Acta Scientific Agriculture (ISSN: 2581-365X)

Volume 2 Issue 8 August 2018

Research Article

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

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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 (15.10t ha^{-1}) were recorded. Also, the lowest yield (0.86 kg m^{-3}) was recorded under P_1h_1 treatment. However, under treatment P_3h_2, CWP value of 2.00 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 (*Lycopersicum 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 pres sure 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: 32012'5N, longitude: 119030'32 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.

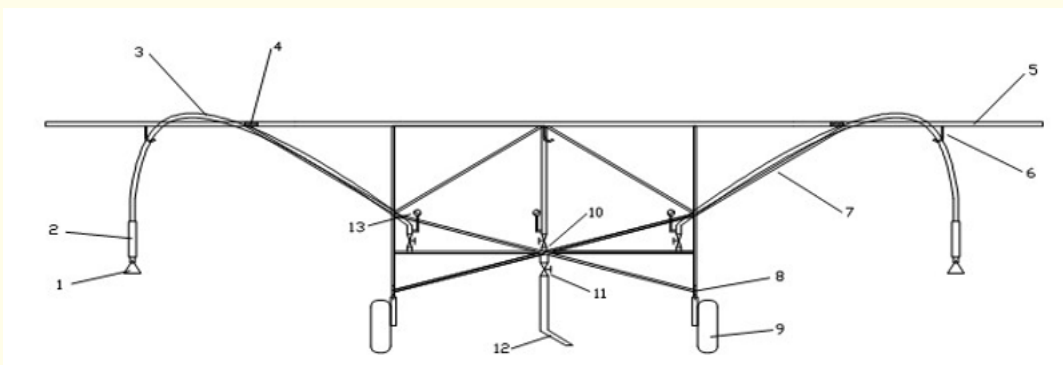

Figure 1: Schematic view of Linearly Moved Irrigation System (LMIS) used in the experiment.

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 1st 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 kgha^{-1} of NPK at 15:15:15 and fed once weekly with 30g Nm^{-2} as potassium nitrate and 30g Pm^{-2} as superphosphate nutritive solution. Weeds were removed by hand picking as soon as they appeared and plants were sprayed with Dithane M 45 (2 gL^{-1} 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_1-10psi, P_2-15psi, and P_3-20psi 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_1-100 cm and h_2-150 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^{3}ha^{-1}. The time set

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

for each 3rd 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^{-1})	1.32
Organic matter (%)	1.2
N (mg kg^{-1})	62
P (mg kg^{-1})	14.6
K (mg kg^{-1})	132
Mg (mg kg^{-1})	105
Ca (mg kg^{-1})	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_i is the water depth collected from the ith 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 consid eration.

Distribution Uniformity

The distribution uniformity (DU) was calculated using

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

Coefficient of Variation (CV)

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

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

where σ 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) = Loss in weight of buckets

ETc for growth=Summation of ETc 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^3)

A: Plot area (m^2)

ETc: Crop water requirements (mm/day)

Ii: Irrigation intervals (3 days)

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

LR: Leaching requirement (m^3).

Crop water productivity

Crop water productivity (CWP), kg m^{-3} which is defined as water utilization efficiency was calculated according to Doorenbos and Pruitt [22] as

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

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^{-1} 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_3. It was however observed that the average minimum values (82.30% and 70.39%) were obtained at P_1 which reflects similar results obtained by Suharto and Susanawati [23]. The CU which was lowest was recorded at P_1 (10psi) as 82.30% while the highest value (93. 17%) was recorded at P_3 (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_3 to obtain the highest CU and DU.

Operating Pressure (P)	Riser height (h)	Uniformities (%)		
		CU	DU	CV
P_1	h_1	82.30	70.39	22.5
	h_2	88.57	81.02	14.40
	Mean	85.44	75.71	18.45
P_2	h_1	85.87	78.96	16.98
	h_2	91.28	85.62	11.3
	Mean	88.56	82.29	14.14
P_3	h_1	90.05	84.18	12.7
	h_2	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_1) 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_3), while the maximum value (22.5%) was obtained at P_1. The CV value at P_1 was highest among all values of all operating pressures. It ranked highest compared with values of P_2 and P_3 respectively for the two riser height positions. Hence, the LMIS must operate at the pressure level of P_3.

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_1 (82.30%) and h_2 (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 h1 and h2 respectively. This means that DU was increased by 7.19% as the riser height increased from h_1 to h_2 respectively (Table 2). CV value at the lowest riser height h_1 (22.5%) was higher than that of h_2.

Both DU and CU were increased with the increase in both height (h) and pressure (P). Under P1 combined with different h (h_1 and h_2), the CU values were 82.30% and 88.57% respectively. The corresponding values of DU were 70.39% and 81.02% respectively P_2 and P_3 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_3h_2 which was in contrast with that obtained at P_1h_1 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_3 and h_2) recorded the lowest CV value (10.3%). Hence P_3 and h_2 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_1 and h_1) 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_3h_2 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_1h_1 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 empahsising on the need for good uniformity for a better yield results. This became evident for P_1h_1 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^{-3} and 2.00 kg m^{-3}

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
$LSD_{0.05}$ for P	2.22	1.14	1.81
$LSD_{0.05}$ 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
$LSD_{0.05}$ for P	0.067	0.017	0.042
$LSD_{0.05}$ 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
$LSD_{0.05}$ for P	0.91	0.37	0.64
$LSD_{0.05}$ 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
$LSD_{0.05}$ for P	0.61	0.20	0.41
$LSD_{0.05}$ for Ph	60.5	30.6	45.55
	Fruit yield (t ha^{-1})		
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
$LSD_{0.05}$ for P	0.45	0.26	0.36
$LSD_{0.05}$ for Ph	45	39	42
	CWP (kg m^{-3})		
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
$LSD_{0.05}$ for P	0.15	0.1	0.13
$LSD_{0.05}$ 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 kg $m^{-3,}$ 1.83 kg m-3 and 2.90 kg m-3 for P_1, P_2 and P_3 respectively. The CWP value of 2.96 kg m-3 which was highest occurred for treatment P_3h_2 with the lowest value (0.86 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 t ha^{-1}) were recorded. Also, the lowest yield (0.86 kg m^{-3}) was recorded under $P1h_1$ treatment. However, under treatment P_3h_2, CWP value of 2.00 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).

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