



## Field Evaluation of Tomato Yield Affected by Uniformity of Sprinkler-Applied Water

Ransford Opoku Darko<sup>1,2\*</sup>, Shouqi Yuan<sup>1</sup>, Livingstone Sam-Amoah<sup>2</sup>, Junping Liu<sup>1</sup> and Zakaria Issaka<sup>3</sup>

<sup>1</sup>Research Centre of Fluid Machinery Engineering and Technology, Jiangsu University, Zhenjiang, Jiangsu, China

<sup>2</sup>Department of Agricultural Engineering, University of Cape Coast, Central Region, Cape Coast, Ghana

<sup>3</sup>Department of Agricultural Engineering, Tamale Technical University, Northern Region, Tamale, Ghana

**\*Corresponding Author:** Ransford Opoku Darko, Research Centre of Fluid Machinery Engineering and Technology, Jiangsu University, Zhenjiang, Jiangsu, China.

**Received:** May 21, 2018; **Published:** July 11, 2018

### Abstract

All irrigation systems apply water nonuniformly to a varying degree; yet the nonuniformity of the applied water can significantly affect the final yield of the crop. In our study, growth parameters, crop water productivity and yield of tomato were observed to be largely affected by irrigation uniformity. A newly designed and built linearly moved irrigation system with operating pressures (P) of  $P_1$ -10psi,  $P_2$ -15psi, and  $P_3$ -20psi with sprinkler heights varying at  $h_1$ -100 cm and  $h_2$ -150 cm from the ground were utilised in the experimental set up. Our findings indicated that minimum values of distribution uniformity (70.39%) and coefficient of uniformity (82.30%) were observed at  $P_1h_1$ , whereas the maximum values (88.44% and 91.17% respectively) were obtained at  $P_3h_2$ . Under  $P_3h_2$  treatment, the highest values of plant height (60.7 cm), stem girth (0.96 cm), number of leaves per plant (26.4), number of fruits per plant (10) and fruit yield ( $15.10\text{t ha}^{-1}$ ) were recorded. Also, the lowest yield ( $0.86\text{ kg m}^{-3}$ ) was recorded under  $P_1h_1$  treatment. However, under treatment  $P_3h_2$ , CWP value of  $2.00\text{ kg m}^{-3}$  was highest. The results under this experimental, environmental and similar geo-hydrological condition are recommended to operate the sprinkler irrigation system for maximum crop productivity.

**Keywords:** Crop Water Productivity; Growth; Sprinkler Irrigation Uniformity; Tomato; Yield

### Introduction

Tomato (*Lycopersicon esculentum*) is one of the most important and popular vegetable crop in China. The crop is grown for domestic consumption both in fresh and for processing. The presence of antioxidants including carotenes in tomatoes consumption, lately, has been confirmed by some studies to prevent some diseases [1-3]. Currently, China is the leading producer of tomato in the world, producing about 50 million metric tons followed by India (18 million metric tons) and United States of America (12 million metric tons). Egypt is the leading producer of tomato in Africa producing about 8 million metric tons whereas Ghana produces 0.51 million metric tons [4].

Among the different irrigation systems used in tomato cultivation, sprinkler irrigation solutions, though expensive to set up, are more efficient at delivery of water to crops, enabling higher yields with lower water utilization. In regions where water is limited, sprinkler irrigation is gaining grounds [5]. Some of the irrigation systems have pumping systems which requires less energy and

potentially minimizes negative irrigation impacts on the soil and facilitates the use of fertigation [6]. However, it is very important to study the basic principles of water and fertilizer management to sustainable irrigated agriculture [7], as well as the amount of water required for best efficiency [8].

