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Full length research paper

Water management and appropriate irrigation system for greenhouse tomato production in soilless media

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Soilless farming is an advanced agricultural mechanization method recently practiced in many countries of the world where agricultural soils are scarce, like Israel and Japan or where alternative to soil cropping is desirable like Florida and Californian. Apart from the weather condition, one major requirement which is very crucial to successful soilless farming in a greenhouse is the choice of irrigation method and water management skill. Sprinkler and drip irrigation systems were designed, constructed and calibrated. These were used to fertigate the tomato crop with a pre-mix NPK 20:20:20 liquid fertilizer in various soilless media. Water use efficiencies of tomato were compared under the sprinkler and the drip irrigation systems, benefit-cost ratio of producing tomato using the two irrigation systems were determined. The uniformity coefficience obtained for the sprinkler unit was 91% while the emission uniformity of the drip was 95%.Sprinkler used up to 3 times the amount of water used by the drip and water used efficiency of tomato varied from 5.4 to 6.8 g/l under sprinkler and 16.7 to 24.4 g/l under drip irrigation. The benefit-cost ratio of drip irrigation versus micro sprinkler irrigation was 2:1. Yield of tomato under drip irrigation was twice the yield under the sprinkler irrigation and also drip produced tomato of higher marketable quality than sprinkler. Drip irrigation system is a recommended practice for greenhouse-grown tomato in the study area.

Key words: Soilless media**,** appropriate irrigation system, greenhouse, tomato, water use efficiency.

INTRODUCTION

Soilless culture is a modern practice, although growing plants in containers has been used in the past to produce aesthetic plants, rare fruits and expensive vegetables. However, it played no role in commercial food supply. In the early 70s, researchers developed complete nutrient solutions, coupled their use to appropriate rooting media, and studied how to optimize the levels of nutrients, water and oxygen to demonstrate the superiority of soilless media in terms of yield. This technique was further developed for food production in soilless media, first in the Netherlands and later in a few other countries (Raviv, 2010). Soilless culture used in greenhouse provides alternative to soil-based culture especially for situations where suitable chemical treatments do not exist (George and Robert, 1999). Soilless culture in greenhouse for vegetable is relied on heavily in Europe, United States, the Middle East, Japan and Canada among others (George and Robert, 1999). Jensen (1991) observed that a high degree of competence in engineering skills, irrigation techniques and cost reduction is required for its successful operation. Naasz and Bussieres (2010) conducted a research in Canada on wetting properties of growing media which are important factors to consider in optimizing irrigation management (water and fertilizer inputs) thereby minimizing environmental concerns (pollution of ground and surface waters). Hochmuth (1991) reported that vegetables produced in greenhouses require ample amounts of water for optimum growth, yield, and fruit quality. Water is the “universal solvent” in plant cells and is involved in many biochemical processes. Growth processes will slow down and fruit yield and quality will also result if the plant is without water for even a very short period. Greenhouse growers apply irrigation water daily in frequent, short applications. Fertilizers are generally applied through the irrigation water.

