Pak. J. Bot., 46(3): 1019-1025, 2014.

EFFECTS OF DRIPPER DISCHARGE AND IRRIGATION FREQUENCY ON GROWTH AND YIELD OF MAIZE IN LOESS PLATEAU OF NORTHWEST CHINA

WANG XIUKANG[1*], LI ZHANBIN[1] AND XING YINGYING[2]

[1]*Institute of Soil and Water Conservation, Chinese Academy of Sciences and Ministry of Water Resources, Yangling, shaanxi 712100, China*
[2]*Key Laboratory of Agricultural Soil and Water Engineering in Arid and Semiarid Areas of Ministry of Education, Northwest Agriculture and Forestry University, Yangling, shaanxi 712100, China*
**Corresponding author's e-mail: wangxiukang@126.com*

Abstract

A field experiment was conducted at the Changwu Experimental Station in Changwu County, Shaanxi Province, in northwestern China from 2010 to 2011 with four treatments and six replicates in a randomized complete block design to determine appropriate dripper discharge and irrigation frequency for maize (*Zea mays*, L.) irrigated by drip irrigated system. Dripper discharge was applied to maize 1L/h of dripper discharge, 2 days irrigation frequency and 100% of evaporation from a class a pan (T1), 2, 3 and 4 L/h corresponding to 4, 6 and 8 days irrigation frequency, and deficit irrigation water levels was 90%, 80% and 70% of evaporation (T2, T3 and T4), respectively. The results indicated that longest root, root activity, plant height, leaf area, biomass and grain yields values were highest in T1 in both years. The highest grain yield was obtained of 8.78 and 8.84 t ha^{-1} under T1 in both years, and the minimum yield was obtained with 8.15 and 7.78 t ha^{-1} under T4 in 2010 and 2011, respectively. The maximum irrigation water use efficiency (IWUE) was 3.247 and 3.283 kg m^{-3} in both years under T4. Despite the reduction of growth and grain yield in T3, the dripper discharge was 3L/h, 6 days irrigation frequency and 80% of evaporation was still high and acceptable for maize production and irrigation water use efficiency in Loess Plateau of Northwest China.

Introduction

Drought and water shortage is more serious in Northwest China, particularly in the Loess Plateau. The waste of water resources is a major issue. Surface irrigation methods are used on more than 80% of the world's irrigated lands yet their field-level application efficiency is often only 40-50% (Bhattaral *et al.*, 2011). There are amount of literatures on conserving and utilizing water with drip irrigation and other methods (Phene & Howell, 1984; Cai *et al.*, 2003; Maisiri *et al.*, 2005; Lal, 2009). For the reason of future food demand had a strong competition for limited land and water resources, this will necessitate a study of improving the efficiency of water and increasing grain yield.

The irrigation studies have made great achievements on improving the efficiency of water and ensuring food security, but still has great potential for improving water use efficiency in many field crops (Fereres & Soriano, 2007). Dukes & Scholberg (2005) reported that high frequency irrigation with reducing irrigation amounts can maintain crop yields. Kang *et al.*, (2002) reported that limited water application does not decrease yields and but increases water use efficiency. A two year study carried out by Abdullah (2006) in Turkey indicated a 4 day irrigation frequency and 90% ET water application by a dripper system would be optimal for corn grown in semi-arid regions. Increasing the amount of water applied while planting in furrows improved economical and biological water use efficiency (Lack *et al.*, 2012). Some studies have focus on the effects of irrigation on the production of maize (Pandey *et al.*, 2000; Stone *et al.*, 2001b; Dagdelen *et al.*, 2006; Payero *et al.*, 2006; Abdullah, 2008; Oktem, 2008; Perveen *et al.*, 2010). The optimum efficiency is deficit irrigation in 80% level treatment (Hussein *et al.*, 2011;Salemi *et al.*, 2011). Modarres *et al.,* (1998) indicated plant height and ear height increased under high density of maize. Decreases in leaf area, plant height and biomass yield were attributed to the fluctuations of rainfall (Amanullah *et al.*, 2009).

