Korean J. Soil Sci. Fert. Vol.51, No.4, pp.608-615, 2018

Korean Journal of Soil Science and Fertilizer

Article

https://doi.org/10.7745/KJSSF.2018.51.4.608
pISSN : 0367-6315 eISSN : 2288-2162

Effect of Sprinkler, Surface Drip and Subsurface Drip Irrigation Methods on 'Fuji'/M9 and 'Fuji'/M26 Apple Orchards Growth, Soil Properties, and Water Consumption

Seung Gab Han*, Gopal Selvakumar, Pyoung Ho Yi, and Seong Eun Lee

Horticultural and Herbal Crop Environment Division, National Institute of Horticultural and Herbal Sciences, Rural Development Administration, Wanju 55365, Korea

***Corresponding author:** skhan@korea.kr

Received: October 22, 2018
Revised: November 29, 2018
Accepted: November 29, 2018

ABSTRACT

Conventional irrigation methods require high amount of water to meet 'Fuji'/M9 and 'Fuji'/M26 apple orchards irrigation requirement. In this study, the efficiency of sprinkler, surface drip and subsurface drip irrigation methods on water use efficiency, tree growth, yield, and canopy volume were compared. Experiment I ('Fuji'/M9 apple orchard) consisted of sprinkler, surface drip and subsurface drip irrigation methods. Subsurface drip irrigation method consumed 37% and 27% less irrigation water to maintain same matric potential compared to sprinkler and surface drip irrigation methods, respectively. In addition, subsurface drip irrigation method showed less sunburn fruits and contained less weed growth compared to sprinkler and surface drip irrigation methods. In experiment II ('Fuji'/M26 apple orchard), subsurface drip irrigation method at different depths (0, 15 and 30 cm) were compared. The results showed that irrigation at 30 cm depth consumed 52% less water to maintain the same matric potential compared to 0 cm (or surface drip) irrigation. However, apple tree stem circumference, new shoot length and canopy volume were not significantly different between treatments. These results suggest that subsurface drip irrigation can be used as an efficient method to reduce the irrigation water in 'Fuji'/M9 and 'Fuji'/M26 apple orchards and to reduce weed growth.

Keywords: Canopy volume, 'Fuji'/M9, Sprinkler, Subsurface drip irrigation, Tree stem circumference

Apple tree response to surface and subsurface drip irrigation methods.

Irrigation methods	Date of flowering	Stem circumference (cm)	Shoot length (cm)	Canopy volume (m^3)	Irrigation water (Mg $10a^{-1}$)
Surface (0 cm)	April 19	19.3 a†	44.4 a	17.5 a	288.2±33.8 a
Subsurface (15 cm)	April 18	21.1 a	41.2 a	17.2 a	167.2±34.8 ab
Subsurface (30 cm)	April 18	20.3 a	44.8 a	17.6 a	138.4±25.3 b

†Each value represents the mean of three replications ± standard error (SE).

Introduction

The amount of fresh water available for irrigation is decreasing worldwide, especially in semi-arid zones where drinking water resources are limited. Therefore, there is a constant need for water use efficiency. The accurate irrigation scheduling can help growers to manage the irrigation water efficiently (Naor and Cohen, 2003). Irrigation techniques have been studied in detail for decades and considerable progress has been achieved in understanding of water relations among soil, plant and atmosphere (Naor et al., 2001). However, more accurate predictions of the crop water requirement for field conditions in perennial fruit tree orchards are necessary to reduce the water consumption.

Controlled efficient irrigation system, if applied judiciously, saves water, reduces leaching of nutrients and biocides into ground water, and may improve fruit quality (Kruse et al., 1990; Behboudian and Mills, 1997). Soil water status sensors are widely used as water status indicator for irrigation in fields (Phene et al., 1990). They are easy to use and provide analog outputs that allow continuous monitoring. The root zone of perennial trees is irregular and occupies the larger volume which may exceed the irrigated volume. So the proper monitoring of water status in orchard is very important as the soil water content is spatially variable within an orchard (Russo and Bresler, 1982). Subsurface drip systems may help to improve the irrigation systems in orchard as they offer to deliver the water and nutrients directly to the root zone (Camp, 1998).