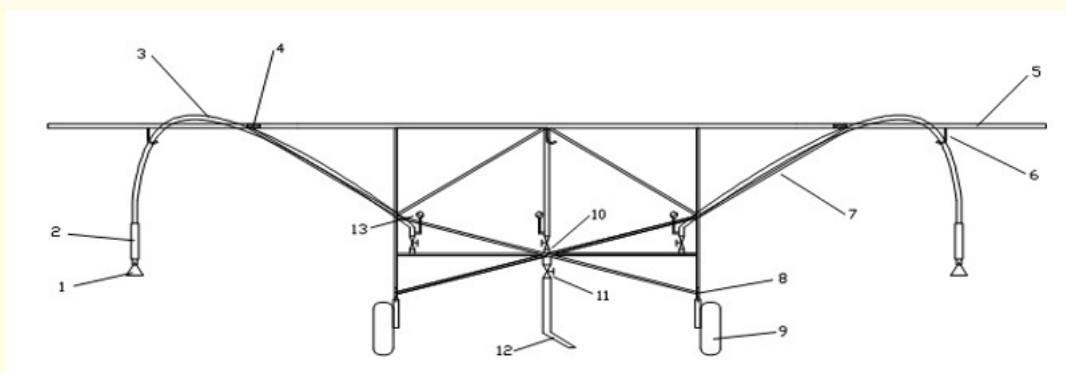
Several coefficients of uniformity have been developed in the past to contribute to the spatial distribution of water for sprinkler irrigation systems of different kinds [9]. Uniformity coefficient of the sprinkler irrigation system was first expressed by Christiansen [10, 11]. The uniformity coefficient of a sprinkler system has a direct correlation with the system's application efficiency and crop yield [12-14]. The areas on the field which receive the smallest amount of irrigation water is calculated by using the Distribution uniformity (DU). Higher values of the CU and DU will therefore increase the uniformity of sprayed water on the field [15]. Poor uniformity results in either parts of the field been over-irrigated or under-irrigated, hence adequacy of water to the crops will be

threatened [16]. As available water resources become scarcer, more emphasis is given to efficient use of irrigation water for maximum economic return and water resources sustainability. Researches on factors affecting the uniformity of sprayed water in sprinkler irrigation are very common leaving behind the effect of the system on water application rates, crop growth and yield [17,18]. It is in this regard that this experiment was carried out to

1. Investigate the effect of a newly built Linearly Moved Irrigation System (LMIS) parameters (operating pressure and riser height) on irrigation uniformity.
2. Evaluating the direct impact of the LMIS parameters on tomato fruit yield and crop water productivity.

### Materials and Methods

The laboratory of the National Research Centre of Fluid Machinery and Technology, Jiangsu University, Zhenjiang, China was utilized to conduct the study during the late winter season of 2015. Zhenjiang coordinates are Latitude: 32°12'5"N, longitude: 119°30'32" and 26m above sea level. It has a relative humidity of 76%. The newly designed and built linearly moved irrigation system (Figure 1) was designed and assembled by the National Research Centre of Fluid Machinery Engineering and Technology, Jiangsu University, China. The system can be easily installed and used for efficient management of crop-water productivity at farm level due to its simplicity in operation, more portable and robustness.



**Figure 1:** Schematic view of Linearly Moved Irrigation System (LMIS) used in the experiment.

- 1: Low Pressure Nozzle; 2: Counterweight; 3: Water Hose; 4 : Quick-Release Connectors; 5: Slotted Truss; 6, 7: Pitch Means the Support Bar; 8: Height Adjustment Bolt; 9: Sprinkler Wheels; 10: Water Way; 11: Supply Valve; 12: Pipe Water Supply Interfaces; 13: Gauge.

Seedlings of tomato variety; Jinpeng No.5 were nursed in the green house for three weeks after which were transplanted into buckets already filled with sandy loam soil which were placed in the laboratory where the experiments were conducted starting on the 1<sup>st</sup> of March, 2015. Water supply at the nursery was reduced a week prior to transplanting in order to harden the seedlings to reduce transplanting shock. All field conditions necessary for crop growth were adhered to prior to transplanting. One seedling was planted into it each bucket. The plants were fertilized with nutrients one Week After Transplanting (WAT) with 50 kg ha<sup>-1</sup> of NPK at 15:15:15 and fed once weekly with 30g N m<sup>-2</sup> as potassium nitrate and 30g P m<sup>-2</sup> as superphosphate nutritive solution. Weeds were removed by hand picking as soon as they appeared and plants were sprayed with Dithane M 45 (2 g L<sup>-1</sup> of water) fortnightly to control fungal and insect infestation.

Randomized Complete Block Design (RCBD) was used to design the field layout. Three (3) different set of Nelson spray heads representing P<sub>1</sub>-10psi, P<sub>2</sub>-15psi, and P<sub>3</sub>-20psi were fixed on a riser of the newly designed LMIS (Figure 1) of 12m long to aid in the distribution of water over the demarcated area of 6m × 4m at height (h) above the ground surface at h<sub>1</sub>-100 cm and h<sub>2</sub>-150 cm as per the treatment combination under consideration. Catch cans with height of 22 cm and an inside diameter of 20 cm were placed by the side of each bucket with planted tomato and were set at 1m apart from another set of catch can with pot planted tomato (Figure 2).

