INTERNATIONAL JOURNAL OF AGRICULTURE & BIOLOGY
ISSN Print: 1560–8530; ISSN Online: 1814–9596
12–162/AWB/2012/14–6–887–893
http://www.fspublishers.org

Full Length Article

Yield and Water Use Efficiency of Pear Trees under Drip Irrigation with Different Surface Wetted Percentages

ZHI ZHAO, WEI WANG[1]†, YANG WU AND XINGFA HUANG[1]
College of Water Resources and Civil Engineering, China Agricultural University, 100083, Beijing, China
†*College of Engineering, China Agricultural University, 100083, Beijing, China*
[1]Corresponding author's e-mails: weiwang@cau.edu.cn; huangxingfa@cau.edu.cn

ABSTRACT

Field studies were conducted for two consecutive years in Korla, Xinjiang, China, to investigate the response of pear trees to different surface wetted percentages under drip irrigation on an oasis around Taklimakan desert. The 24-year-old pear trees were weekly irrigated at a level to replace 80% of the US Class A Pan evaporation, with three different surface wetted percentages: 16, 32 and 43%. A control (CK) was flood irrigated with a monthly applied amount of 300 mm. All drip irrigated treatments applied about 50% water less than control. A larger (43%) surface wetting had a significantly low yield (two year average of 17% reduction) than the flood irrigated treatment, but there were no significant yield differences among the other treatments. Maximum irrigation water use efficiency was observed in 32% surface wetting (on an average 3.02 kg/m^3). However, there was a significant reduction in the mass of new shoots with drip irrigation. Under the extremely arid climatic conditions of this study, during the initial period, 32% surface wetted percentage proved optimal for mature pear trees that had been transferred from flood irrigation into drip irrigation.

Key Words: Microirrigation; Vegetative growth; Fruit growth; Pan coefficient; Fruit quality

INTRODUCTION

Korla is adjacent to the Taklamakan Desert，located in the middle of Eurasia, and is considered to be the main area of origin of the Korla fragrant pear. The climate of Korla is extremely arid, and overexploitation of water resource is resulting in the deterioration of vegetation. Water is increasingly scarce in the Xinjiang Autonomous Region of China because of the region's developing population, industry and agriculture, especially in areas where water resources are limited. As the main source of income for local farmers, the fragrant pear industry has developed rapidly. The average annual increase of the planted area is 5.6×10^3 ha (Ma & Li, 2010). The expanding fragrant pear production and the corresponding increase in the demand for irrigation water is a challenge considering the fragile oasis ecosystem in the region. A main commercial fruit, Korla fragrant pear, is now irrigated by traditional flooding irrigation, which wastes a large volume of irrigation water. Therefore, if more efficient drip irrigation is adopted, water would be saved, and the urban-agricultural water conflicts could be avoided.

Most studies to date on fragrant pear have mainly focused on food science and biology. The response of the fragrant pear under microirrigation conditions is rarely discussed. Therefore, fundamental research on the water needs of the fragrant pear is needed. There is an increasing use of microirrigation for fruits, vegetables and other high value crops (Bresler, 1978; Mmolawa & Or, 2000). Reducing the microirrigation level from 1.3 to 0.7 ET_C for pear had no statistical effect on fruit yield, fruit number, or fruit size at harvest (Marsal *et al.*, 2002). According to Kang *et al.* (2002), the maximum daily water consumption of pear tree is about 7.0 mm/d in summer and about 3.5 mm/d in autumn. Partition of water extracted from the wet and dry zones was determined by Bielorai (1981), who found about 86% of the total amount of water depleted was from the wet zone. Sufficient water must be present in active crop root zone for germination, evapotranspiration and nutrient absorption by roots (Rashidi & Seyfi, 2007). So the surface wetted percentage should be satisfied in microirrigation. Thus, determining a feasible irrigation method and surface wetted percentage for fragrant pears is necessary.