Self-propelled center pivot and linear move sprinkler irrigation systems are currently used worldwide. Although sprinkler systems offer many advantages including good uniformity over large areas, they are not appropriate for all conditions, crops or sites (Evans et al., 2013). Surface drip and subsurface drip irrigation methods are more efficient in terms of reducing water requirement and decreasing weed growth. However, monitoring the irrigation amount and scheduling irrigation is a major concern to execute these methods in large field scale application especially perennial orchards. The present study aimed to (i) compare the efficiency of different types of irrigation methods on ‘Fuji’/M9 apple orchard and (ii) influence of burying depths of subsurface drip irrigation tubes on ‘Fuji’/M26 apple tree growth, yield and canopy volume.

Materials and methods

Site description The experimental site was located in research fields of National Institute of Horticultural and Herbal Sciences, Wanju-gun, South Korea. The apple orchard experiment was established in 2015. During the spring of 2015, the apple nursery plants (‘Fuji’/M9 and ‘Fuji’/M26) were purchased and planted in experimental fields. In each row, 26 apple trees were planted with 2.5 m interval between the trees. The gap between the two adjutant rows was 4 m. Each row consisted three replications belonged to different treatments. In each row, first 9 trees were assigned to one treatment as one replication, last 9 trees were assigned to another treatment as one replication and the middle 8 trees were assigned to another treatment as one replication. Two different experiments were conducted simultaneously in the same research field.

Experiment I This experiment was to examine the different types of irrigation methods including subsurface drip irrigation, surface drip irrigation and sprinkler irrigation. The treatment replications were randomly assigned in each row of 'Fuji'/M9 orchard. Each apple orchard replication was continuously irrigated with same type of irrigation during the entire experimental period. For subsurface drip irrigation, drip tubes were buried 0.7 m away from the trees. The discrete emission point of the water from drip tubes was set at 50 cm intervals. To monitor and control the water supply tensiometer was installed about 10 cm from the drip tubes. The tensiometer was placed straight to the middle of two water emission points of the drip tube. In the surface drip irrigation, the drip tubes were placed on the surface and 0.7 m from the apples trees. The discrete emission point of the water from drip tubes were set at 50 cm intervals as well. Tensiometer was installed about 10 cm from the drip tubes and from the middle point between two water emission points of drip tubes. In sprinkler irrigation system, the drip tubes were installed 1 m above the ground. Tensiometer was installed about 25 cm away from the tree. The irrigation in each treatment was controlled through automatic irrigation system and the water potential was maintained between at -30 kPa during growth season (March to August) and at -40 kPa during fruit color change (from September onwards). Weed growth was controlled during the tree growth season.

Soil samples were collected from the each treatment replications in late spring 2016 (before treatment) and in August 2017 (during second year treatment) to analyze the chemical properties. Stem circumference, tree height and canopy volume were measured. Total number of fruits and number of sun burnt fruits were counted from each tree. The amount of weed in each treatment were determined by examining the amount of weed in 1 m^3. The amount of water irrigated in each treatment were also measured using flow meter.

Experiment II In this experiment, subsurface drip irrigation was extensively assessed for their efficiency at different depths. The landscape of this experiment location was considerably flat. The 'Fuji'/M26 apple orchard was irrigated using subsurface drip irrigation system. The depths of the irrigation were 0, 15 and 30 cm. Each depth was considered as one treatment and each treatment consisted of three replications. The replications were randomly assigned in the apple orchard. For 0 cm depth, the drip tubes were placed on the surface and 0.7 m from the apple trees. The discrete water emission point of this drip tubes were set at 50 cm intervals. For 15 and 30 cm subsurface drip irrigation, the drip tubes were buried 0.7 m away from the applied trees at 15 and 30 cm depth, respectively. To monitor and control the water supply tensiometer was installed about 10 cm from the drip tubes. The tensiometer was placed straight to the middle of two water emission points of the drip tube. The irrigation in each treatment was controlled through automatic irrigation system and the water potential was maintained between at -30 kPa during growth season (March to August) and at -40 kPa during fruit color change (from September onwards). Weed growth was controlled during the tree growth season.