The tomato plants were irrigated at three days interval to maintain soil moisture near field capacity (75 - 80%). Irrigation treatment started after 3WAT where plants were fully established and the total amount of water applied was 5100 m<sup>3</sup>ha<sup>-1</sup>. The time set



**Figure 2:** Display of tomato at 3WAT for In-lab experiment.

for each 3<sup>rd</sup> day irrigation was 15 minutes, followed by closing the valve and taking readings. Plants in pots were carried outside the laboratory 3 hours after irrigation to receive enough sunlight for photosynthesis. However, this movement was stopped prior to the stage of flower bearing as the movement could have resulted in dropping down of premature fruits. Harvesting (5 plants per each treatment) was carried out 16WAT. The physical and chemical analyses of the soil used in this study are listed in table 1.

Physical and chemical analyses of soil used in the study	
Sand (%)	67.5
Silt (%)	42
Clay (%)	21
Soil texture	Sandy loamy
pH	6.9
E.C (dsm <sup>-1</sup> )	1.32
Organic matter (%)	1.2
N (mg kg <sup>-1</sup> )	62
P (mg kg <sup>-1</sup> )	14.6
K (mg kg <sup>-1</sup> )	132
Mg (mg kg <sup>-1</sup> )	105
Ca (mg kg <sup>-1</sup> )	439

**Table 1:** Soil analyses.

### Determination of the growth and yield of tomato

Plant height was determined with the use of tape rule measured from the base of the plant above the ground to the last expanded leaf of the growing tip and expressed in centimeters at the end of

the growing period for each treatment. Calculations were on average basis. Similarly, the total number of fruits clusters was also counted for each treatment and their means were calculated and recorded. The fruit weights for each treatment were recorded at the time of harvest. After each harvest, the individual data on fruit weight was summed up and expressed in grams for the observations on yield to be made.

### Uniformity test

The test was conducted for 15 minutes for each treatment. The water deposited in each catch can was measured volumetrically with a calibrated test tube after each test ended. For each treatment, coefficient of uniformity (CU), distribution uniformity (DU) and coefficient of variation (CV) were as follows.

### Coefficient of uniformity

Christiansen 1942 [19] expressed the most common method used in agricultural sprinkler assessment as Coefficient of uniformity (CU).

$$CU = \left[ 1 - \frac{\sum_{i=1}^n (X_i - \bar{X})}{n\bar{X}} \right] \times 100\%$$

Where

- X<sub>i</sub> is the water depth collected from the i<sup>th</sup> catch can (mm/h).
- X̄ is the mean water depth collected in all catch cans within the area (mm/h).
- n is the total number of catch cans in the area under consideration.

### Distribution Uniformity

The distribution uniformity (DU) was calculated using

$$DU = \frac{\text{Mean low quarter caught in the cans}}{\text{Average depth caught in all the cans}} \times 100\%$$

### Coefficient of Variation (CV)

The coefficient of variation (CV) is the quotient between the standard deviation of the applied water depths ( $\sigma$ ) and the average of water depth collected according to ASAE [20].

$$CV = \frac{\sigma}{\bar{x}}$$

where  $\sigma$  is the standard deviation of water depth of catch cans.

### Calculation of Crop Water requirement (ETc) and Crop Coefficient (Kc)

Crop water requirement and crop coefficients were determined as follows:

$$ETc = ETo \times Kc$$

$$Kc = \frac{ETc}{ETo}$$

$$ETo = Epan \times Kpan$$

$$ETc (3d) = \text{Loss in weight of buckets}$$

$$ETc \text{ for growth} = \text{Summation of } ETc \text{ for the number of irrigation days}$$

Where

ETc: Crop water requirements/crop evapotranspiration, mm/d.

Kc: Crop coefficient.

ETo: Reference crop evapotranspiration, mm/d

Kpan: pan coefficient (0.80)

Epan: Pan evapotranspiration, mm/d

The crop coefficients (Kc) of initial, mid and end stage were 0.30, 1.15 and 0.25, respectively according to Allen., *et al* [21].