According to A-A turbogarden (a publication in Turnkey),

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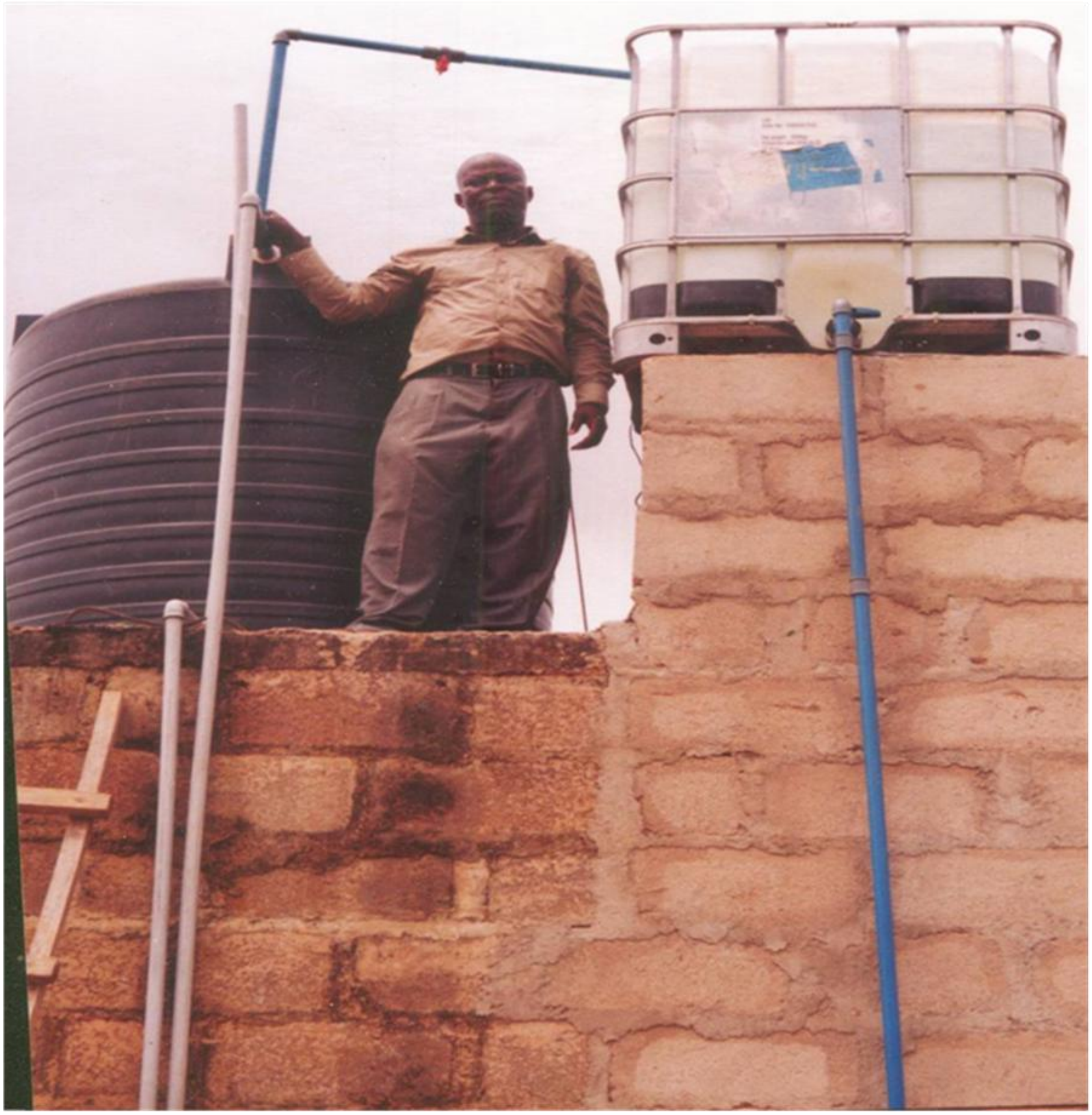

Plate 1. Transparent rubber tank with the scaffold.

there are five basic hydroponic systems which are aeroponics, drip method**,** ebb and flow, NFT (Nutrient Film Technique) and the aeration method. Sorenson and Relf (1996) divided hydroponic systems into two broad divisions, namely the water culture systems and the aggregate systems. The water systems include the nutrient film technique, aeroponics and aeration methods while the aggregate systems are the flood and drain method, trickle feed method and the tube culture which is a modification of the trickle method. The aggregate system is what is referred to as soilless planting where an inert object such as rockwool, coconut fiber, sawdust, pumice, rice husk, sand or bark of some trees are used as replacement for soil whereas in water culture plants are grown in water and nutrient solution without any use of any object for mechanical support. Soilless planting is easier to achieve with lesser skill than the water culture and its better for commercial production of most vegetables in greenhouses. Flood and drain will result in waste of water and fertilizers and the tube method which is modification of trickle method will conserve water but cannot be used for mechanized or commercial farming. Drip and modified sprinkler (micro-sprinkler) has being solicited for use in commercial irrigation of vegetables planted in soilless media under greenhouse condition (Sorenson and Relf, 1996).

Drip irrigation is an irrigation method which minimizes the use of water and fertilizer by allowing water to drip slowly to the roots of plants, either onto the soil surface or directly onto the root zone, through a network of valves,

Table 1. Determination of application rate from the flow rate.

Cat cans	Flow rate (Q x 10-4 m3/s)	Application rate (mm/hr)
1	5.00	10.60
2	6.52	13.82
3	5.87	12.45
4	5.80	12.30
5	5.40	11..45
6	5.06	10.73
7	6.68	14.42
8	5.70	12.08
9	6.51	13.80
10	5.72	12.13
11	6.38	13.53
12	6.26	13.27
13	4.70	9.96
14	6.31	13.38
15	6.41	13.59
16	5.38	11.41
17	5.11	10.83
18	6.22	13.19

pipes, tubing, and emitters. Drip irrigation is mostly suitable in areas where water supplies are limited or recycled water is used for irrigation. Careful study of all the relevant factors like land topography, soil, water, crop and agro-climatic conditions are needed to determine the most suitable drip irrigation system and components to be used in a specific installation. Fertilizer savings of up to 95% are being reported from recent field tests using drip fertigation and slow water delivery as compared to timed-release and irrigation by micro spray heads (Wikipedia, 2007). If properly designed, installed, and managed, drip irrigation may help achieve water conservation by reducing evaporation and deep drainage when compared to other types of irrigation such as flood or overhead sprinklers since water can be more precisely applied to the plant roots. In addition, drip can eliminate many diseases that are spread through water contact with the foliage.