Soil samples were collected from the each treatment replications in late spring 2016 (before treatment) and in August 2017 (during second year treatment) to analyze the chemical properties. Stem circumference, tree height and canopy volume were measured. The amount of water irrigated in each treatment were also measured using flow meter.

Statistical data analysis The irrigated water data presented here are for 2018 from March to October. Each replication had 8 or 9 apple trees as described in the site description. The data were statistically analyzed using analysis of variance (ANOVA) with SAS package ver. 9.2 software and the differences in means were determined by the least significant differences (LSD). Duncan's multiple-range test was performed at $P \leq 0.05$ on each of the significant variables measured.

Results and discussion

Experiment I The soil chemical properties are important factors which influence plant growth significantly. The chemical analysis of the soil from different irrigation methods is presented in Table 1. The analysis showed that the irrigation methods did not affect the soil chemical properties significantly. Soil pH, electrical conductivity and organic matter content were similar in all the irrigation methods. Soil macronutrient contents such as available phosphorous, potassium and calcium also were similar in all the irrigation methods. Previous studies (Caspari et al., 2004; Chai et al., 2016) of irrigation on apple tree growth and yield showed less importance to changes in soil chemical properties. The present study compared the soil chemical properties before the treatment and during the treatment of second year. The results showed that soil EC, available P and Ca were increased after two years of irrigation. However, no significant difference was observed between the treatments.

The first flowering date of the apple trees was almost same in all irrigation methods (Table 2). The circumference of the apple tree stem indicated that surface drip irrigation and subsurface drip irrigation slightly increased stem circumference, however, the difference was not statistically different. Likewise, the new shoot growth in all the

Table 1. Effect of different types of irrigation methods on soil chemical properties.

Treatments	pH	EC	OM	Av.P_2O_5	K	Ca	Mg	NH_4-N	NO_3-N
	(1:5)	(dS m^{-1})	(%)	(mg kg^{-1})	(cmol kg^{-1})			(mg kg^{-1})	
Soil properties of the apple orchard on spring 2016									
Sprinkler	5.97 a[†]	0.15 a	0.89 a	4.95 a	2.15 a	0.72±0.01 b	4.01 a	14.3±2.03 b	26.46 a
Surface	5.78 a	0.23 a	0.61 a	7.16 a	2.13 a	0.91±0.04 a	3.87 a	39.27±2.35 a	22.68 a
Subsurface (30 cm)	6.1 a	0.19 a	0.61 a	15.55 a	2.15 a	0.73±0.01 b	3.98 a	45.13±1.91 a	22.52 a
Soil properties of the apple orchard on summer 2017									
Sprinkler	6.42 a	0.44 a	0.99 a	40.79 a	1.3 a	4.16 a	3.39 a	52.97 a	14.93 a
Surface	5.91 a	0.49 a	1.51 a	16.12 a	0.94 a	3.74 a	3.45 a	54.13 a	24.97 a
Subsurface (30 cm)	6.05 a	0.42 a	0.88 a	19.04 a	0.75 a	3.91 a	3.57 a	48.77 a	13.07 a
Percentage change in soil properties from 2016 to 2017 (Unit in %)									
Sprinkler	7.54	199.33	11.97	723.77	-39.83	477.98	-15.40	270.31	-43.56
Surface	2.25	114.96	146.17	125.13	-55.74	309.96	-10.80	37.85	10.08
Subsurface (30 cm)	-0.82	114.81	45.44	22.44	-65.13	434.73	-10.30	8.07	-41.97

[†]Each value represents the mean of three replications ± standard error (SE).

irrigation methods showed no significant difference between the treatments. One reason for this could be shoot pruning during early spring. The canopy volume of the apple tree orchard also was similar in all the irrigation methods. Proper irrigation is required to obtain maximum fruit yield. Reduced irrigation could negatively affect fruit size (Naor et al., 1997; Mpelasoka et al., 2015). The amount of water required to maintain the same matric potential was lower in surface drip irrigation (14%) and subsurface drip irrigation (37%) methods compared to sprinkler irrigation (Table 2). Kanber et al. (1996) found that drip and sprinkler irrigation systems had similar effect on root distributions in young orange trees.