### Amount of irrigation water

It was calculated by the formula

$$IWA = \frac{A \times ETc \times Ii}{Ea \times 1000} + LR$$

Where:

IWA: Irrigation water applied (m<sup>3</sup>)

A: Plot area (m<sup>2</sup>)

ETc: Crop water requirements (mm/day)

Ii: Irrigation intervals (3 days)

Ea: Application efficiency, (%), (Ea = 70%)

LR: Leaching requirement (m<sup>3</sup>).

### Crop water productivity

Crop water productivity (CWP), kg m<sup>-3</sup> which is defined as water utilization efficiency was calculated according to Doorenbos and Pruitt [22] as

$$CWP = \frac{\text{Grain yield (kg ha}^{-1}\text{)}}{\text{irrigation water applied (m}^3\text{ ha}^{-1}\text{)}}$$

### Reference evapotranspiration rate and rainfall reading

Amount of rainfall and Evaporation rate readings were obtained from a rain gauge and a US Class A evaporation pan respectively situated near the laboratory where the experiments were conducted. There were thirteen rainfall events. Each of these readings was accumulated for the growth period and was multiplied by the pan factor (0.8) to obtain the reference evapotranspiration (ETo). The pan factor of 0.8 was chosen because it was placed in an area which has a moderate wind speed of 2 - 3 ms<sup>-1</sup> and a high humidity.

### Data analysis

All the data collected from the observations were averaged and subjected to analysis of variance (ANOVA) and statistical test tools in the Microsoft excel program (2010) were used for data interpolation and representation of catch can coordinates and water application depths.

## Results and Discussion

### Effect of operating pressure on LMIS uniformity

Table 2 shows the values of CU, DU and CV which resulted from testing different operating pressures and riser heights. The CU values were relatively higher than those of the DU.

As shown in table 2, while increasing the operating pressures (P), the CU and DU values also increased. The data revealed that, the average of maximum values of CU and DU (93.17% and 88.44% respectively) were obtained at P<sub>3</sub>. It was however observed that the average minimum values (82.30% and 70.39%) were obtained at P<sub>1</sub> which reflects similar results obtained by Suharto and Susanawati [23]. The CU which was lowest was recorded at P<sub>1</sub> (10psi) as 82.30% while the highest value (93.17%) was recorded at P<sub>3</sub> (20psi). This trend is found to be in full agreement with Topak., *et al.* [24] who recommended that the sprinkler irrigation system should operate within higher operating pressures. This implies the LMIS must operate at a pressure of P<sub>3</sub> to obtain the highest CU and DU.

Operating Pressure (P)	Riser height (h)	Uniformities (%)		
		CU	DU	CV
P <sub>1</sub>	h <sub>1</sub>	82.30	70.39	22.5
	h <sub>2</sub>	88.57	81.02	14.40
	Mean	85.44	75.71	18.45
P <sub>2</sub>	h <sub>1</sub>	85.87	78.96	16.98
	h <sub>2</sub>	91.28	85.62	11.3
	Mean	88.56	82.29	14.14
P <sub>3</sub>	h <sub>1</sub>	90.05	84.18	12.7
	h <sub>2</sub>	93.17	88.44	10.3
	Mean	91.61	86.31	11.5

**Table 2:** The effects of operating pressure and riser height on uniformity (CU, DU and CV) values.

A reduction in throw radius was observed at the lowest P (P<sub>1</sub>) which Keller [25] reiterated that as operating pressure lowers, the dispersion intensifies and water drops hit the ground with greater effect which causes a decrease in distribution uniformity of water. This indicates that the LMIS at this point, (lowest P) is not good in delivery of uniform irrigation water for the crop to receive equal amount of water as a result of sprinkler overlap changing.

The CV decreased gradually with the increase in P. The minimum value of CV (10.3%) was obtained at the highest operating pressure (P<sub>3</sub>), while the maximum value (22.5%) was obtained at P<sub>1</sub>. The CV value at P<sub>1</sub> was highest among all values of all operating pressures. It ranked highest compared with values of P<sub>2</sub> and P<sub>3</sub> respectively for the two riser height positions. Hence, the LMIS must operate at the pressure level of P<sub>3</sub>.