However, drip irrigation has some disadvantages or shortcomings which make sprinkler irrigation an acceptable alternative especially where water is sufficient. These disadvantages include the following:

- Cost: Initial cost can be more than overhead systems.
- Waste: The sun can affect the tubes used for drip irrigation, making them last shorter than they would otherwise. Longevity is variable.
- Clogging: If the water is not properly filtered and the equipment not properly maintained, it can result in clogging.
- Drip irrigation might be unsatisfactory if herbicides or top dressed fertilizers need sprinkler irrigation for activation.
- Drip tape causes extra cleanup costs after harvest. The user needs to plan for drip tape winding, disposal, recycling or reuse.
- Waste of water, time and harvest, if not installed properly.

According to Haman and Yeager (2005), there are some good reasons why overhead sprinkler irrigation systems are commonly used in the container nursery industry. Apart from being used for several years they are reliable, relatively low in maintenance and they can be used for chemical injection. The biggest drawback is that they are inefficient in water application, unless water can be recycled. In sprinkler or overhead irrigation, water is piped to one or more central locations within the field and distributed by overhead high-pressure sprinklers or guns. A system utilizing sprinklers, sprays or guns mounted overhead on permanently installed risers is often referred to as a solid-set irrigation system. Leboeuf J (2012), concluded that choosing the right irrigation system requires more than grower experience. To be most effective, he suggested irrigation system should be designed by experts. Leboeuf J (2012), reported that two primary methods are used for the in-field distribution of irrigation water in Ontario which is the drip irrigation and the sprinkler or overhead irrigation.

Given these numerous advantages and disadvantages of both the sprinkler and drip irrigation systems as applied to greenhouse vegetable production, it is therefore desirable to determine which of the two is better for vegetable production in some selected soilless media.

MATERIALS AND METHOD

Two irrigation systems namely sprinkler (s) and drip (d) were developed, calibrated and applied to fertigate tomato planted in six soilless media namely: Washed sand (T1), sterilized sawdust (T2), grinded coconut fiber (T3), sand/sawdust (1:1) (T4), sawdust/coconut fiber (1:1) (T5) and coconut fiber/sand (1:1) (T6). Each soilless medium was replicated three times under each irrigation systems inside a greenhouse.The experiment was a 2x6 factorial combination with three replicate, using a Randomized Complete Block Design.Water was stored in big transparent rubber tank of 1000 l capacity at a very high elevation of 4.5m to provide the high pressure needed by both systems to deliver the water (Plate 1). Liquid fertilizer (Boost Extra – N: P: K: 20:20:20) was applied through the irrigation water (fertigation) at the rate of 60ml to 15l as recommended by the manufacturer. The nutrient content in the fertigated water was monitored by measuring the pH and EC values of the water before application.The pH and the EC of the water varied between 7.3 to 7.7 and 0.27dS/m to 0.3dS/m respectively. Water Use Efficiencies (WUE) of tomato under the two irrigation systems was calculated while yield and percentage of marketable fruits of tomato were determined at maturation. Marketability of tomato was determined by physical observation of tomato fruit for mechanical damage, insect attack or rot (as a result of water application directly on tomato fruits at maturation under sprinkler irrigation). The experiment was repeated for two growing cycles. Data were analyzed using ANOVA at p = 0.05. Cost benefit analyses of using drip versus micro sprinkler irrigation system was evaluated.

The Sprinkler System Design

Component parts

- Overhead tank to store water and fertilizer and to provide the needed operating pressure.
- Main supply pipeline consisting of 25mm diameter and 9.8m long PVC pipe.
- One gauge valve installed at 1.5m height on the main supply pipeline below the overhead tank
- Three 20 mm diameter risers each of 100cm height.
- Three gauge valves (installed at middle of each riser) for controlling the application rate of the sprinklers in each lateral.
- Three 1.25cm diameter perforated pipe sprinkler that sprayed water in a non overlap pattern at fairly uniform rate which serve as the laterals.
- Eighteen graduated plastic cans of the same size (volume) for uniformity coefficient determination.

Sprinkler distribution pattern

Materials used include the following:

- 9″ block Scaffold (4.5m high)
- Storage tank (1000 l)
- Perforated pipe sprinklers
- Measuring cylinder
- Stopwatch
- Rubber cans (area, a = 2.83 x $10^{-3}m^2$) r = 0.03m

Eighteen rubber cans were placed at an equidistance of 35cm along each of the three parallel perforated pipe laterals containing six nozzles each. The laterals were spaced at 35cm to one another, all corresponding to within and between row spacing’s respectively. The whole arrangement was on a common platform with the drip irrigation unit. The volume of water caught by each can after 3 min was recorded from which sprinkler discharge, Q was determined. Application rate for each discharge was computed using the relationship given by Robert and James (2001) as follows.