Fresh ear yield was reduced as the amount of irrigation water decreased (Oktem *et al.*, 2003). Liu *et al*., (2012) indicated the leaf area index was not affected by irrigation patterns under similar plant density. Dukes & Scholberg (2005) indicated 23 cm deep subsurface drip irrigation is a feasible alternative to sprinkler irrigation in sandy soils. Kang *et al.,* (2002) reported that grain yield response to irrigation varied considerably because of differences in soil moisture content and irrigation scheduling between seasons. Ayars *et al.,* (1999) indicated a slight deficit might decrease deep percolation and increased irrigation efficiency.

In summary, while authors often assume full irrigation for crops using drip irrigation systems is preferable to deficit irrigation, and many scholars indicated the optimum deficit level of irrigation is the most advantageous. Irrigation frequency is one major management variable with drip irrigation systems and have few studies have been conducted to determine the effects of irrigation frequency regimes on maize growth. Scant evidence exists that is related to any previous investigations of the effects of dripper discharge on the yield of maize in the northwestern China. The present experiment was the first conducted on the Loess Plateau to study the influence of dripper discharge and irrigation frequency management on the yield of maize. The objectives of this study were to evaluate the effects of different dripper discharge under four irrigation treatments and to evaluate their effect on maize, and to compare these treatments and to determine the most appropriate dripper discharge and irrigation scheduling designed to conserve irrigation water and improve IWUE for maize with drip irrigation systems in the Loess Plateau of northwestern China.

Materials and Methods

Experimental and soil description: This study was conducted during 2010 and 2011 at the Changwu Experimental Station for agricultural and ecological experimentation station, Shaanxi Province, China. The experimental field is located on the Loess Plateau (altitude: 1200 m; 35º12′ N and 107º40′ E) of northwestern China. The warm, semi-humid continental monsoon climate has a mean annual rainfall, evaporation, temperature and sunshine duration of 580 mm, 1500 mm, 9.1°C and 2230 h, respectively. The soil of experimental field had a light loamy texture. Field capacity of the soil was 27.5% (dry basis), the permanent wilting point was 12.6% with bulk density of 1.38 g cm^{-3}. The topsoil (0-20 cm) has a pH of 8.1, and organic content of 14.77 g kg^{-1}, total nitrogen, phosphorus and potassium were 0.81 g kg^{-1}, 0.53 g kg^{-1} and 15.46 g kg^{-1}, respectively. Nitrate nitrogen, ammonium nitrogen and available phosphorus (Olsen test) were 68.5 mg kg^{-1}, 7.89 mg kg^{-1} and 23.34 mg kg^{-1}, respectively (Lehmann, 2003; Dang *et al.*, 2006; Amanullah & Khan, 2010).

Experimental design and irrigation scheduling: The experiment used randomly assigned field plots with six replicates per treatment with the four treatments designated as T1, T2, T3 and T4. The four dripper flow rates in the surface drip irrigation system's four treatments were 1 L/h (T1), 2 L/h (T2), 3 L/h (T3), 4 L/h (T4). Irrigation water was applied as follows: 100%, 90%, 80% and 70% of evaporation of a Class A Pan with a 2-, 4-, 6- and 8-day irrigation frequency for T1, T2, T3 and T4, respectively. The drip irrigation systems were installed each year after the maize seed were planted. The drip tube in each plot consisted of five rows of 7.5 m long and 50 cm apart between the rows with 20 cm spacing in each row. Each plot had one valve, one flow meter, and one pressure gauge to control the operating pressure and measure the irrigation volume (Fig. 1). Irrigation treatments were started using surface drip irrigation system when the water content of soil decreased to 50% of available soil water measured by the oven method.