#### Effect of riser height on LMIS uniformity

As h increased, the CU and DU values also increased. The lowest and highest values of CU were recorded at h<sub>1</sub> (82.30%) and h<sub>2</sub> (93.17%) respectively. This result may be associated to other portions of the field receiving more or less of the distributed water. The average values of DU overall h were 77.84% and 85.03% for h<sub>1</sub> and h<sub>2</sub> respectively. This means that DU was increased by 7.19% as the riser height increased from h<sub>1</sub> to h<sub>2</sub> respectively (Table 2). CV value at the lowest riser height h<sub>1</sub> (22.5%) was higher than that of h<sub>2</sub>.

Both DU and CU were increased with the increase in both height (h) and pressure (P). Under P<sub>1</sub> combined with different h (h<sub>1</sub> and h<sub>2</sub>), the CU values were 82.30% and 88.57% respectively. The corresponding values of DU were 70.39% and 81.02% respectively P<sub>2</sub> and P<sub>3</sub> followed the same order. The data also revealed that the maximum values of CU and DU (93.17% and 88.44%) respectively were recorded at P<sub>3</sub>h<sub>2</sub> which was in contrast with that obtained at P<sub>1</sub>h<sub>1</sub> which recorded lower values (Table 2). Hence the LMIS should operate at the high levels of both pressure and riser height to obtain the highest CU and DU.

CV decreased with increasing P and h. The highest P and h treatment (P<sub>3</sub> and h<sub>2</sub>) recorded the lowest CV value (10.3%). Hence P<sub>3</sub> and h<sub>2</sub> recorded the lowest CV for which the LMIS must operate. The highest CV value (22.5%) which was recorded under the lowest P and h treatment (P<sub>1</sub> and h<sub>1</sub>) must therefore be avoided in the systems operation, all things been equal.

#### Effect of operating pressure and riser height on tomato

Considering the above results on system performance it's obvious that the consequences of riser height and operating pressure on uniformity will contribute to variations in Plant height (PH), Stem girth (SG), Number of leaves (NL), Number of fruit per plant (NFP), Fruit yield (FY) and Crop water productivity (CWP). P<sub>3</sub>h<sub>2</sub> treatment recorded the highest values of plant height, stem girth, number of leaves, number of fruit per plant and fruit yield as compared with other treatments whereas P<sub>1</sub>h<sub>1</sub> recorded the lowest values for all the parameters. Li and Rao [13] and Dechmi., *et al.* [14] argued that uniformity coefficient of sprinkler irrigation system has direct impact on the yield of the crop. Haman., *et al.* [16] also supported their assertion emphasising on the need for good uniformity for a better yield results. This became evident for P<sub>1</sub>h<sub>1</sub> values which recorded the lowest CU of 82.30%.

Table 3 represents the effect of operating pressure and riser height on Plant height (PH), Stem girth (SG), Number of leaves (NL), Number of fruit per plant (NFP), Fruit yield (FY) and Crop water productivity (CWP).

#### Effect of operating pressure and riser height on crop water productivity

Crop water productivity (CWP) was significantly affected by different operating pressures and riser heights as observed in table 3 above. The averages of CWP were 1.82 kg m<sup>-3</sup> and 2.00 kg m<sup>-3</sup>

Operating pressures	$h_1$	$h_2$	Mean
	Plant Height per plant (cm)		
$P_1$	48.5	51.8	50.15
$P_2$	50.2	55.6	52.9
$P_3$	54.7	60.7	57.7
Mean	51.13	56.03	53.58
LSD <sub>0.05</sub> for P	2.22	1.14	1.81
LSD <sub>0.05</sub> for Ph	222	170.45	196.225
	Stem girth per plant (cm)		
$P_1$	0.42	0.60	0.51
$P_2$	0.51	0.81	0.66
$P_3$	0.79	0.96	0.88
Mean	0.57	0.79	0.68
LSD <sub>0.05</sub> for P	0.067	0.017	0.042
LSD <sub>0.05</sub> for Ph	6.66	2.51	4.585
	Number of leaves per plant		
$P_1$	14.9	18.2	16.55
$P_2$	17.6	21.1	19.32
$P_3$	21.3	26.4	23.85
Mean	17.93	21.9	19.96
LSD <sub>0.05</sub> for P	0.91	0.37	0.64
LSD <sub>0.05</sub> for Ph	90.6	54.68	72.64
	Number of fruits per plant		
$P_1$	3	4	3.5
$P_2$	4	6	5
$P_3$	8	10	9
Mean	5	6.67	5.84
LSD <sub>0.05</sub> for P	0.61	0.20	0.41
LSD <sub>0.05</sub> for Ph	60.5	30.6	45.55
	Fruit yield (t ha <sup>-1</sup> )		
$P_1$	4.39	5.97	5.18
$P_2$	9.10	9.60	9.35
$P_3$	14.50	15.10	14.8
Mean	9.33	10.22	9.78
LSD <sub>0.05</sub> for P	0.45	0.26	0.36
LSD <sub>0.05</sub> for Ph	45	39	42
	CWP (kg m <sup>-3</sup> )		
$P_1$	0.86	1.17	1.02
$P_2$	1.78	1.88	1.83
$P_3$	2.84	2.96	2.90
Mean	1.83	2.00	1.92
LSD <sub>0.05</sub> for P	0.15	0.1	0.13
LSD <sub>0.05</sub> for Ph	14.45	14.45	14.45