A = KQ/a ……………………… (1)

where, A = application rate in mm/hr

Q = Sprinkler discharge in l/min

a = wetted area of sprinkler (surface area of can)

K = 60 for A when A is expressed in mm/hr

The uniformity coefficient of the sprinkler system was determined. This coefficient represents the potential efficiency of operation of the sprinkler. The Christiansen’s formula (Michael and Ojha, 2003) for uniformity coefficient, C_u can be expressed as follows

C_u = 100 (1.0 – ΣX/mn) --- (2)

Where m = average application rate, mm/hr

n = total number of observation points

X = deviation of individual observations from the average application rate, mm/hr,

mn = sum of application rates for all the observation points

Tables 1 and 2 shows the application rate and the coefficient of uniformity for all the observation points.

Now, n= 18, mn = 222.81, therefore m = 222.81/18 = 12.38mm/hr

C_u = 100 (1.0 - 19.96/222.81)

= 100 (0.9104)

= 91.04 %

Table 2. Determination of uniformity coefficient (frequecy = 1/ Observation point).

Application rates mm/hr	Frequency	Numerical deviation
10.60	1	1.78
13.82	1	1.44
12.45	1	0.07
12.30	1	0.08
11..45	1	0.93
10.73	1	1.65
14.42	1	2.04
12.08	1	0.30
13.80	1	1.42
12.13	1	0.25
13.53	1	1.15
13.27	1	0.89
9.96	1	2.42
13.38	1	1.00
13.59	1	1.21
11.41	1	0.97
10.83	1	1.55
13.19	1	0.81
mn = 222.81		∑ X = 19.96

Other Design criteria

i)Topographic features: The only important factor that was considered is the slope of the greenhouse floor which is about 15%.
ii) Water supply: This was from a 15.6m deep well capable of supplying three flats throughout the year. The pH of the water was between 7.3 and 7.7 while the EC was between 0.27 and 0.3dS/m.
iii) Climatic conditions: The consumptive use of a crop depends upon the climatic parameters such as temperature, radiation intensity, humidity and wind velocity. The sprinkler was designed for the daily peak rate of consumptive use of the crop. To achieve uniform sprinkling of water, the perforations on lateral lines were made of the same number of uniform openings of about 1mm diameter and were not overlapping.
iv) Soilless media properties: The infiltration rate of all the media selected was higher than the water application rate of the irrigation system which was determined to be m = 12.38mm/hr. The application rate however can be adjusted by a control valve which was installed in each of the riser supplying each of the laterals.
v) Depth of irrigation: This was determined from the table provided by FAO (1998) for tomato in sandy soil similar to soilless media (30mm) on the basis of available moisture holding capacity of the chosen soilless media.
vi) Irrigation Interval: This was determined to be 5 days.
vii)Sprinkler spacing: Spacing of the sprinkler heads (within rows) and spacing of pipes (between rows) are both 35cm as against 60cm within rows and 75cm between rows when staked or 60cm within rows, 90cm between rows when not staked when planting on the soil. This results into a very much higher planting density when compare with soil culture.

The Drip System Design

Component parts and dimensions

i) The overhead unit consists of 1000 l overhead tank (which creates the required pressure), filter and a pressure valve.
ii) 2.5 cm diameter PVC pipe (main).
iii) Three 2.0 cm diameter PVC risers, each 0.3m above the platform (0.8m above the ground)
iv) Three 1.25 cm diameter drip lines, each 2.34m long
v) 18 short path orifice type, point source drip emitters (6 on each of the 3 drip lines) with each at 0.12m below the