Surface irrigation method is most widely used all over the world (Mustafa *et al.*, 2003). Revealing the optimal soil moisture status and cutting down the initial cost of drip irrigation system are important. Since the percentage of wetted area was introduced by Keller and Karmeli (1974), it has been widely used in microirrigation systems design. The wetted pattern is one of the main design parameters, which directly relates to the initial installation cost. Excessive wetted percentage would increase the cost of drip irrigation system, lower the efficiency of irrigation, and excessive irrigation water leaches below the root zone (El-Hendawy *et*

To cite this paper: Zhao, Z., W. Wang, Y. Wu and X. Huang, 2012. Yield and water use efficiency of pear trees under drip irrigation with different surface wetted percentages. *Int. J. Agric. Biol.*, 14: 887–893

al., 2008). On the contrary, a small wetted percentage causes plant water stress, reducing crop yield. Every component of crop has a different sensitive level to water stress in different growing seasons, especially in a dry climate (Plaut *et al.*, 1996). Wetting pattern can be obtained by measurement in field or by numerical simulation (Singh *et al.*, 2006). Several computer programs, such as HYDRUS-2D, have been developed to model infiltration and soil water redistribution (Cook *et al.*, 2003; Amin & Ekhmaj, 2006; Kandelous & Šimunek, 2010). A typical analytical approach was suggested by Lei (1994) for estimating wetted percentage. Some of these models and software are practical and convenient to use in designing drip irrigation systems. Certain studies have described surface infiltration from a point or line source (Camp, 1998; Singh *et al.*, 2006), as well as from a number of numerical and empirical models. Such models can be applied to field study for increasing water use efficiency.

Lack of weather station data and the expense of maintaining stations have led to the use of pan evaporation in scheduling irrigation in recent decades. The US Class A pan is commonly used for real-time determination of irrigation scheduling for microirrigated orchards in many countries, such as the United States and Australia (Huang *et al.*, 2001). The pan must be properly constructed, located and managed for accurate use in irrigation scheduling, and a suitable pan coefficient must be determined as well (Huang *et al.*, 2002).

However, detailed hydraulic properties of soil, ill-defined and complex flow condition cause problems to run those soil water simulation models. Moreover, there is little information available in literature about crop growth affected by wetted percentage. The objectives of this study were: (1) to quantify the fruit growth, yield, and characteristics of the fragrant pear under both traditional flood irrigation and drip irrigation, (2) to determine an optimal surface wetted percentage for mature fragrant pear trees, which had initially been flood irrigated and (3) to analyze the feasibility of using class A pan in managing irrigation of fragrant pear tree on the oasis.

MATERIALS AND METHODS

Experimental site: Field experiment was conducted for two consecutive years (2009 & 2010) at Korla, in Xinjiang Uyghur Autonomous Region China. Korla has a typical arid climate, with the mean annual precipitation of only 50-56 mm and the average annual evaporation at 2,770 mm. It is also a typical irrigated agricultural area. The experiment was conducted in a commercial 24-year old irrigated pear orchard located at 41°43′N, 86°6′E, with tree spacing of 5 m × 6 m. The soil was classified as silt loam (International soil classification system: sand 44.0%, silt 50.4% & clay 5.6%), and the average soil bulk density was 1.5 g/cm^3. All the treatments were cultured by the recommended standard practices in the region.

Surface wetted percentage determination: Three irrigation treatments were established by drip irrigating at surface wetted percentage of 16, 32 and 43%. Using the empirical model suggested by Amin and Ekhmaj (2006), the average surface wetted dimension is estimated as:

$$R=0.2476\Delta\theta^{0.5626}V_{\mathrm{w}}^{0.2686}Q^{-0.0028}K_{\mathrm{S}}^{-0.0344} \quad (1)$$

Where, R is the horizontal distance from the surface drip emitter (m); $\Delta\theta$ is the average volumetric water content change behind the wetting front; V_{w} is the total volume of applied water (m^3); Q is the emitter discharge (m^{3}s^{-1}); and K_{S} is the soil saturated hydraulic conductivity (ms^{-1}). In this study, the surface wetted percentage (SWP) is defined as the ratio of Surface wetted dimension, which is double of R, to the row space, and the calculated SWP is shown in Table I. The SWP was calculated directly from the actual water volume applied and measured parameters in all irrigation events of growing season.

Experimental design and treatments: The pear orchard was divided into two sections, one for flood irrigation, and the other for drip irrigations. Three drip irrigation treatments with SWP of 16, 32 and 43% (P1, P2 and P3), each of them was replicated three times, were randomly arranged in the drip irrigation section. For 16% SWP, water was applied via single lateral, 1 m away from the tree row, with emitter spacing of 25 cm; for 32% SWP, water was applied via two laterals, 1 m away from and on both sides of the tree row, with emitter spacing of 50 cm; and for 43% SWP, the lateral layout was similar to that of 32% SWP, but water was applied by three uniform laterals with one more lateral laid along the tree row. The outside diameter of lateral was 16 mm, and emitter discharge was 2.8 L/h. All drip-irrigated pear trees received weekly irrigation to replace 80% of the accumulated evaporation of US Class A pan throughout the growing season. The control treatment (CK) followed the traditional flooding irrigation practice, which received 300 mm water once a month.