**Table 3:** Effect of LMIS parameters (P and h) on Plant height (PH), Stem girth (SG), Number of leaves (NL), Number of fruit per plant (NFP), Fruit yield (FY) and Crop water productivity (CWP).

for  $h_1$  and  $h_2$  treatment respectively and were  $1.02 \text{ kg m}^{-3}$ – $1.83 \text{ kg m}^{-3}$  and  $2.90 \text{ kg m}^{-3}$  for  $P_1$ ,  $P_2$  and  $P_3$  respectively. The CWP value of  $2.96 \text{ kg m}^{-3}$  which was highest occurred for treatment  $P_3h_2$  with the lowest value ( $0.86 \text{ kg m}^{-3}$ ) at  $P_1h_1$ . The above observation signifies that good uniformity coefficients positively results in the crop water productivity which translates into better crop yield. Without good uniformity, CWP will not be achieved as was observed in  $P_1h_1$ . Simulation results by Li [12], Li and Rao [13] and Moteos., *et al.* [26] and field experiments by Espinoza., *et al.* [27] suggested that crop yield increased clearly with sprinkler uniformity which is in agreement with this study.

## Conclusion

The field experiments conducted in this study demonstrated that the uniformity of sprinkled water had an impact on the fruit yield of tomato. Our study revealed that both coefficient of uniformity and distribution of the linear moved irrigation system were increased with increasing both the riser height and the operating pressure. The minimum values of distribution uniformity (70.39%) and coefficient of uniformity (82.30%) were observed at  $P_1h_1$ , whereas the maximum values (88.44% and 91.17% respectively) were obtained at  $P_3h_2$ . This also became evident as it reflected under  $P_3h_2$  treatment with the highest values of plant height (60.7 cm), stem girth (0.96 cm), number of leaves per plant (26.4), number of fruits per plant (10) and fruit yield ( $15.10 \text{ t ha}^{-1}$ ) were recorded. Also, the lowest yield ( $0.86 \text{ kg m}^{-3}$ ) was recorded under  $P_1h_1$  treatment. However, under treatment  $P_3h_2$ , CWP value of  $2.00 \text{ kg m}^{-3}$  was highest

We recommend that the study should be extended on how the operative conditions of the LMIS can be improved and utilized in other areas on the globe and probably using an integrated approach that will cater for the evaporative losses. The system could also be used outside the laboratory to reduce the bulkiness and tedious nature of carrying the tomato plants outside for sunlight.

## Acknowledgments

We greatly appreciate the careful and precise reviews by the anonymous reviewers and editors. The National key research and development program No.2016YFC0400202, the key teacher training project of Jiangsu University and the Priority Academic Program Development of Jiangsu Higher Education Institutions (PAPD).

