Water distribution uniformity of sprinkler irrigation systems for different design and environmental conditions

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Abstract

Proper design, installation, maintenance-repair works and favorable environmental conditions as brief qualified managerial processes are necessarily prerequisites for obtaining optimal water distribution uniformity in sprinkler irrigation systems. In this study, effects of some important parameters such as operating pressure, riser height, sprinkler spacing and environmental conditions on water uniformity were comparatively analyzed by using previous study findigs. In general, increasing sprinkler spacing caused reductions in water application uniformity. Wind speed was main environmental factor influencing water homogeneity e.g. differences between water uniformities were very little under wind speed up to 2.0 m/s (maximum 5 m/s). As expected, sprinkler Precipitation Rate, SPR, was found greater under close sprinkler spacing. Improvement of water distribution uniformity had positive effect on high crop yield and water use efficiency (WUE) consequently better economical gains. Water and energy savings consequently satisfactory crop production could be obtained under sprinkler irrigation systems managing adequately.

Key Words: Sprinkler irrigation, water uniformity, wind speed, water saving.

Introduction

In water poor climates e.g. Konya plain of Turkey, efficient water usage in agriculture is necessarily prerequisites for maximal crop yield with current water resources. Irrigation has great contributions in increasing crop production (Yavuz *et al.* 2015 a,b) and even it is almost impossible for farmers to obtain reliable benefits without irrigation in those regions (Yavuz *et al.* 2019). Correct design and proper operation of irrigation systems have produced better water distribution. Adequate water distribution within crop root systems has led to reductions in losses of both plant nutrients and applied water by deep percolation consequently ideal crop production (Ascough and Kiker, 2002; Nassab *et al.* 2013; Bishaw and Olumana, 2015; Darko *et al.* 2017; Acar, 2019). Preference of crop cultivars, like pumpkin, having low water consuming or more tolerant to certain amount of water deficiency is also one of the applicable strategies for improvement water productivity (Seymen *et al.* 2019) and if farmers goal is to put more areas into production, deficit irrigation could be practical solution especially in arid and semi-arid environments like Konya plain, Turkey (Yavuz *et al.* 2018). In world general, pressurized irrigation methods have used at about 15% of irrigated lands. The one of the most advantages of those systems is best suited for various soil, crop and topographical conditions (Ahaneku, 2010; Kulkarni, 2011). The utilization of sprinkler irrigation system is around 98% in irrigated agriculture and application efficiency was almost between 58% and 84% with an average of 71% in potato production areas of Afyon-Sandıklı province (Bakbak and Uçar, 2018) and is also the widest used irrigation technique in Konya Closed Basin of Turkey.

Water loss during reaching of water to sprinkler nozzles is little and much water losses have been witnessed during process of water spraying over soil/crops (Mclean *et al.* 2000; Yavuz *et al.* 2016). The major target of irrigation process is to apply water for crops as uniform as possible. The uniformity shows how uniformly water is distributed a cross field. The performance of irrigation systems can be evaluated by comparing water distribution uniformities (Keller and Bliesner, 2000) and is satisfactory in sprinkler irrigation system under proper management (Acar and Hamur, 2019). Beside that, evaporation and wind drift losses, EDL, is other important parameter affecting sprinkler irrigation system performance (Yacoubi *et al.* 2012). The losses after spraying water over air via sprinkler heads are evaporation from soil surface, runoff, deep percolation, and wind drift. The percentage of canopy cover has effect on soil water intake e.g little amount of vegetation cover at early stage of peanut plants resulted surface runoff and poor water distribution uniformity (Plaut and Ben-Hur, 2005). There are two well-known uniformity indicators e.g. Uniformity Coefficient, CU, and Distribution Uniformity, DU. In sprinkler irrigation systems, according to CU values, water distribution levels are (Little *et al.* 1993); Very Good, Good, Poor and Unacceptable for CU= 90%, 80-89%, 70-79%, and less than 60%, respectively. DU value should be greater than 70% for acceptable water application uniformity at sprinkler systems (Wilson and Zoldoske, 1997).

The aim of current study is, therefore, to analyze water delivery performance of sprinkler irrigation systems for different design and environmental conditions, and to present practical solutions for obtaining adequate water delivery or crop performances.

Material and Methods

The data were obtained from the worldwide previous study findings relevant to the water application uniformities for sprinkler irrigation systems under different design, operation and environmental conditions. In those studies, common way for determination of water distribution uniformity in sprinkler irrigation systems is calculation of CU and DU. In that regard, catch cans are placed within grids. Replacement of catch cans to rain gauge is other way for determination of applied water by sprinkler/s. After placements of the cans or rain gauges, sprinkler system is operated about 1.5-2.0 h. Water depths are measured by graded cylinder/s, and they are converted to the unit of mm. By uses of water depths, CU and DU values can be computed.