Evaporation and soil moisture measurements: Soil volumetric water content was measured by a portable capacitance probe (Diviner, 2000; Sentek Pty Ltd). Two access tubes were installed per replicate, one was under and the other 0.5 m away from the lateral, which is laid 1 m away from the tree row. Soil moisture was measured on the day of and immediately before the irrigation. Crop water use throughout the entire growing season, ET_C (mm), was estimated using the following water balance equation:

$$ET_C=\Delta W+I+P-S+WT \quad (2)$$

Where, ΔW is the change in the soil water storage (mm), I is irrigation water (mm), P is precipitation (mm), S is water deep percolation below root zone (mm), and WT is groundwater recharge (mm). The deep percolation in the drip irrigation treatment was found to be negligible by monitoring the soil water content at 150 cm depth. The deep percolation of flood irrigation in 2009 and 2010, which was calculated from the measured soil water content and hydraulic conductivity data at depth of 150 cm, was 321 mm and 372 mm, respectively. The groundwater recharge was assumed to be zero.

Evaporation was measured by a US Class A pan (120.7 cm in diameter, 25 cm in depth). Changes in the surface water level in the pan were recorded daily, which were taken as the daily pan evaporation. Precipitation was collected by an automatic weather station (Vantage Pro2, Davis Instruments Corp.), which are shown in Fig. 1.

Tree measurements: Measurements included shoot growth, biomass of strong shoots, and fruit growth. Six trees were randomly selected from each treatment for measuring shoot growth and fruit growth, and the measurements were conducted once a week. Ten shoots and ten fruits, which were tagged and numbered on each of the six trees, were randomly selected for measuring the changes in shoot length and longitudinal diameter of fruits. The measurement of new growing shoots was started at the time when their length reached 10 cm. Fruit size measurement was conducted when the average longitudinal diameter was about 1 cm. Strong shoots were pruned yearly in summer. Pruned strong shoots of six trees randomly selected from each treatment were weighed immediately.

Twenty pear fruits were picked every 14 days in 2008. Fruit volume measurement was conducted by water displacement, and a relationship was derived as follows:

$$V=2.494D^{2.662} \quad (R^2=0.938) \qquad (3)$$

Where, V is the volume of the fruit (mm^3) and D is the longitudinal diameter (mm). The fruit volume was calculated by this equation in 2009 and 2010.

Yield: Two trees were randomly sampled from each replication, six trees per treatment, to measure the fruit yield. Fruits were harvested by hand and weighed by an electronic scale. The production of each tree was measured and recorded individually.

Fruit quality measurements: Ten fruits per treatment were sampled, and fruit quality parameters including soluble solid (according to the national standard of GB12295-90), soluble sugar (according to the national standard of GB6194-86), and titratable acidity (according to the national standard of GB12293-90) were measured at harvest. These three parameters are Chinese national standard evaluation indexes for fragrant pears.

Statistics analysis: Analysis of variance was done using Statistical Analysis Software (SPSS 16.0). The means under different treatments were compared for any significant differences using the Tukey test at significant level of P<0.05.

RESULTS

Irrigation and crop water consumption: Soil water content at 30 cm depth in the wetted zone measured before each of irrigations was given in Fig. 2a. The volumetric soil water content of drip irrigation treatments varied within a

Fig. 1: Daily pan evaporation and rainfall in 2009 (a) and 2010 (b)