## Bibliography

1. Willcox JK., *et al.* "Tomato and cardiovascular health". *Critical Reviews in Food Science and Nutrition* 43.1 (2003): 1-18.
2. Sharori Y and Levi Y. "Cancer prevention by dietary tomato lycopene and its molecular mechanisms". Lycopene and human health. A. V. Rao, Ed. Caledonian Science Press Ltd, Barcelona, Spain (2006): 111-125.
3. Periago MJ., *et al.* "Bioactive compounds, folates and antioxidant properties of tomatoes (*Lycopersicon esculentum*) during vine ripening". *International Journal of Food Sciences and Nutrition* 60.8 (2009): 94-708.
4. FAO. "FAOSATAT" (2016).
5. Uddin J., *et al.* "Measurement of evapotranspiration during sprinkler irrigation using a precision energy budget (Bowen ratio, eddy covariance) methodology". *Agricultural Water Management* 116 (2013): 89-100.
6. Nascimento JMS., *et al.* "Avaliação da uniformidade de aplicação de água em um sistema de gotejamento para pequenas propriedades". *Ciência e Agrotecnologia* 33 (2009): 1728-1733.
7. Bernardo S., *et al.* "Manual de irrigação". 8<sup>th</sup> edition. Viçosa: UFV (2008): 625.
8. Harmanto VM., *et al.* "Water requirement of drip irrigated tomatoes grown in greenhouse in tropical environment". *Agricultural Water Management* 71.3 (2005): 225-242.
9. Maroufpoor E., *et al.* "Evaluation of uniformity coefficients for sprinkler irrigation systems under different field conditions in kurdistan province (Northwest of Iran)". *Soil and Water Research* 5.4 (2010): 139-145.
10. Christiansen JE. "Irrigation by sprinkler". California Agricultural Experimental Station Research Bulletin 670 (1942): 123.
11. Karmeli D. "Estimating sprinkler distribution pattern using linear regression". *Transactions of the ASAE* 21.4 (1978): 682-686.
12. Li J. "Modeling crop yield as affected by uniformity of sprinkler irrigation system". *Agricultural Water Management* 38.2 (1998): 135-146.
13. Li J and Rao M. "Sprinkler water distributions as affected by winter wheat canopy". *Irrigation Science* 20.1 (2000): 29-35.

14. Dechmi F, *et al.* "Wind effects on solid set sprinkler irrigation depth and yield of maize (*Zea mays*)". *Irrigation Science* 22.2 (2003): 67-77.
15. Ortíz JN, *et al.* "Analysis of water application uniformity from a center pivot irrigator and its effect on sugar beet (*Beta vulgaris* L.) yield". *Biosystems Engineering* 105.3 (2010): 367-379.
16. Haman DZ, *et al.* "Uniformity of Sprinkler and Micro irrigation Systems for Nurseries". BUL321, Florida Cooperative Extension Service University of Florida (2003).
17. Ali OO. "A Simulation model for centre pivot system design and optimization of operation". PhD. Thesis, University of Khartoum, Sudan (2008).
18. Al-Ghobari HM. "Effect of maintenance on the performance of sprinkler irrigation systems and irrigation water conservation". *Food Science and Agricultural Research Centre, Research Bulletin* 141 (2006): 1-16.
19. ASAE. "Test Procedure for Determining the Uniformity of Water Distribution of Center Pivot and Lateral Move Irrigation Machines Equipped with Spray or Sprinkler Nozzles". ANSI/ASAE Standard S436.1, American Society of Agricultural Engineers, St. Joseph, MI (2001).
20. ASAE. "Design and Installation of Micro Irrigation Systems". ASAE Engineering Practice ASAE.EP, USA (1991): 4051.
21. Allen RG, *et al.* "Crop Evapotranspiration. Guidelines for Computing Crop Water Requirements. FAO Irrigation Drainage Paper. 56". FAO, Rome (1998): 300.
22. Doorenbos J and Pruitt WO. "Guidelines for predicting crop water requirements, Food and Agriculture Organization Irrigation and Drainage Paper No. (24)". Rome, Italy (1977).
23. Suharto B and Susanawati LD. "Design and construction of sprinkler irrigation for stabilizing apple crop in dry season". *Journal of Applied Environmental and Biological Sciences* 2 (2012): 134-139.
24. Topak R, *et al.* "Performance evaluation of sprinkler irrigation in a semi-arid area". *Pakistan Journal of Biological Sciences* 8.1 (2005): 97-103.
25. Keller J. "SCS National Engineering Handbook Section 15". US Government Office, Washington, DC (1983).
26. Moteos L, *et al.* "Cotton response to non-uniformity of conventional sprinkler irrigation". *Irrigation Science* 17.2 (1997): 47-52.
27. Espinoza B, *et al.* "Impact of pressurized irrigation systems performance on productivity of eight crops, in Guanajuato, Mexico". *Agrociencia-Montecillo* 38.5 (2004): 477-486.

**Volume 2 Issue 8 August 2018**

**© All rights are reserved by Ransford Opoku Darko, *et al.***