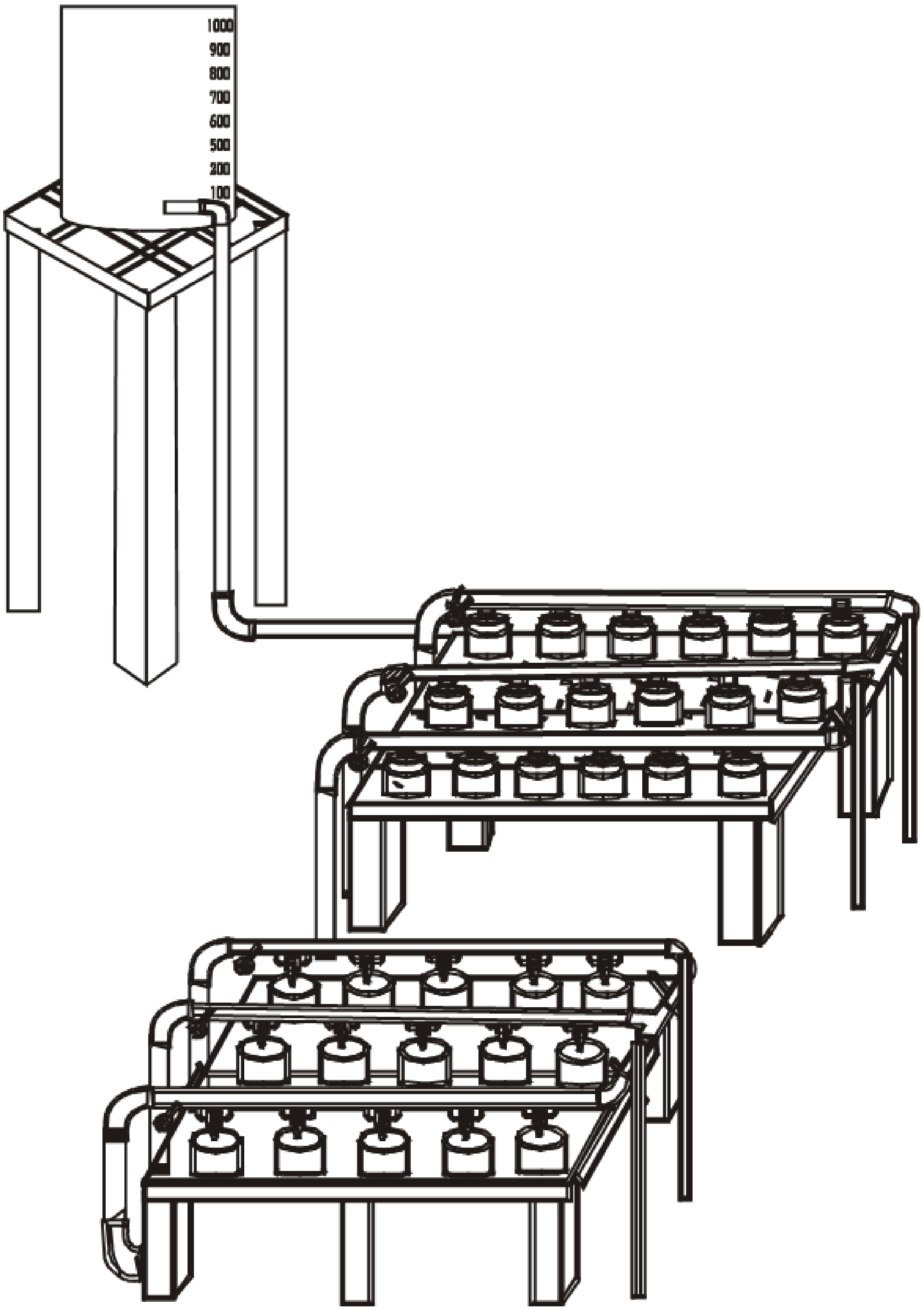

Figure 1.Pictorial of the combined irrigation units.

drip line.

Emission uniformity of the drip irrigation unit

The emission uniformity of drip was estimated using the relationship quoted by Fasinmirin (2007) as:

$$E_n = 100(1.0 - 1.27\, C_v/\sqrt{N_e})\, Q_{min} / Q_{ave} \quad \text{………………………..} \quad (3)$$

Where E_n = The design emission uniformity (%)
N_e = number of point source emitters per emission point

