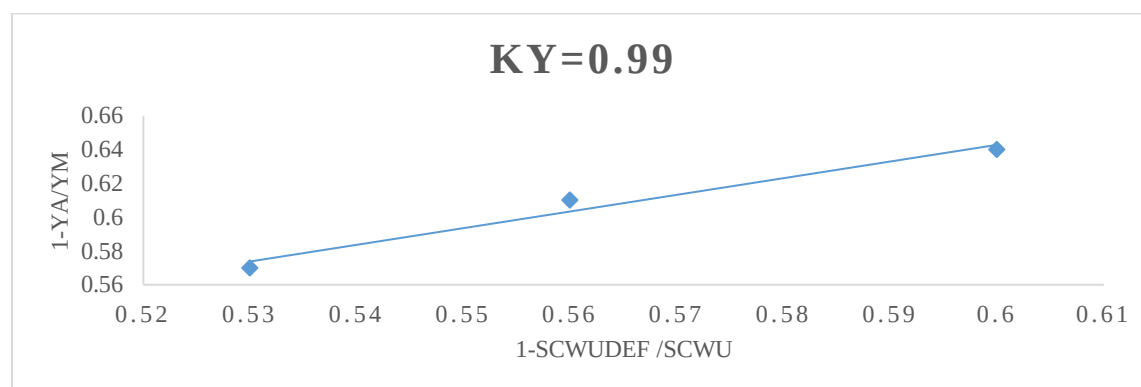


Fig. 6: Combine treatment 4

Partial Economic Analysis

Gross margin analysis (Table 9) indicated that, the highest gross return of ₦1,629,535.1 and a net profit of ₦2.23 per naira invested were achieved by I₁₀₀F₁₀₀ for growing Roma VF tomato. The least return of ₦573,887.1 gain was observed from I₄₀F₁₀₀ in which ₦1.92 was gain per naira invested.

This might be connected to higher fertilizer application which served the crop nutrient demand and in turn significantly affected the establishment, vegetative and reproductive developmental stages of the Roma VF.

Table 9: Cost - Benefit Analysis of Roma VF tomato Production Under Deficit Irrigation and Fertigation

S/No.	Treatment	Total Yield (ton/ha)	Gross Price (₦/ha) (GR)	Total Revenue Ton ⁻¹ (TVC) (₦/ha)	Gross Variable Cost (₦/ha)	Gross Margin (GR-TVC) (₦/ha)	Margin per Naira Investment (₦/ha)
1	I ₁₀₀ F ₁₀₀	14.8	200000	2960000	1330464.9	1629535.1	2.23
2	I ₁₀₀ F ₈₀	14.4	200000	2880000	1264431.9	1615568.1	2.28
3	I ₁₀₀ F ₆₀	14.0	200000	2800000	1197731.9	1602268.1	2.34
4	I ₈₀ F ₁₀₀	13.4	200000	2680000	1139702.9	1540297.1	2.35
5	I ₈₀ F ₈₀	12.4	200000	2480000	1073669.9	1406330.1	2.31
6	I ₈₀ F ₆₀	12.0	200000	2400000	1007636.9	1392363.1	2.38
7	I ₆₀ F ₁₀₀	9.6	200000	1920000	949141.0	970859.0	2.02
8	I ₆₀ F ₈₀	9.0	200000	1800000	883108.0	916892.0	2.04
9	I ₆₀ F ₆₀	8.4	200000	1680000	817075.0	862925.0	2.05
10	I ₄₀ F ₁₀₀	7.0	200000	1400000	758178.9	641821.1	1.85
11	I ₄₀ F ₈₀	6.4	200000	1280000	692145.9	587854.1	1.85
12	I ₄₀ F ₆₀	6.0	200000	1200000	626112.9	573887.1	1.92

Total revenue is based on ₦12,000 per basket (60 kg) of tomato price at Janguza market (Kano) around 2016/2017 dry season.

wheat Improvement Centre (CIMMYT), Mexico City, Mexico: DF. 59 pp

CONCLUSION

Chapin Bucket drip irrigation system has 98.0% and 80.0% efficiency and uniformity indices respectively in irrigation water application and management. Roma VF tomato variety had a yield response factor (ky) less than 1, hence indicated high tolerance to moisture stress under this system of irrigation. Furthermore, highest gross return of ₦1,517,292.3 with a projection of ₦2.18 per naira invested and least return of ₦401,751.1 gain with a projection of ₦1.40 per naira invested could be generated using this system of irrigation. It's therefore recommended that, the use of Bucket drip irrigation system could be adopted for production of Roma VF tomato owing to its performance efficiency, increased productivity and profitability.

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