Results and Discussions

Evaporation and EDL as well as CU and DU were determined for different operating pressure, wind conditions and riser heights in sugar cane farm at Wanji-Ethiopia (Bishaw and Alumana, 2015). In results, EDL increased with increasing operating pressure, air temperature, and reducing relative humidity e.g. it was maximum as 16.4 % at 3.5 bar, 33.6 ^{o}C and relative humidity of 23% (Table 1). Kuti *et al.* (2019) have similar report that EDL is highly dependent on riser height. In this research, wind speed was less than 5 m/s so it had almost no affect on EDL.

Table 1. EDL for different operating conditions (Bishaw and Alumana, 2015).

Operating pressure (bar)	Wind speed (m/s)	Temperature (ºC)	Relative humidity (%)	Evaporation & Drift Losses, EDL (%)
2.5	4.2	33.4	26	11.6
3.0	4.77	31.6	37	11.8
3.5	4.72	33.6	23	16.4

In present study, increasing operating pressure produced improving CU and DU under similar environmental and riser height conditions. The maximum CU and DU values as about 81% (riser height of 2.5 m) - 82% (riser height of 4.0 m) and 73% -76% were obtained from operating pressure of 3.0 bar. The minimum CU and DU values were obtained from 2.5 bar operating pressure and wind condition at mid-day under both riser heights (Table 2). CU values varied from 72% (**Poor** Water Distribution) to 79% (**Poor** Water Distribution) at 2.5 bar operating pressure. They varied from 75 % (**Poor** Water Distribution) to 81% (**Good** Distribution) and from 73% (**Poor** Water Distribution) to 82% (**Good** Distribution) for 2.5 m and 4.0 m riser height respectively at operating pressure of 3.0 bar. Several authors (Moazed *et al.* 2010; Dehkordi, 2014) have reported that CU is dependent on operating pressure, and higher operating pressure greater CU. In current study, DU value was between 56% and 76% which was mostly less than lower threshold acceptable level of 70% as reported by Wilson and Zoldoske (1997).

Table 2. CU and DU values for different conditions (Bishaw and Alumana, 2015).

Ope. pres. (bar)	Wind conditions	2.5 m Riser height			4.0 m Riser height		
		Wind speed (m/s)	CU (%)	DU (%)	Wind speed (m/s)	CU (%)	DU (%)
2.5	Morning	2.5	79	70	2.28	74	65
	Mid-day	2.9	72	56	2.96	72	61
	Late-afternoon	1.76	73	62	1.73	79	71
3.0	Morning	2.38	81	73	2.26	82	76
	Mid-day	3.29	75	65	4.42	73	64
	Late-afternoon	2.32	77	68	2.02	81	73

Dehkordi (2014) stated that CU increased with increasing working pressure at sprinkler nozzle from 30 m to 50 m (Table 3). Combination of (15x15) m sprinkler spacing produced the greatest CU values for both square and triangle sprinkler design. The maximum CU was as about 96 % (**Very Good** Water Distribution) from wind speed, WS, of 0-4 m/s with working pressure of 50 m and (15x15) m square sprinkler design. WS greater 7 m/s caused reduction in CU values at same working pressure and sprinkler spacing. These results are consistent with some authors (Moazed *et al.* 2010; Dehkordi, 2014; Yacoubi *et al.* 2012) that they stayed that 5 m/s wind speed is upper boundary for good water uniformity.

Table 3. CU (%) values for different sprinkler designs and wind speeds (Dehkordi, 2014).

Wind speed (m/s)	Working pressure (m)	Sprinkler spacing (m)				
		Square	Square	Rectangular	Triangle	Triangle
		15 x 15	24 x 24	21 x 15	15 x 15	24 x 24
0-4	30	94.5	85.3	86.6	92.1	84.0
	40	94.4	86.7	87.3	93.7	85.2
	50	96.1	87.9	88.6	94.9	86.9
4-7	30	91.8	81.2	85.3	90.3	80.1
	40	93.9	83.1	86.1	91.4	82.1
	50	94.9	86.7	87.5	92.7	85.5
7-10	30	80.7	72.3	67.1	80.3	65.0
	40	86.4	76.4	72.2	86.3	72.4
	50	88.9	77.5	75.9	87.6	73.5

Moazed *et al.* (2010) found maximum CU value as 88% from working pressure of 45 m (Table 4). These results are full agreement with Dehkordi (2014) and Bishaw and Alumana (2015). The square sprinkler placement produced better CU (86%) by comparison to rectangular and triangle sprinkler designs. The CU values were for WS of 0-5 m/s, 5-7 m/s and > 7 m/s were 90% (**Very Good** Water Distribution), %88 and 75%, respectively. The difference in CU value between WS of 0-5 m/s and 5-7 m/s were very little, but between WS of 0-5 m/s and 5-7 m/s, and > 7 m/s is much. Therefore, sprinkler irrigation system should be operated at maximum WS of 7 m/s for minimal differences in water distribution uniformity.