In this study, Merit hybrid maize (Liyu 18) was used. The seeds were sown on 21 April 2010 (day of year: 134) in the first year and on 25 April 2011 (day of year: 141) in the second year. At sowing, 80 kg N ha^{-1} (urea) and 60 kg P ha^{-1} (single super phosphate) were applied uniformly to the field before planting, and this was followed by160 kg ha^{-1} N as urea which was applied to each plot when the plant reached 50-60 cm height (at 60, 66 days after sowing in 2010 and 2011).

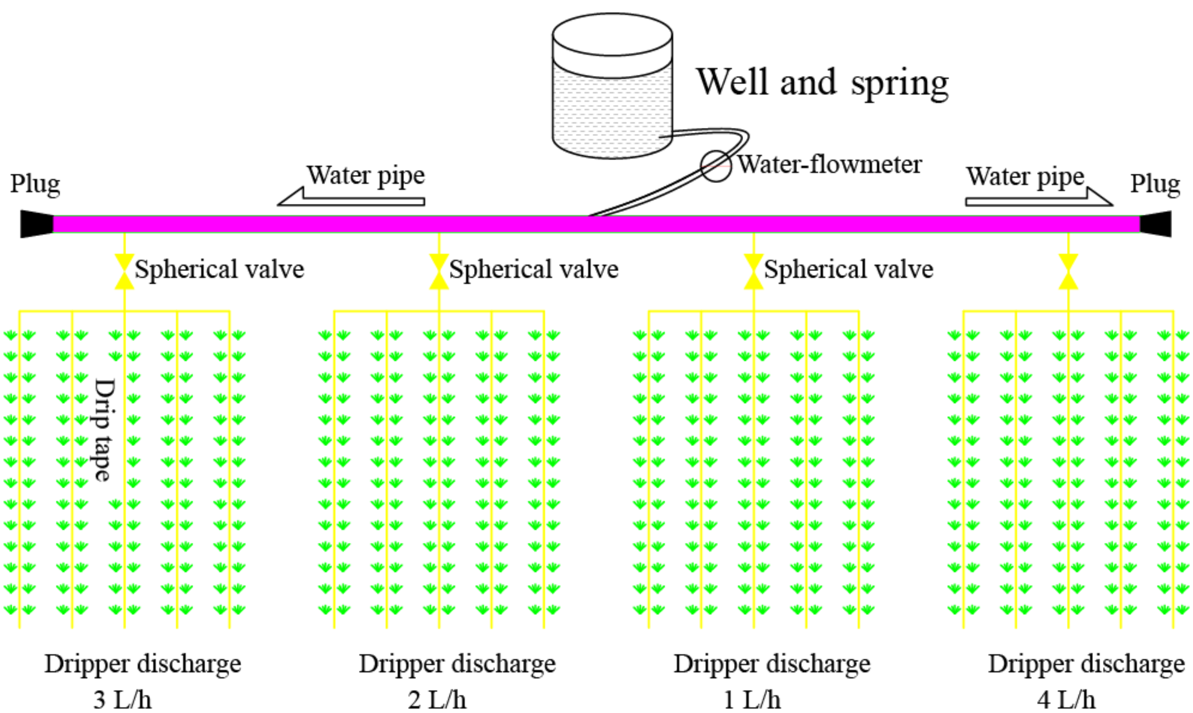

Fig. 1. The layout of experiment included a water-flow meter, plugs and spherical valves, the corn rows and drip tape position of different emitter discharge treatments in four plots in the greenhouse.

Data collection and measure: The six representative root samples were collected from different root zones in 38, 70, 92 and 134 days after sowing. To collect the roots a vertical incision was made with shovel from half of plant and row spacing, vertical incision until not to see the root hairs, then remove and soak the soil column in water, when the soil column become un-consolidation, flush it to get the complete root and put it on graph paper to measure length.