The number of apple fruits in all irrigation methods were counted and the data showed that all treatments yielded similar number of fruits (Table 3). Since the apple trees were young, the total number of fruits in each tree were less. Drip irrigation has previous been shown to increase production and fruit quality while reducing shoot growth, compared with sprinkler irrigation of apples (Proebsting et al., 1984). The sunburn apple fruits showed that the number of damaged apple fruits were higher in apple trees irrigated with sprinkler method (Table 3) followed by apple trees irrigated with surface drip irrigation method. Whereas, apple trees irrigated subsurface drip irrigation method had less number of sunburn fruits. However, the data were not statistically different among the treatments. A previous study by Bryla et al. (2003) investigated the effect of furrow, microjet, surface drip and subsurface drip irrigation on peach tree. They found that surface drip and subsurface drip irrigation showed higher water use efficiency and had higher yield than furrow and microjet irrigations despite similar tree growth across all irrigation systems. Similarly, Ebel et al. (2001) reported that continuous irrigation or early termination (water deficit) did not alter the fruit weight in a semi-arid environment.

The amount of weed emergence in each irrigation method was analyzed and the data showed that sprinkler irrigation method had significantly high weed amount (24.5 Mg per 10a) followed by surface drip irrigation method

Table 2. Apple tree response to different types of irrigation methods.

Irrigation methods	Date of flowering	Stem circumference (cm)	Shoot length (cm)	Canopy volume (m^3)	Irrigation water (Mg $10a^{-1}$)
Sprinkler	April 18	17.7 a†	41.8 a	15.9 a	299.7 a
Surface	April 18	19.3 a	38.0 a	17.4 a	258.4 a
Subsurface (30 cm)	April 17	19.1 a	37.3 a	16.7 a	188.1 a

†Each value represents the mean of three replications ± standard error (SE).

Table 3. Effect of different types of irrigation methods on apple tree fruit yield and weed growth.

Irrigation methods	Number of fruits	Number of sunburn fruits	Percentage damaged (%)	Weed growth (Mg $10a^{-1}$)
Sprinkler	10.6 a†	4.0 a	35.7 a	24.5±0.37 a
Surface	9.7 a	3.3 a	33.6 a	23.7±0.32 a
Subsurface (30 cm)	9.0 a	2.3 a	25.7 a	20.7±0.41 b

†Each value represents the mean of three replications ± standard error (SE).

(23.7 Mg per 10a). The subsurface drip irrigation method had significantly low weed amount (20.7 Mg per 10a) compared to other two methods (Table 3). Kruse et al. (1990) also reported that drip irrigation may reduce the weed control costs as they reduce the weed emergence.

Experiment II In this experiment, subsurface drip irrigation at different depths were examined to find out the efficient irrigation depth to reduce the water consumption. Soil analysis showed that the irrigation depth did not alter the soil chemical properties after two years of treatment (Table 4). No change in soil pH, EC and organic matter content was observed between the treatments. There was no significant difference in soil nutrient contents irrigated at different depths. However, two years of irrigation increased soil EC, Ca and NH_4-N.

The date of first flowering was similar in all treatments regardless of the subsurface drip irrigation depths (Table 5). Although the apple tree stem circumference was slightly higher in subsurface drip irrigation method at 15 and 30 cm depth, the data were not significantly different from 0 cm depth (surface drip) irrigation method. The new shoot length was also similar in all the irrigation methods. The canopy volume of apple trees was similar in all the three irrigation treatments.