Table 4. Working pressure effect on CU (Moazed *et al.* 2010).

Working pressure, m	CU, %
35	81
40	86
45	88

Ngasoh *et al.* (2018) tested sprinklers with two nozzles, diameters of (4.4 x 2.5) mm and (4.8 x 3.1) mm, under sprinkler spacing of (24 x 24) m. They found CU value as about 91% (**Very Good** Water Distribution).

Ahaneku (2010) determined CU, sprinkler flow rate and SPR at Ilorin, Nigeria. Sprinkler nozzle diameter, WS and direction, and soil type were (6 x 6) mm, less than 1.53 m/s, northeast direction and sandy-loam, respectively. The CU, average sprinkler discharge, and SPR were found as 86%, 3 t/h, and 24 mm/h, respectively. In this research, CU was greater than 85% so it was within acceptable boundary. The measured value of SPR as 24 mm/h was within boundaries of sandy-loam soil infiltration rate of 20-30 mm/h so all applied water could be infiltrated to the soil.

Kuti *et al.* (2019) researched EDL, SPR, CU and DU values at Nigeria under constant operating pressure of 1.6 bar. In results, EDL varied from 5.2% to 10.2% depending on the riser heights. Riser height of 1.5 m was suitable for minimizing EDL. SPR was found the highest as 8.6 mm/h at riser height of 1.5 m and should be equal or lower than soil water intake to avoid ponding on soil surface. CU and DU were maximum as 89% and 85%, respectively at riser height of 2.0 m. This result is almost consistent with Bishaw and Alumana (2015) since they found maximum CU as 82% (**Good** Water Distribution) from riser height of 4 m. In this study, DU values were calculated as 70%, 78% and 85% for 4 m, 3 m and 2 m riser heights, respectively, and are greater than lower boundary level of 70% so water uniformity is well in accordance of Wilson and Zoldoske (1997).

Solomon (1990) suggested following sprinkler spacing in accordance of wind conditions (Table 5). In accordance of such table, sprinkler spacing should be greater under low wind condition.

Table 5. Relationships between wind speed and sprinkler spacing ratios (Solomon, 1990).

Wind status	Sprinkler spacing
Low	50-65 % of wetted diameter
Medium	50 % of wetted diameter
High	35-50 % of wetted diameter

Yacoubi *et al.* (2012) made field study for determination of CU under different working pressure, WS and sprinkler spacing at Medjarda, Tunusia. In results, increasing working pressure resulted increasing sprinkler discharge e.g it was 1.05 m^3/ h for 200 kPa whereas it was 1.48 m^3/h for 400 kPa WP. As expected, increasing sprinkler spacing resulted decrease SPR at same WP condition. The maximum SPR was found as about 10.3 mm/h at 400 kPa WP and (12 x 12) m sprinkler spacing (Table 6). The maximum CU value of 86 % (**Good** Water Distribution) was obtained from 300 kPa WP, 0-2 m/s WS and (12 x 12) m sprinkler spacing (Table 7). Similar results were reported elsewhere (Moazed *et al.* 2010; Bishaw and Alumana, 2015). Finding of current study was lower than result of Abl El-Wahed *et al.* (2015). The difference can be associated from differences of sprinkler nozzle size, sprinkler spacing, operating pressure heads and environmental factors such as wind speed and its direction as well as managerial performances.

Table 6. SPR (mm/h) for different WP and sprinkler spacing (Yacoubi *et al.* 2012).