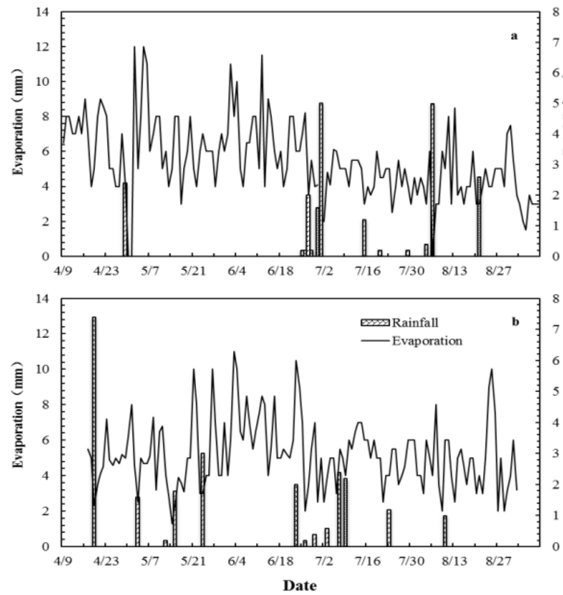
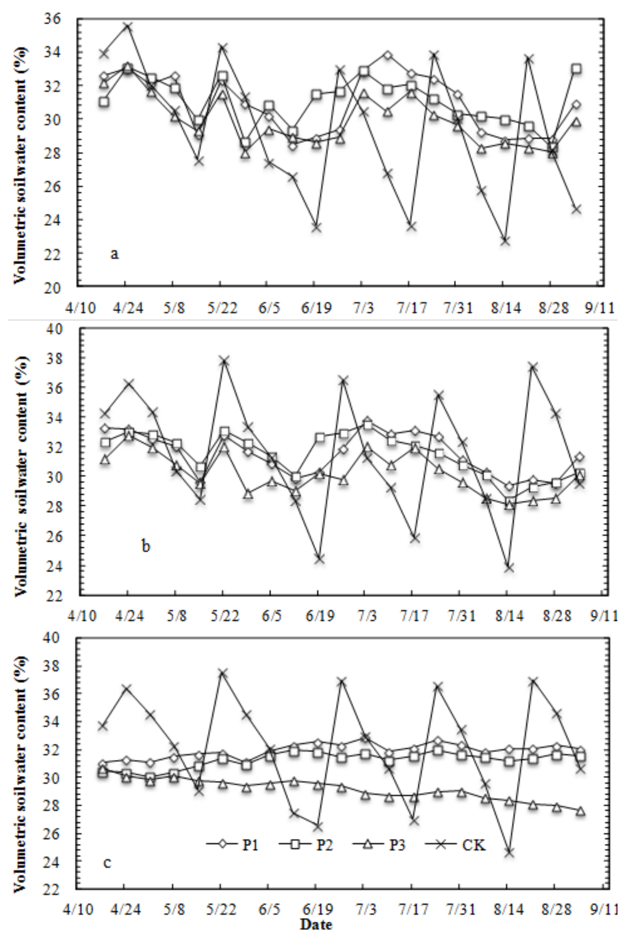


Fig. 2: volumetric soil water content at 30 cm depth (a), 60 cm depth (b), and 100 cm depth (c) under the lateral measured before each of irrigations in 2010



narrow range of 29-33% for most the time in the growth season. By contrast，flood irrigation treatment showed an obvious fluctuation periodically. As irrigation water distributed in only 16% of soil surface，soil water content of 16% SWP was a little higher than the other two drip irrigation treatments sometimes. Soil water content of 43% SWP was obviously lower than the other two drip-irrigated treatments at 60 cm depth (Fig. 2b), averaged 30.2% in the growth season, and that of 16% and 32% SWP averaged 31.5% both. Due to a larger wetted soil surface area, less irrigation water reach deeper root zone of pear trees in treatment of 43% SWP (Fig. 2c).

Total crop water consumption is shown in Table II. Crop water consumption of 43% SWP increased markedly in both years. Moreover, the differences of water consumption among treatments were smaller in 2010; this may be due to the drier climate in 2009.

Shoot growth: Growth of shoot was significantly affected by drip irrigation, as compared to flood irrigation (Table III). The shoot growth of 43% SWP was 8.3% and 14% lower than that of the trees in the control group at the end of 2009 and 2010 growing season, respectively. As shown in Fig. 3 and 4, drip irrigation had no effect on the shape of the shoot growth curve, which fitted the spline function (R^2>0.9). A higher growth rate in traditional flood irrigation treatment (CK) was observed in both years. The length of shoots obtained from all treatments was similar in the initial 40 days after blooming; however, the shoot growth rate of CK was greater during following 2 weeks (Fig. 3 & 4). Effects of irrigation treatment on development of strong shoots can be reflected by the fresh weight of pruned shoots. There were no significant differences of the pruned fresh weights among the three drip irrigation treatments in either year, but the drip-irrigated pear trees had a significantly less pruning than that of flood irrigation (Table III). Drip-irrigated pruning ranged from 26% to 32% less than that of flood irrigated treatment in 2009 and the decrease in 2010 ranged from 37% to 41%. Luxuriant strong shoots consume precious water and nutrition, resulting in fewer fruits. In addition, summer pruning requires additional labor. Thus, reducing growth of the strong shoots with drip irrigation can increase water use efficiency and fertilization use efficiency, as well as save on the cost of labor.