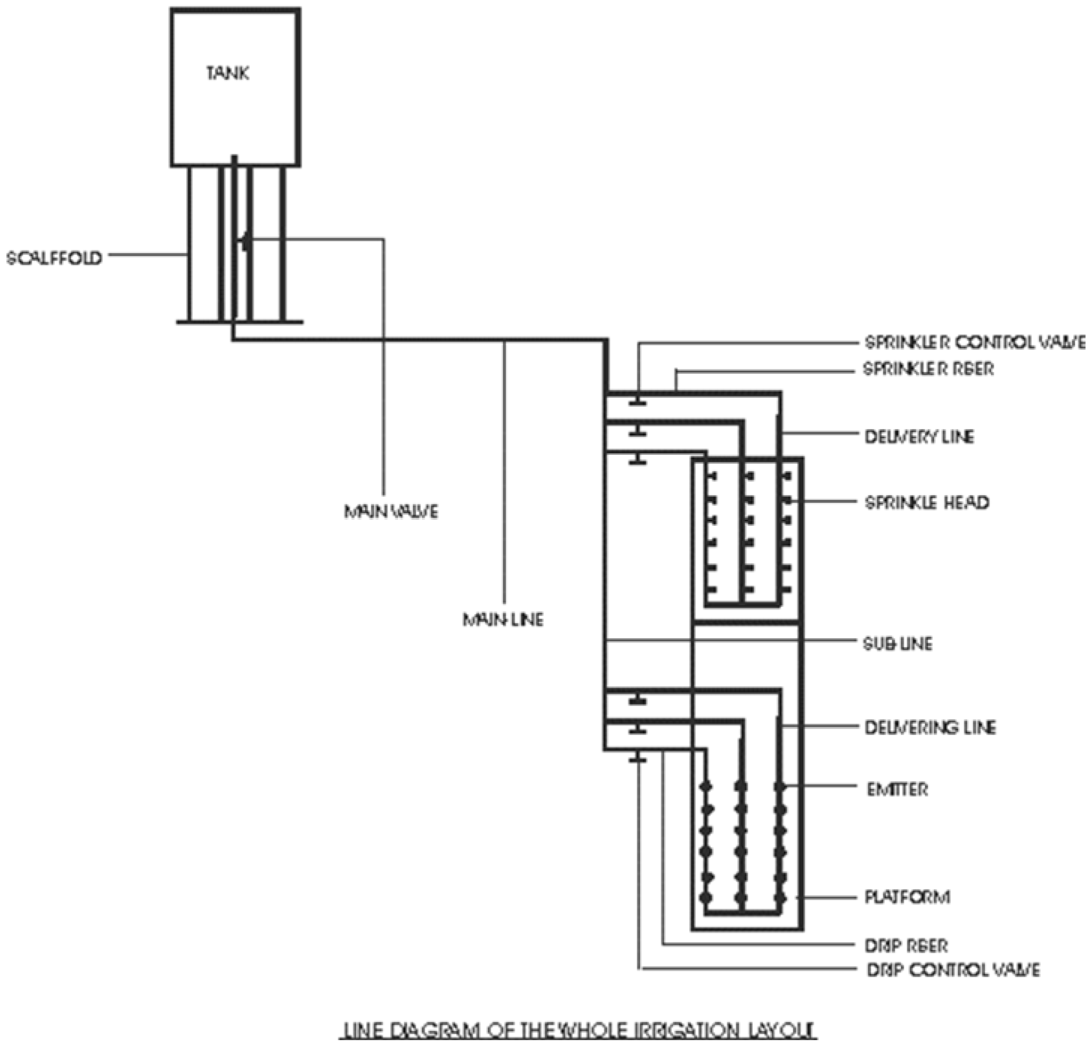

Figure2. The line diagram of the combined irrigation units.

C_v= manufacturer's coefficient of variation which is 0.03 for point source emitters

Q_{min} = the minimum emitter discharge rate in the system (l/h)

Q_{ave}= the average or design emitter discharge rate (l/h)

If C_v= 0.03, Q_{ave} = 1.84 l/hr, Q_{min}= 1.84 l/hr, = 1 are substituted in equation 3, then

E_n = 95%

Volume of water required per plant per day was estimated from the following relationship:

Volume of water required/plat/day = (ET_p * area/crop)/E_n …………… (4)

Similarly, $ET_p = ET_0 * P / 85$ …….. (5)

where ET_p= Peak evapotranspiration rate for the month under consideration (February)

ET_o = Reference evapotranspiration rate for the month = 8 mm/day

P = percentage of total area shaded by crop which is close to 80% based on Ewemoje et al., (2004) studies.

With all the values inputted into equation 5,

ET_p = 7.53 mm/day.

Area/crop = surface area of bag = 0. 0283m^2

Volume of water/ plant/day = 7.53 x 0.0283/0.95 = 0. 22l/plant/day.

Because the media do not communicate with soil mass and water soon drain out of the drainage holes at the bottom of each bag, this value was increased by a factor of safety which was chosen to be 2.

Therefore, volume of water/plant/day was 0.44l/plant/day.

Other design considerations

i) Total head required for easy flow of fertigated water in the system was put at 0.96m based on Fasinmirin (2007) study for similar point source emitter

ii) Plant spacing: This was the same as for the sprinkler system.