Previous studies reported that irrigation practices did not affect yield of apple (Wunsche et al., 2000; Neilsen et

Table 4. Effect of different depths of subsurface drip irrigation on soil chemical properties.

Treatments	pH	EC	OM	Av.P_2O_5	K	Ca	Mg	NH_4-N	NO_3-N
	(1:5)	(dS m^{-1})	(%)	(mg kg^{-1})		(cmol kg^{-1})		(mg kg^{-1})	
Soil properties of the apple orchard on spring 2016									
Surface (0 cm)	5.99 a	0.33±0.05 a	0.8 a	31.45 a	2.08 a	1.3 a	3.46 a	35.91 a	22.49±0.75 a
Subsurface (15 cm)	5.9 a	0.22±0.01 b	0.64 a	13.63 a	2.26 a	1.01 a	3.99 a	30.38 a	19.13±0.69 b
Subsurface (30 cm)	6.05 a	0.2±0.02 b	0.8 a	12.37 a	2.18 a	1.27 a	3.87 a	41.04 a	23.26±0.66 a
Soil properties of the apple orchard on summer 2017									
Surface (0 cm)	6.3 a	0.42±0.05 ab	0.95 a	21.3 a	0.73 a	4.36 a	3.63 a	66.5 a	9.33 a
Subsurface (15 cm)	5.85 a	0.33±0.05 b	1.1 a	12.15 a	0.82 a	4.2 a	3.54 a	57.4 a	10.5 a
Subsurface (30 cm)	5.39 a	0.6±0.04 a	1.41 a	49.55 a	0.99 a	5.17 a	3.87 a	44.8 a	28 a
Percentage change in soil properties from 2016 to 2017 (Unit in %)									
Surface (0 cm)	5.18	25.41	18.73	-32.29	-65.02	235.74	5.05	85.19	-58.51
Subsurface (15 cm)	-0.79	50.04	71.67	-10.83	-63.43	317.39	-11.35	88.94	-45.12
Subsurface (30 cm)	-10.96	205.12	76.34	300.59	-54.29	307.60	0.07	9.15	20.36

Table 5. Apple tree response to surface and subsurface drip irrigation methods.

Irrigation methods	Date of flowering	Stem circumference (cm)	Shoot length (cm)	Canopy volume (m^3)	Irrigation water (Mg $10a^{-1}$)
Surface (0 cm)	April 19	19.3 a[†]	44.4 a	17.5 a	288.2±33.8 a
Subsurface (15 cm)	April 18	21.1 a	41.2 a	17.2 a	167.2±34.8 ab
Subsurface (30 cm)	April 18	20.3 a	44.8 a	17.6 a	138.4±25.3 b

[†]Each value represents the mean of three replications ± standard error (SE).

al., 2006 and 2010). The amount of water used to maintain the same matric potential was significantly lower in subsurface drip irrigation at 30 cm depth compared to 0 cm depth (surface drip) irrigation method (Table 5). To maintain the same matric potential with subsurface drip irrigation at 30 cm, subsurface drip irrigation 15 cm and 0 cm consumed 21% and 108% more water, respectively. The irrigation depths did not affect tree growth or yield.

Conclusions

The present study found that subsurface drip irrigation method was efficient to reduce the water requirements to irrigate 'Fuji'/M9 apple orchard. Subsurface drip irrigation at 30 cm depth can be desirable to meet apple orchard water requirement with reduced irrigation water amount. In addition, subsurface drip irrigation can decrease weed growth. The results presented here are for single growing season. The data from following years may help to understand more about the efficiency of different types of irrigation systems in 'Fuji'/M9 and 'Fuji'/M26 apple orchards.

Acknowledgment

This research was supported by the "Cooperative Research Program for Agriculture Science & Technology Development (Project No. PJ01192001)" of the Rural Development Administration, Republic of Korea.

References

Behboudian, M.H. and T.M. Mills. 1997. Deficit irrigation in deciduous orchards. Hortic. Rev. 21:105-131.