Fruit growth: In both years, treatment of 43% SWP resulted in the smallest fruit size, measuring 88.7 cm^3 and 103.0 cm^3 in 2009 and 2010, respectively (Table III). Though differences of fruit volume among drip irrigation treatments were not significant, fruit size tended to decrease with increasing SWP, and the maximum fruit size was obtained in trees irrigated with 16% SWP. The fruit growth curves are shown in Fig. 3 and 4, which fit a quartic polynomial. According to Table III, the maximum final fruit volume in the drip irrigation treatments was approximately 99.5 cm^3 in 2009 and 114.9 cm^3 in 2010, respectively. The flood irrigated pear trees had the largest, while 43% SWP got the smallest harvest fruit volume. Although fruit volumes of 16% and 32% SWP treatments were smaller than that of flood irrigated, there were no significant differences in the fruit volume among these three treatments.

Yield and irrigation water use efficiency: The maximum yield was obtained from the trees irrigated with 32% SWP, followed by those in the control treatment (Table III). Trees irrigated with 43% SWP had significantly lower yields than all the other treatments in 2009 and significantly lower than 32% SWP and CK treatments in 2010. In 2009, yield of 16% SWP trended lower than that of 32% SWP and CK, though not statistically lower.

Table I: Calculated surface wetted percentage of drip irrigation

Treatment	Surface wetted percentage (2009)			Surface wetted percentage(2010)		
	Max	Min	Ave	Max	Min	Ave
P1	0.18	0.14	0.16	0.18	0.14	0.16
P2	0.35	0.28	0.32	0.35	0.28	0.32
P3	0.48	0.39	0.43	0.47	0.38	0.43

Table II: Crop water consumption, mm

Treatment	2009	2010
P1	740	692
P2	717	690
P3	766	703
CK	1179	1128

Table III: Growth parameters, yield and IWUE of fragrant pear trees

Year	Treatment	Final length of Shoots (cm)	Pruned-branch Weight (kg/tree)	Average fruit volume (cm^3)	Yield (Mg/ha)	IWUE (kg/m^3)
2009	P1	32.8b	5.8b	99.5a	16.9a	2.59a
	P2	32.4b	6.3b	98.2a	18.6a	2.86a
	P3	33.9ab	6.1b	88.7b	13.1b	2.01b
	CK	36.8a	8.5a	99.6a	18.5a	1.23c
2010	P1	30.9 b	5.3b	114.9a	19.2bc	3.10b
	P2	31.3b	5.5b	114.3ab	19.8a	3.19a
	P3	30.2 b	5.2b	103.0b	18.1c	2.91b
	CK	35.4 a	8.8a	115.4a	19.3ab	1.28c

Each parameter means within the columns in the same year marked by different letters (a, b, c) are significantly different at $P_{0.05}$ level

Table IV: Fruit quality parameters as affected by the irrigation treatment

Year	Treatment	Soluble solid (g/100 g)	Soluble sugar (g/100 g)	Titratable acidity (mmol/100 g)
2009	P1	11.4a	7.50a	1.08a
	P2	11.5a	6.93b	0.83c
	P3	11.7a	7.65a	0.98b
	CK	11.8a	7.86a	0.84c
2010	P1	12.45b	8.17b	1.68b
	P2	13.65a	7.63c	1.81a
	P3	14.4a	8.22a	1.36d
	CK	13.59a	8.18b	1.55c

Each parameter means within the columns in the same year marked by different letters (a, b, c) are significantly different at $P_{0.05}$ level

Fig. 3: Growth of shoots and fruits in 2009

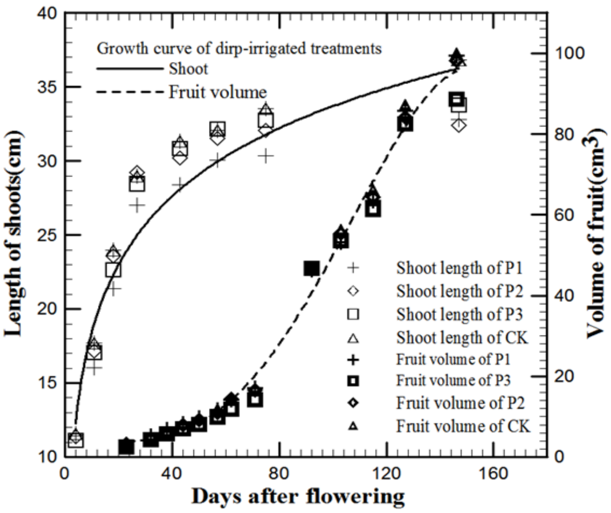
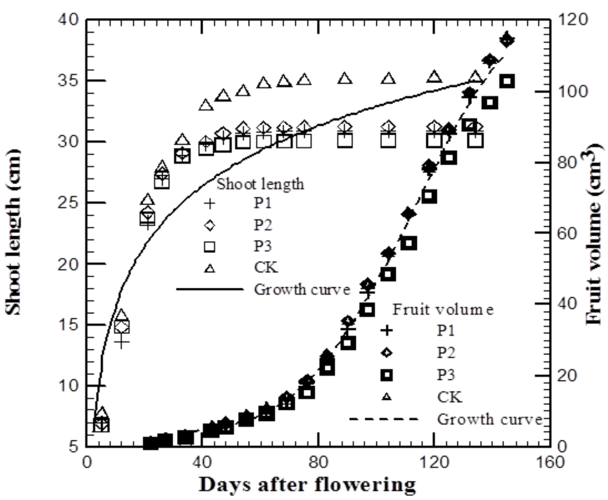