First to take root tip (0.5g) into small beaker and then add 0.4% TTC solution and phosphate buffer (pH7.5) solution 5 ml for each sample, and make the root fully immersed in the solution. In 37°C with constant temperature in a dark condition for one hour, then immediately join 1 mol/L sulfuric acid 2 ml in order to stop the reaction. Second to remove the root tip with filter paper blot moisture and mix with 3-4 ml ethyl acetate and a small amount of quartz sand in mortar grinding in order to extract TTF. The red leaching liquid filter into the tube, and a small amount of ethyl acetate residue washing it 2-3 times, filter into the test tube, and finally with ethyl acetate make overall product for 10 ml. Use spectrophotometer in the wavelength of 485 nm with a blank color was used to measure absorbance, a standard curve was used to determine the TTC reduction amount. Root activity was obtained using the following formula:

Root activity = C / (1000×W×H) [mg TTF / (g×H)]

where C is the TTC reduction amount (μg), TTC is tripheye tetrazolium chloride, TTF is TTC after reduction of material, W is root weight (g) and H is time (hour).

Data were collected on mean individual plant and leaf area plant^{-1}, plant and ear heights, and biomass yield were measured at various growth stages. Leaf area, length and width of six leaves were measured using a leaf area machine in the Agronomy laboratory and the factor (0.75) was calculated in each treatment. Length and width of the five middle leaves of 6 plants in each sub plot were measured using measuring tape. Mean leaf area and leaf area per plant was obtained using the following formulas according to (Amanullah *et al.*, 2009):

Mean Leaf area = Leaf length x Leaf width x 0.75
Leaf area per plant = Mean leaf area x Number of leaves per plant

When kernel humidity declined to 70-75%, ears from two rows in the center of each plot (50 plants) were harvested manually on September 2 in 2010 and September 13 in 2011. Plant height was obtained by measuring the height of six plants from ground level to the tips of the tassels at physiological maturity and then average plant height was determined. Similarly, ear height was recorded by measuring the height of six plants from ground level to the top ear at physiological maturity and then average ear height was determined. Six plants in the four middle rows in each experimental unit were harvested at silking and physiological maturity. The plants were dried, weighed and then converted to biomass yield ha^{-1}. The spike length, grain weight per spike and 1000 grain weight was also measured.

An analysis of variance (ANOVA) was conducted on longest root, root activity, biomass, spike length, panicle weight, 1000 grain weight and grain yield using PROC GLM (SAS 9.2, SAS institute Ltd., USA). Duncan's multiple range tests at 0.05 probability level was used for paired mean comparison.

Results

Root distribution: The maize root vertical distribution was measured under different dripper discharge patterns and no significant difference in the longest root has found between treatments 38 days after sowing which means the dripper discharge, irrigation frequency and deficit irrigation during the vegetative growth stage did not affected root system development, and the fine root system were concentrated below the head of the dripper on the soil wetting pattern in both years. Application of dripper discharge significantly decreased the length of the longest root at 70 days after sowing, when the maximum length of the longest root was 74.1 cm in 1L/h dripper discharge T1 while the minimum was 34.6 cm in 4L/h dripper discharge T4 during 2010 (Table 1). In 2011, the values were 67.1 cm for the maximum and 42.5 cm for the minimum in the T1 and T4 treatments, respectively. The results were similar in both years. Longest root significantly longer in T1 than others at 92 days after sowing: the results are more significant during the harvest season. The explanations of this phenomenon could be that a higher frequency of irrigation would produce a smaller soil wetting pattern in the upper soil layer and the increase of dripper discharge and growth period of maize affects the root system to cover a wider range of horizontal extension growth. The densest roots appeared around the main roots in the 0-10 cm soil layer.

Table 1. Response of maize roots to different dripper discharge rates during 2010 and 2011 in China.