Bryla, D.R., T.J., Trout, and J.E., Ayars. 2003. Growth and production of young peach trees irrigated by furrow, microjet, surface drip, or subsurface drip systems. HortScience. 38:1112-1116.

Camp, C.R. 1998. Subsurface drip irrigation: A review. Trans. ASAE 41:1353-1367.

Caspari,, H.W., S. Neal, and P. Alspach. 2004. Partial rootzone drying − a new irrigation strategy for apple? Acta Hortic. 646:93-100.

Chai, Q., Y. Gan, C. Zhao, H.L. Xu, R.M. Waskom, Y. Niu, and K.H.M. Siddique. 2016. Regulated deficit irrigation for crop production under drought stress. A review. Agron. Sustain. Dev. 36:3.

Ebel, R.C., E.L. Proebsting, and R.G. Evans. 2001. Apple tree and fruit responses to early termination of irrigation in a semi-arid environment. HortScience. 36:1197-1201.

Evans, R.G., J. LaRue, K.C. Stone, and B.A. King. 2013. Adoption of site-specific variable rate irrigation systems. Irrig. Sci. 31:871-887.

Kanber, R., H. Koksal, S. Onder, and M. Eylen. 1996. The effects of different irrigation methods on young orange tree's yield, water consumption and root growth. Ankara. Turk. J. Agric. For. 20:163-172.

Kruse, E.G., D.A. Bucks, and R.D. von Bernuth. 1990. Comparison of irrigation systems. p. 475-508. In B.A. Steward and D. Nielson (ed.) Irrigation of agricultural crops. Agronomy Monographs, ASA-CSSA-SSSA publications, Madison, Wisconsin.

Mpelasoka, B., M.H. Behboudian, and T. Mills. 2015. Water relations, photosynthesis, growth, yield and fruit size of

‘Braeburn’ apple: responses to deficit irrigation and crop load. J. Hortic. Sci. Biotech. 76:150-156.

Naor, A. and S. Cohen. 2003. Sensitivity and variability of maximum trunk shrinkage, midday stem water potential, and transpiration rate in response to withholding irrigation from field-grown apple trees. HortScience. 38:547-551.

Naor, A., H. Hupert, Y. Greenblat, M. Peres, and I. Klein. 2001. The response of nectarine fruit size and midday stem water potential to irrigation level in stage III crop load. J. Am. Soc. Hortic. Sci. 126:140-143.

Naor, A., I. Klein, I. Doron, Y. Gal, and Z. Ben-David. 1997. The effect of irrigation and crop load on stem water potential and apple fruit size. J. Hortic. Sci. 72:765-771.

Neilsen, D., G.H. Neilsen, L. Herbert, and S. Guak. 2010. Effect of irrigation and crop load management on fruit nutrition and quality for Ambrosia/M.9 apple. Acta Hortic. 868:63-71.

Neilsen, D., G.H. Neilsen, L.C. Herbert, P. Millard, and S. Guak, 2006. Allocation of dry matter and N to fruit and shoots in dwarf apple in response to sink size and N availability. Acta Hortic. 721:33-40.

Phene, C.J., R.J. Reginato, B. Itier, and B.R. Tanner. 1990. Sensing irrigation needs. p. 207-261. In G.J. Hoffman et al. (ed.) Management of farm irrigation systems. American Society of Agricultural Engineering, St. Joseph, Mich.

Proebsting, E.L., S.R. Drake, and R.G. Evans. 1984. Irrigation management, fruit quality and storage life of apples. J. Am. Soc. Hortic. Sci. 109:229-232.

Rousso, D., and E. Bresler. 1982. Soil hydraulic properties as a stochastic process: II. Error of estimates in a heterogenous field. Soil Sci. Soc. Am. J. 46:20-26.

Wunsche, J.N., J.W. Palmer, and D.H. Greer. 2000. Effects of crop load on fruiting and gas exchange characteristics of Braeburn/M.9 apple trees at full canopy. J. Am. Soc. Hortic. Sci. 125:93-99.