Fig. 4: Growth of shoots and fruits in 2010



Irrigation water use efficiency (IWUE) is the ratio of yield and the total irrigation water volume. IWUE was significantly affected by the irrigation treatments in both years. Higher yield and a lower irrigation amount than that of CK treatment resulted in the highest IWUE for 32% SWP, with 2.86 kg/m^3 in 2009 and 3.19 kg/m^3 in 2010, respectively (Table III). Averaged across the two years of the study, IWUE of drip irrigation treatments were 190-240% greater than that of flood irriagted treatment.

Fruit quality: No significant differences of soluble solid were found among all treatments in 2009, however, a marked reduction of soluble solid was observed in treatment of 16% SWP in 2010 (Table IV). The soluble sugar values in 2009 achieved a result similar to that in 2010, and the soluble sugar in treatment of 32% SWP kept minimal in both years. A significant impact was observed on titratable acidity in 2010, and the results indicate that drip irrigation could significantly increase titratable acidity of the pear fruit, as compared with the flood irrigation.

Fig. 5: Relationship between yield and surface wetted percentage

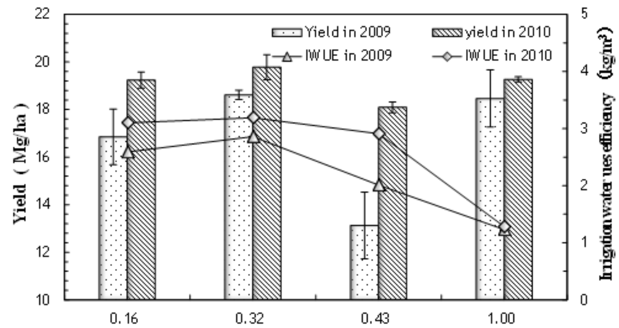
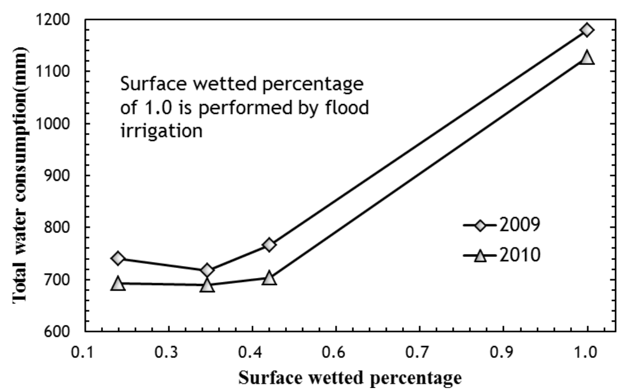


Fig. 6: Relationship between total water consumption and surface wetted percentage



DISCUSSION

Plants adapt to drought through various physiological and biochemical strategies (Kusvuran, 2012). In our study, all drip irrigated treatments received identical amount of irrigation water, however, surface wetted area of 16% SWP was smaller, which resulted in water going deeper and passing the active root zone; On the contrary, the 43% SWP wetted larger surface area, leading to the shortage of water supply for the deeper roots. Moreover, larger soil surface was wetted, resulting in a more intense surface evaporation. Generally, evaporation increases as wetted area increases using surface irrigation method, like surface drip irrigation and micro-sprinkler irrigation. A similar research showed that the highest yield of cherry was generally obtained at percentages of wetted soil surface larger than 30% (Yildirim *et al.*, 2012). Too large or too small surface wetted percentage resulted in yield reduction (Fig. 5) and increasing water consumption (Fig. 6). However, Some researches showed different results. Morales *et al.* (2010) reported that peach trees had no response to the change of wetted soil volume. This may be due to the distinctly different climate of two experimental locations. Our experimental site, Southren Xinjiang, is on the oases, which is extremely arid and there is almost no rain affecting the irrigated (wetted) soil volume. The surface wetted percentage may affect tree nutrition. Dehghanisanij *et al.* (2007) found that the mean concentration of Fe, Mg, P and K in cherry leaves from double drip lines array was significantly higher than in those from a single drip line. This is a possible reason for how wetted percentage affact fruit yield. But they did not give the exact relationship between nutrition concentration and wetted percentage.