Year	Treatments [a]	Days after sowing							
		38		70		92		134	
		Longest root (cm)	Root activity mg/(g.h)	Longest root (cm)	Root activity mg/(g.h)	Longest root (cm)	Root activity mg/(g.h)	Longest root (cm)	Root activity mg/(g.h)
2010	T1	40.4a [b]	0.157a	58.1a	0.349a	60.1a	0.042a	74.1a	0.042a
	T2	44.3a	0.146b	50.7ab	0.326ab	46.9b	0.043a	52.9b	0.034a
	T3	40.2a	0.143b	44.6b	0.305ab	40.0b	0.051a	39.6c	0.035a
	T4	36.7a	0.135b	42.9b	0.264b	41.0b	0.052a	34.6c	0.028a
2011	T1	40.5a	0.156a	54.2a	0.367b	56.5a	0.066a	67.1a	0.034a
	T2	39.1a	0.141b	49.8a	0.342ab	50.6ab	0.051a	57.3ab	0.029a
	T3	37.2a	0.148b	43.8a	0.310ab	41.0b	0.043a	46.9b	0.030a
	T4	34.4a	0.139b	44.2a	0.269a	41.6b	0.030a	42.5b	0.030a

[a] dripper discharge 1L/h (T1), dripper discharge 2L/h (T2), dripper discharge 3L/h (T3), dripper discharge 4L/h (T4), and irrigation water was applied as 100% of evaporation of Class A Pan in the 2-day irrigation frequency (T1), 90% of evaporation in the 4-day irrigation frequency (T2), 80% of evaporation in the 6-day irrigation frequency (T3) and 70% of evaporation in the 8-day irrigation frequency (T4), respectively

[b] Values in a column followed by the same letter are not significantly different at the 5% level using PROC GLM

Root growth is heavily influenced by environmental conditions such as soil moisture and nutrient levels. The strength of the root activity is related to the enzyme activity and protein content and the measures of root activity are based on the root's ability to absorb nutrients and water. In 2010, the highest of root activity was 0.349 mg/ (g.h) in 1L/h dripper discharge of 70 days after sowing. In the whole growth period, the strongest root activity was seen at 70 days after sowing seed and showed maize grew most vigorously at that time while root activity began to decline. Growth with a dripper discharge of 1 L/h was significantly higher than in the other treatments at 38 days after sowing, although the significant difference declined 38 days after sowing and there was no significant difference between all for treatments at 92 days of sowing, with a minimum value for root activity at 134 days of sowing. In the second year, the values were 0.367 mg/ (g.h) for maximum in the 1 L/h dripper discharge treatments. The results were similar in both years.

Leaf area and plant height: Leaf area played an important role in the interception and use of solar radiation which directly influenced the maize dry matter accumulation and grain yield. Leaf area and plant height is less influence by dripper discharge and irrigation frequency in maize before 38 days of sowing (Fig. 2), but the balance has changed at 70 days after sowing, when the maximum plant height and leaf area were seen in T1 and the minimum in T2. These differences between treatments continued to exist until harvest and the variation in leaf area and plant height stabilized at 92 days after sowing. The results were similar in both years, but the maize grew shorter in 2010 when compared to 2011. The increase in the height of maize plants in 2010 might be attributed to differences in irrigation and evapotranspiration in the two years.

Maize response to different dripper discharge and irrigation frequency: Plants transpire less under conditions with high humidity and more when the vapour pressure deficit of ambient air is high. Since relative humidity is very low in the Loess Plateau, especially during summer, plants transpire more for each unit of dry matter accumulation than they would in other areas with higher humidity's. Also, other factors such as percent ground cover and a low leaf area index early in the growing season accelerates evaporative loss soil water. The highest grain yield was obtained from the 1 L/h dripper discharge and 2-day irrigation frequency at 8.78 t ha^{-1} in 2010 and 8.84 t ha^{-1} in 2011 (Table 2).