iii) Slope of the land (15 %) was used to determine the

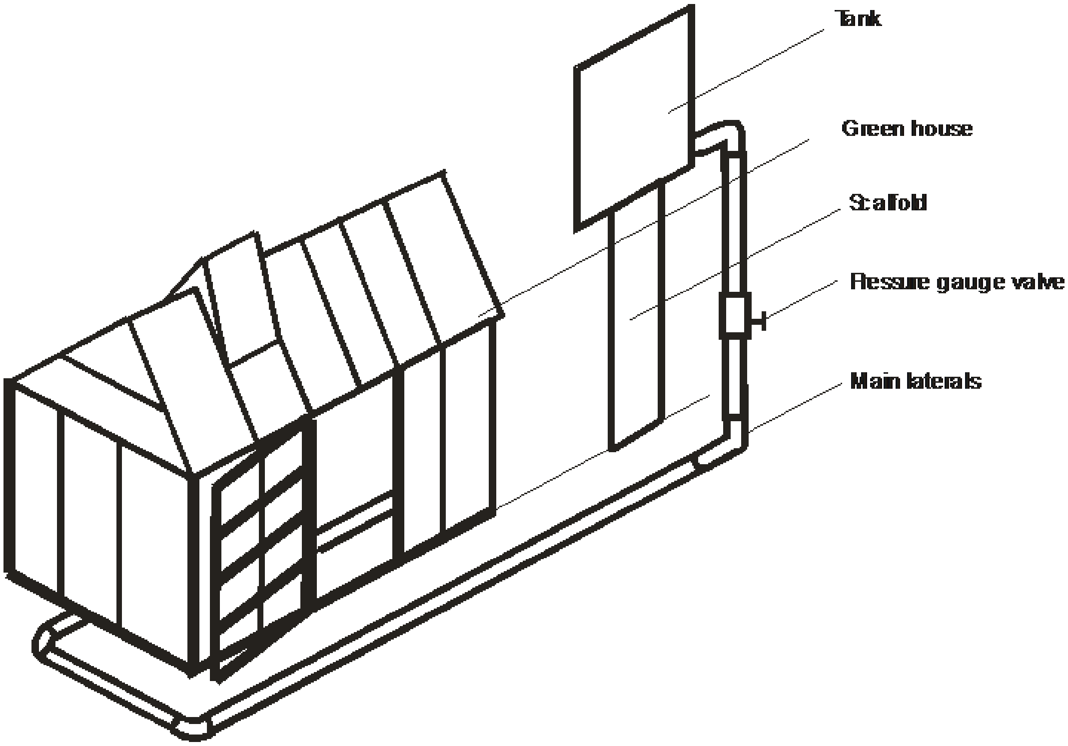

Figure 3. Combined assemblage of the two irrigation systems inside the greenhouse.

Table 3.Average water use, yield and water use efficiencies (WUE) of tomato for all soilless and irr-igation treatments.

TREATMENT	WATER USE (l)		YIELD (Kg)			WUE (g/l)				
SPK DRIP	SPK	DRIP	SPK	DRIP		SPK DRIP			SPK	DRIP
Month/yr	02 / 09		06 / 09		(Average)					
T1	82	28.6	78	22.7	80	28.2	4.6	5.5	5.8	19.5
T2	68	25.1	72	24.6	70	24.9	4.4	4.8	6.3	19.3
T3	72	25.9	71	25.6	72	25.8	4.8	6.3	6.7	24.4
T4	78	27.7	73	25.5	76	26.6	4.1	4.3	5.4	16.2
T5	67	24.5	66	24.2	76	24.4	3.8	4.2	5.0	16.8
T6	72	27.4	77	26.6	75	27.0	5.1	6.6	6.8	24.4

SPK – sprinkler, WUE – Water Use Efficiency.

location of the main and the laterals

Layout of the Combined Sprinkler and Drip Irrigation Systems

The spacing between laterals and between emitters in the drip system are the same as that of the sprinkler system. The drip laterals and the emitters were laid horizontally on the surface of the bags containing the soilless media.

Generally, all the bags were perforated at the base to provide for drainage. The leachate from each bag was collected through a system of network of pipes that delivered the leachate to a common trough, where it was collected and recirculated. Figures 1 and 2 shows the line diagram of the combined irrigation units before the erection of the greenhouse while Figure 3 shows the combi-

Table 4. Yield and quality of tomato planted in various soilless media (Feb 2009 planting).

	Yield (kg/plant)		Size (cm^3)		% of marketable fruits	
Treatment	**Sprinkler**	**Drip**	**Sprinkler**	**Drip**	**Sprinkler**	**Drip**
T1	4.5	5.4	117	129	55	68
T2	4.3	4.6	110	125	50	63
T3	4.7	6.2	111	131	56	67
T4	4.1	4.2	109	111	57	64
T5	3.8	4.1	105	113	52	64
T6	5.1	6.5	126	134	68	77

Table 5. Procedure for estimating Benefit from tomato per year while using Sprinkler, drip or the control.