The reason for yield reduction in 2009 (Table III) may be that as the mature pear trees have grown under flood irrigation for many years, their root development may be adapted to flood irrigation. The roots of mature pear trees need some time to adjust the spatial and temporal distribution to drip irrigation to absorb sufficient amount of water. However, Küçükyumuk *et al.* (2012) irrigated apple trees, which had been flood irrigated, with two irrigation intervals (4 & 7 days) and four pan coefficients (0.50, 0.75, 1.0 & 1.25), and the transition to drip irrigation method also achieved positive consequences on vegetative growth and fruit quality. This differences may also be a result of different climate (effect of rain). It indicates that surface wetted percentage may determine the effectiveness of drip irrigation under such extremely arid condition, and surface wetted percentage of 32% is an optimal option during the initial period when the flood irrigated mature fragrant pear trees were transferred into drip irrigatgion.

Fruit quality was not greatly affected by using drip irrigation in our research. Oron *et al.* (2002) arrived at the same conclusion, and found that drip irrigation had no effect on the soluble solids content of pear fruits. The percentage of wetted soil area did not significantly affect fruit weight and attributes such as redness index of fruit skin color, fruit juice content, soluble solids content, titratable acidity (Yildirim *et al.,* 2012). However, drip irrigation with the certain surface wetted percentage may decrease titratable acidity, in our research.

Using Class A evaporation pan with a constant pan coefficient of 0.8 appeared to be acceptable for irriagtion scheduling of pear when using drip irrigation. Only treatment of 42% SWP got lower yield than that of flood irrigated and it is thought that its yield reduction was related to the excessive SWP leading to high evaporation losses and shallower irrigation depth. Panigrahi *et al.* (2012) found that yield of citrus under drip irrigation with a constant pan coefficient of 0.8 was higher than that of 0.4，0.6 and 1.0, and using 29% less irrigation water resulted in 111% improvement in irrigation water productivity. The weekly irrigation frequency also seemed acceptable under this extremely dry climate. Gunduz *et al.* (2011) also discovered that the effect of irrigation interval (4 or 6 days) was not significant on peach yield.

Drip irrigation, with water applied for 80% replacement of pan evaporation and with different surface wetted percentages, was found to be a water-saving method for Korla fragrant pear production. During the initial period of changing the irrigation method from flood irrigation to drip irrigation, mature fragrant pear trees need to adjust for a certain period of time. In addition, applying the surface wetted percentage of 32% is appropriate, which facilitates higher yield and water use efficiency. Irrigation schedule can be established by using easy and inexpensive pan evaporation approach. however, irrigation frequency and a variable pan coefficient in different growing seasons for Korla fragrant pears are debatable.

Acknowledgement: This research was supported by the National Key Technology R and D Program of China (2007BAD38B00) and the China National Natural Science Fund (50879087).

REFERENCES

Amin, M.S.M. and A.I.M. Ekhmaj, 2006. DIPAC-drip irrigation water distribution pattern calculator. *In: 7th International Micro-irrigation Congress*, pp: 505–513. PWTC, Kuala Lumpur, Malaysia

Bresler, E., 1978. Analysis of trickle irrigation with application to design problem. *Irrig. Sci.,* 1: 3–17

Bielorai, H., 1981. The effect of partial wetting of the root zone on yield and water use efficiency in a drip and sprinkler-irrigated mature grapefruit grove. *Irrig. Sci.*, 3: 89–100

Camp, C.R., 1998. Subsurface drip irrigation: a review. *Transactions ASAE*, 41: 1353–1367

Cook, F.J., P.J. Thorburn, P. Fitch and K.L. Bristow, 2003. WetUp: a software tool to display approximate wetting pattern from drippers. *Irrig. Sci*., 2: 129–134

Dehghanisanij, H., A. Naseri, H. Anyoji, A.E. Eneji, 2007. Effects of deficit irrigation and fertilizer use on vegetative growth of drip irrigated cherry trees. *J. Plant Nutr.*, 30: 411–425

El-Hendawy, S.E., E.A. Abd El-Lattief, M.S. Ahmed and U. Schmidhalter, 2008. Irrigation rate and plant density effects on yield and water use efficiency of drip-irrigated corn. *Agric. Water Manag.*, 95: 836–844