Working pressure (kPa)	Sprinkler flow rate (m^3/ h)	Sprinkler spacing (m)		
		12 x 12	12 x 18	18 x 18
200	1.05	7.3	4.9	3.3
300	1.29	9.0	5.9	4.0
400	1.48	10.3	6.9	4.6

Table 7. CU (%) for different operating pressure, wind speed and sprinkler spacing (Yacoubi *et al.* 2012)

WP (kPa)		Sprinkler spacing (m)								
		12 x 12			12 x 18			18 x 18		
200	WS (m/s)	0-2	2-4	4-6.5	0-2	2-4	4-6.5	0-2	2-4	4-6.5
	CU (%)	84	77	69	79	73	63	68	67	59
300	WS (m/s)	0-2	2-4	4-6.5	0-2	2-4	4-6.5	0-2	2-4	4-6.5
	CU (%)	86	77	74	80	72	64	76	71	65
400	WS (m/s)	0-2	2-4	4-6.5	0-2	2-4	4-6.5	0-2	2-4	4-6.5
	CU (%)	84	80	-	85	80	-	83	80	-

Abd El-Wahed *et al.* (2015) studied about different pressures and riser heights affect on CU, DU and grain yield, GY, of permanent sprinkler-irrigated barley crop during the periods 2009-2010 at Sebna, Libya. In such research, seasonal applied water was about 736 mm. Increasing operating pressure resulted increasing CU and DU values. Average maximum CU as 87% (**Good** Water Distribution) and DU as 81% were obtained from the pressure head of P3 (300 kPa). Increasing riser height led to increasing CU and DU values for all pressure conditions e.g at operating pressure P1, CU values for H1, H2 and H3 were 78%, 83%, and 86%, respectively. Similarly, DU values for those conditions were 71%, 74%, and 78%, respectively.

Table 8. Effects of operating pressure and riser height on Cu and DU

Operating pressure (kPa)	**Riser height (m)**	**CU (%)**	**DU (%)**
P1 (200 kPa)	H1 (1 m)	78	71
	H2 (1.25 m)	83	74
	H3 (1.50 m)	86	78
	Average	82	74
P2 (250 kPa)	H1 (1 m)	81	73
	H2 (1.25 m)	86	79
	H3 (1.50 m)	89	79
	Average	85	77
P3 (300 kPa)	H1 (1 m)	83	75
	H2 (1.25 m)	87	83
	H3 (1.50 m)	91	85
	Average	87	81

The P3H3 (**300 kPa operating pressure with 1.5 m riser height**) produced maximum CU as 91% and DU as 85% (Table 8). All DU values are higher than lower acceptable threshold value of 70% so water distribution class is **Good** (Wilson and Zoldoske, 1997). GY was obtained maximum as 5.5 t/ha from the P3H3 treatment. The highest water use efficiency, WUE, as 0.75 kg/m^3 was obtained from P3H3 treatment while the lowest one as 0.38 kg/m^3 from the P1H1 treatment. In such environment, P3H3 resulted increases in CU, DU, GY as well as WUE so that treatment of P3H3 can be highly recommended for better barley production.

Conclusion

It can be noted that irrigation method is important for water productivity but the most important tool is management of irrigation systems. Proper design and adequate management of sprinkler irrigation systems have produced desirable irrigation efficiency. Portable sprinkler irrigation systems have required more manpower particularly at movements of laterals from one site to other. In addition to time consuming, it brings about additional costs for farmers, and labor use in irrigation process is very expensive in Turkey. Farmers have even difficulties in findings of labors during the irrigation season. Preference of permanent sprinkler irrigation system with low discharge rates of sprinklers is therefore great interests in Middle Anatolian Region of Turkey. Agriculture is the single plenty water user activity worldwide so water saving technologies such as sprinkler irrigation should be used at more farm lands for sustainable utilization of current water supplies particularly at arid and semi-arid environments.

References

Abd El-Wahed, M., El Sabagh, A., Saneoka, H., Abdelhalek, A., Barutçular, C. 2015. Sprinkler irrigation uniformity and crop water productivity of barley in arid region. Emir J. Food Agric., 27 (10): 770-775.

Acar, B. 2019. Deficit Irrigation Effect on Water Use Efficiency of Crops in Arid and Semi-Arid Regions. International Journal of Agriculture and Economic Development, 7(2): 18-25.

Acar, B., Hamur, Ş. 2019. Procedures for Successful Agricultural Water Management in Water Poor Environments Under Climate Changes. International Journal of Agriculture and Economic Development,7(2): 26-32.

Ahaneku, IE. 2010. Performance evaluation of portable sprinkler irrigation system in Ilorin, Nigeria. Indian Journal of Science and Technology, 3 (7): 853-857.

Assough, GW., Kiker, GA. 2002. The effect of irrigation uniformity on irrigation water requirements. Water SA, 28 (2): 235-242.

Bakbak, F., Uçar, Y. 2018. Determination of the water use efficiency on potato growing areas in the Sandıklı plain. YYU J AGR SCI, 28 (3): 345-352 (In Turkish).

Bishaw, D., Olumana, M. 2015. Evaluating the effect of operating pressure and riser height on irrigation water application under different wind conditions in Etiopia. Asia Pasific

Journal of Energy and Environment, 2 (1): 1-48.