Description	Sprinkler	Drip
Total yield (Kg)	80.4	94.8
Total area used (m^2)	4.6224	4.6224
Yield (Kg/ m^2)	17.394	20.509
Yield at approx. 5 m^2 (Kg)	86.968	102.544
Estimated market value (#/Kg)	600:00	600:00
Revenue per planting (RPP) (#)	52,181	61,526
Revenue per year (RPPx3) (#)	156,543	184,578

ned assemblage of the two irrigation systems inside the greenhouse.

RESULTS AND DISCUSSION

Average Water Use, Yield and Water Use Efficiencies (WUE) of Tomato

Table 3 presents the data on yield and water use efficiencies (WUE) of tomato under the various soilless media and irrigation treatments. The WUE is the yield (g) per liter of water used to produce the crop. The highest values of 24.44 and 24.42 g/l were obtained for T_6 and T_3 respectively under drip which is significantly different from 6.80 and 6.67g/l obtained for T_6 and T_3 respectively under sprinkler irrigation, at 0.5LSD. On the average the WUE for drip is about three times higher than that for sprinkler which indicates efficient use of water in converting to fruit yield by the drip system.

Yield and Yield Components of Tomato

Table 4 shows very clearly the superiority of tomato fertigated with drip irrigation system as compared to sprinkler system in terms of total yield, fruit size and quality. Yield of tomato under the drip irrigation during the first planting period was generally higher than that of the sprinkler irrigation system. It could further be observed that fruit yield, fruit size and percentage of marketable fruits are generally higher under drip irrigation system than under the sprinkler system. Lower yield under sprinkl-

Table 6. Cost Benefit analysis of using sprinkler, drip and control for the first year (3 cycles).

Type of irrigation	Cost (C) (N)	Benefit (B) (N)	B/C	'B – C'/C	Ranking
Sprinkler	23,675	156,543	6.61	5.61	2nd
Drip	18,875	184,578	9.78	8.78	1st

Table 7. Cost Benefit Analysis of using sprinkler, drip and control for the second year (3 cycles).

Type of irrigation	Cost (C) (N)	Benefit (B) (N)	B/C	'B – C'/C	Ranking
Sprinkler	15,000	156,543	10.44	9.44	2nd
Drip	8,000	184,578	21.46	20.46	1st

er could be adduced to higher water needed at fruiting and maturation stage of tomato which could not be easily achieved as a result of irrigation water intercepted by leaves, shoots and above the ground fissures of tomato which is not the case in drip where irrigation water is applied directly to the root zone. Lower value of percentage of marketable fruits under sprinkler is probably as a result of mechanical damage from direct impact of irrigation water on the surface of the fruits and the resultant rot common under sprinkler irrigation system. It could also be observed that T6 under drip produced the best tomato in terms of fruit yield, fruit size and percentage of marketable fruits. The means of the yield and all the yield variables are higher for tomato planted under the drip system than under the sprinkler system. For all the treatments, values of means obtained for fruit weight, numbers of leaves, plant height, stem girth and stem dry matter are generally higher under drip than under sprinkler, except for number of fruit which is higher under the sprinkler irrigation which implies that tomato fruits under sprinkler are generally smaller. Similarly, the leave area index (LAI) of tomato under sprinkler system is higher than that under the drip.

Cost Benefit Analyses

Total variable and fixed cost of constructing, installing and using sprinkler and drip irrigation for the first and second year were calculated. For both systems cost continues to decrease after the first year because it does not longer include the fixed cost of construction and installation of the systems. The general assumption used in the computation is that tomato was planted three times in a year for two years. Table 5 describes the procedure for estimating benefit from tomato per year while using sprinkler or drip. Yield (Kg/m^2) was estimated from total yield and area used for production of tomato under sprinkler and drip. The area under each of sprinkler and drip irrigation was 4.6224 m^2 which approximately was about 5 m^2.This value was then used as basis for computing the benefits from the two irrigation methods of producing the tomato. Also the market price of tomato during the period under investigation varied between N500 and N800/kg, depending on the quality of tomato and the time of the year. For this analysis N600 was assumed as reasonable for computing total benefits per year for the three systems. Tables 6 and 7 were used to compute the benefit cost ratio of using the two irrigation systems for the first and the second year respectively. Drip was rated as 1st while sprinkler was rated 2nd.The benefit cost ratio continues to increase for both sprinkler and drip with drip having higher rate of increase since running cost of drip will always be lower. The benefit-cost ratio of drip irrigation versus micro sprinkler irrigation was 2:1.

CONCLUSIONS AND RECOMMENDATIONS

It was concluded that drip irrigation produced tomato at a greater yield and better quality than sprinkler irrigation. The amount of water used by sprinkler irrigation was three times the amount used by the drip irrigation. The benefit-cost ratio of drip was higher than sprinkler irrigation. Drip irrigation is the recommended system for soilless planting of tomato in the study area.

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