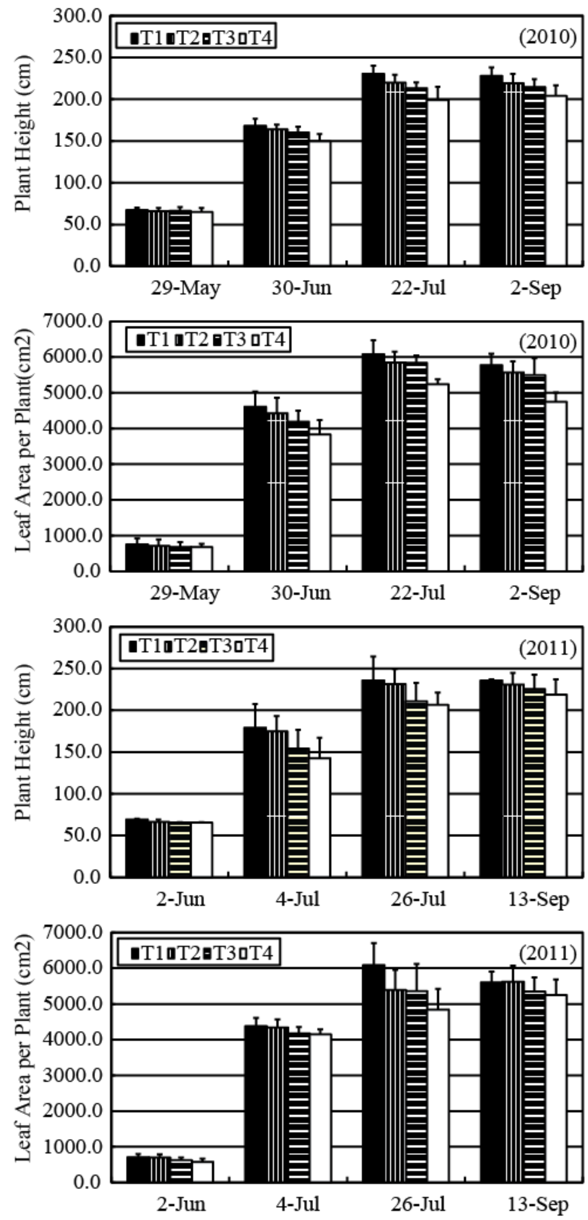

Fig. 2. The plant height and leaf area per plant of average six replicates in different dripper discharge and irrigation frequency treatments in 2010 and 2011.

Table 2. Relationship between the increase dripper discharge and decrease irrigation frequency in relative yield, biomass, spike response factor and IWUE for maize irrigated by a drip system in the two-year study.

Year	Treatments	Grain yield	ET	Irrigation water	Water saving	Biomass	Spike length	Grain weight per spike	1000 grains weight	IWUE
		(t ha^{-1})	(mm)	(mm)	(%)	(t ha^{-1})	mm	(g)	(g)	(kg m^{-3})
2010	T1	8.78a	366	366	0.00	24.42a	201a	146.26a	277.00a	2.399
	T2	8.57ab	351	316	13.69	23.46a	187a	142.92ab	259.33ab	2.712
	T3	8.49ab	346	277	24.37	22.68ab	190a	141.59ab	250.83b	3.065
	T4	8.15b	358	251	31.53	21.30b	165b	135.77b	239.17b	3.247
2011	T1	8.84a	371	371	0.00	25.14a	218a	146.59a	278.50a	2.383
	T2	8.44ab	348	313	15.58	23.10b	169b	143.43a	254.83b	2.696
	T3	8.27bc	333	266	28.19	22.26b	195b	141.25a	245.17b	3.109
	T4	7.78c	339	237	36.04	19.32c	157c	134.59b	231.67c	3.283