Darko, RO., Shaoqi, Y., Junping, L., Hoafang, Y., Xiangye, Z. 2017. Overview of advances in improving uniformity and water use efficiency of sprinkler irrigation. Int. J. Agric & Biol Eng, 10 (2): 1-15.

Dehkordi, DK. 2014. Evaluation of uniformity coefficient of water distribution in sprinkler irrigation under different conditions. Advances in Environmental Biology, 8 (13): 781-786.

Keller, J., Bliesner, RD. 2000. Sprinkler and trickle irrigation. The blackborn press, Cabwell, N.J. p. 652.

Kulkarni, S. 2011. Innovative technologies for water saving in irrigated agriculture. International Journal of Water Reseources and Arid Environments, 1 (3): 226-231.

Kuti, IA., Ewemoje, TA., Adabembe, BA., Musa, JJ., Nwosu, SC. 2019. Effect of different riser heights on sprinkler irrigation performance under constant operating pressure. Arid Zone Journal of Engineering, Technology & Environment (AZOJETE), 15 (1): 124-132.

Little, GE., Hills, DJ., Hanson, BR. 1993. Uniformity in pressurized irrigation system depends on design, weather and installation. California Agriculture, 47: 18-21.

Mclean, R.K., Sri Ranjan, R., Klassen, G. 2000. Spray evaporation losses from sprinkler irrigation systems. Canadian Agricultural Engineering, 42 (1): 1-15.

Moazed, H., Bavi, A., Boroomand-Nasab, S., Naseri, A., Albaji, M. 2010. Effects of climate and hydraulic parameters on water uniformity coefficienct in solid set systems. Journal of Applied Sciences, 10 (16): 1792-1796.

Nassab, SB., Beiranvand, ZM., Maleki, A., Panah, ZI. 2013. Technical evaluation of sprinkler irrigation systems in Khorramabad, Iran. World Rural Observations, 5(3): 23-27.

Ngasoh, FG., Anyadike, CC., Mbajiorgu, CC., Usman, MN. 2018. Performance evaluation of sprinkler irrigation system at Mambilla beverage limited, Kakora-Gembu, Taraba Sate-Nigeria. Nigerian Journal of Technology (NISOTECH), 37 (1): 268-274.

Plaut, Z., Ben-Hur, M. 2005. Irrigation management of peanut with a moving sprinkler system: Runoff, yield, and water use efficiency. Agron. J., 97: 1202-1209.

Solomon, KH. 1990. Sprinkler Irrigation Uniformity. Centre for Irrigation Technology, California State University, USA.

Seymen, M., Yavuz, D., Dursun, A., Kurtar, ES., Türkmen, Ö. 2019. Idendification of drought-tolerant pumpkin (*Cucurbita pepo* L.) genotypes associated with certain fruit characteristics, seed yield, and quality. Agricultural Water Management, 221: 150-159.

Yacoubi, S., Zayani, K., Slatni, A., Playan, E. 2012. Assessing sprinkler irrigation performance using field evaluations at the Medjarda lower valley of Tunusia. Engineering, 4: 682-691.

Yavuz D., Yavuz N., Seymen M., Türkmen, Ö. 2015a. Evapotranspiration, crop coefficient and seed yield of drip irrigated pumpkin under semi-arid conditions. Scientia Horticulturae, 197: 33-40.

Yavuz D., Seymen M., Yavuz N., Turkmen, Ö. 2015b. Effects of irrigation interval and quantity on the yield and quality of confectionary pumpkin grown under field conditions. Agricultural Water Management, 159: 290-298.

Yavuz D., Yavuz N., Suheri S. 2016. Energy and water use for drip-irrigated potato in the Middle Anatolian region of Turkey. Environmental Progress & Sustainable Energy, 35: 212-220.

Yavuz, D., Acar, B., Yavuz, N., Çiftçi, N. 2018. Irrigation in various growth strategies effect on yield and water productivity of drip-irrigated sunflower in semi-arid Konya environment, Turkey. International Journal of Agriculture and Economic Development, 6 (2): 7-17.

Yavuz, N,., Çiftçi, N., Yavuz, D. 2019. Effects of different irrigation interval and plant-pan coefficient applications on yield and quality parameters of oil sunflower grown in semi-arid climate conditions. Arabian Journal of Geoscienses. https//doi.org/10.1007/s12517-019-4867-1

Wilson, T. P., Zoldoske, DF. 1997. Evaluating Sprinkler Irrigation Uniformity. http://. wateright. org/site/publications/970703.html.