Gunduz, M., N. Korkmaz, S. Asik, H.B. Unal and M. Avci, 2011. Effects of various irrigation regimes on soil water balance, yield, and fruit quality of drip-irrigated peach trees. *J. Irrig. Drain. Eng.*, 137: 426–434

Huang, X.F., G.Y. Li, X.W. Wang, D.C. Zeng and N.J. Sun, 2001. Water use of micro-sprinkler irrigated apple trees under full irrigation and regulated deficit irrigation. *Transactions CSAE*, 17: 43–47

Huang, X.F., G.Y. Li, D.C. Zeng, W. Wang and N. J. Sun, 2002. Real time determination of irrigation scheduling for micro-irrigated orchards. *Transactions CSAE*, 18: 79–83

Keller, J. and D. Karmeli, 1974. Trickle irrigation design parameters. *Transactions ASAE*, l7: 678–684

Kang, S.Z., X.T. Hu, I. Goodwin and P. Jerie, 2002. Soil water distribution, water use, and yield response to partial root zone drying under a shallow groundwater table condition in a pear orchard. *Sci. Hortic.*, 92: 277–291

Kandelous, M.M. and J. Šimůnek, 2010. Comparison of numerical, analytical, and empirical models to estimate wetting patterns for surface and subsurface drip irrigation. *Irrig. Sci*., 28: 435–444

Küçükyumuk, C., E. Kaçal, A. Ertek, G. Öztürk and Y.S.K. Kurttaş, 2012. Pomological and vegetative changes during transition from flood irrigation to drip irrigation: Starkrimson Delicious apple variety. *Sci. Hortic.*, 136: 17–23

Kusvuran, S., 2012. Influence of drought stress on growth, ion accumulation and antioxidative enzymes in okra genotypes. *Int. J. Agric. Biol.*, 14: 402–406

Lei, T.W., 1994. Determination of wetted percentage of tricke irrigation system. *J. Hydraul. Eng.*, 16: 19–23

Mustafa, O.S., M. Arshad, I. Sattar and S. Ali, 2003. Adoption of kostiakof model to determine the soil infiltration for surface irrigation methods under local conditions. *Int. J. Agric. Biol*., 1: 40–42

Mmolawa, K. and D. Or, 2000. Root zone solute dynamics under drip irrigation: a review. *Plant Soil*, 222: 163–190

Marsal, J., M. Mata, A. Arbonés, J. Rufat and J. Girona, 2002. Regulated deficit irrigation and rectification of irrigation scheduling in young pear trees: an evaluation based on vegetative and productive response. *European J. Agron.*, 17: 111–122

Ma, Q. and Y. Li, 2010. Industrialization development of Korla fragrant pear in Bayingolin Mongo Autonomous Prefecture. *J. Anhui Agric. Sci.*, 38: 10314–10337

Morales, P., M. García-Petillo, R. Hayashi, L. Puppo, 2010. Peach trees response to different water application patterns. *Rev. Bras. Eng. Agríc. Ambient.*, 14: 17–24

Oron, G., Y. DeMalach, L. Gillerman, I. David and S. Lurie, 2002. SW-Soil and Water: effect of water salinity and irrigation technology on yield and quality of pears. *Biosyst. Eng.*, 81: 237–247

Plaut, Z., A. Carmi and A. Grava, 1996. Cotton root and shoot responses to subsurface drip irrigation and partial wetting of the upper soil profile. *Irrig. Sci.*, 16: 107–113

Panigrahi, P., A.K. Srivastava and A.D. Huchche, 2012. Effects of drip irrigation regimes and basin irrigation on Nagpur mandarin agronomical and physiological performance. *Agric. Water Manag.*, 104: 79–88

Rashidi, M. and K. Seyfi, 2007. Effect of water stress on crop yield and yield components of cantaloupe. *Int. J. Agric. Biol.*, 9: 272–273

Singh, D.K., T.B.S. Rajput, D.K. Singh, H.S. Sikarwar, R.N. Sahoo and T. Ahmad, 2006. Simulation of soil wetting pattern with subsurface drip irrigation from line source. *Agric. Water Manag.*, 83: 130–134

Yildirim, O., H. Dumanoğlu, N.Tuna Güneş, M. Yildirim, A. Aygün and B. Şan, 2012. Effect of wetted soil area on trunk growth, yield, and fruit quality of drip-irrigated sour cherry trees. *Turkish J. Agric. For.*, 36: 439–450

(Received 06 April 2012; Accepted 21 August 2012)