In the irrigated treatments, seasonal evapotranspiration ranged from 346 to 366 mm and grain yield from 8.15 to 8.78 t ha^{-1} in 2010, and seasonal evapotranspiration varied between 333 and 371 mm and grain yield from 7.78 t ha^{-1} to 8.84 in 2011, which depending on the amount of water applied time of irrigation. The results of this study indicate the highest yield was obtained under T1 while the lowest yield was obtained under T4. Evapotranspiration and yield depend on the different dripper discharges and different frequencies of irrigation. The high value of evapotranspiration was 366 mm in 2010 and 371 mm in 2011 which may be attributed to the frequent irrigation, which provided sufficient air humidity for evaporation. In 2010, the rates of water savings were 13.69%, 24.37% and 31.53% of T2, T3 and T4, respectively, and 15.58%, 28.19% and 36.04% for the treatment in 2011. However, the decreases in grain yield were 2.39%, 3.30% and 7.18% in 2010, and 4.52%, 6.45% and 11.99% in 2011, respectively.

The dripper discharge and irrigation frequency treatments provided a gradient of biomass yield. At the T2, T3 and T4 treatments, the rates of the decrease in biomass yield were 3.93%, 7.13% and 12.78% in 2010, and 8.11%, 11.46% and 23.15% in 2011, respectively. The maximum biomass of 24.42 t ha^{-1} in 2010 was relatively lower in 2011. The increase in maize biomass yield in 2010 might be attributed to the longer growth period and increased consumption of irrigation water. These relationships also indicate that the highest biomass was associated with maximum evapotranspiration, but not with the highest grain yield, which was reached by appropriately controlling soil water content and limiting evapotranspiration and biomass. Minimum spike length was recorded under 4 L/h dripper discharge and 8-day irrigation frequency conditions (T4) 165 mm in 2010 and 157 mm in 2011, and the maximum in the 2- day irrigation frequency (T1) 201 mm in 2010 and 218 mm in 2011. The reductions in spike length were related to evapotranspiration and the availability of irrigation water. However, the reduction in spike length was small in T2 and T3 in both 2010 and 2011. This was the result of a compensatory effect of the dripper discharge production and the soil wetting pattern under controlled frequency irrigation.

Application of dripper discharge and irrigation frequency significantly decreased the grain weight per spike (2.2%-8.2%, $p<0.05$) for 2010, 2011. However, except in 2010 cropping year that the T2 and T3 relevant T4, and the grain weight per spike of T4 was significantly lower than other treatment, there were no significant differences between T1, T2 and T3. Thus, the results suggested that in the Loess Plateau area of maize reduces irrigation frequency to 6 days could maintain the grain weight per spike.

Irrigation water use efficiency: Irrigation water use efficiency ranged from 2.383 to 3.283 kg m^{-3} under different treatments. As a result, different drip irrigation treatment significantly increased IWUE, which variation depends on the controlled ranges of dripper discharge in different irrigation frequency. IWUE in the T4 was higher than in other treatments and the values were 3.247 and 3.283 kg m^{-3} in 2010 and 2011. Similar result has been reported showing IWUE increased with a more severe deficit (Dagdelen *et al.*, 2009). The highest grain yield which IWUE was not as high as expected based on available information on yield and seasonal evapotranspiration, because seasonal evapotranspiration was variation.

Discussion

Crop root uptake of nutrients and water from upper levels of soil under conditions of low water stress are such that root contact is driven by extensive root branching and long root hairs which is a main determinant of moisture extraction from dry soil (White & Kirkegaard, 2010). With the effect on soil wetting patterns, the dripper discharge has influences on crop root development. Vazquez *et al.,* (2006) indicated excess water applied to assist root development created low soil water potential. Boote *et al.,* (1996) indicated that leaf area is the main factor in estimation of dry matter accumulation based on temporal integration of canopies photosynthesis in the canopy. Caviglia & Sadras (2001) reported the leaf area index was lower in crops grown with a N deficiency. Leaf area development and leaf senescence are both affected by the availability of water (Connell *et al.,* 2004; Raziuddin *et al.*, 2011) .

The highest grain yield was obtained from the 1 L/h dripper discharge and 2-day irrigation frequency at 8.78 t ha^{-1} in 2010 and 8.84 t ha^{-1} in 2011. Oktem *et al.,* (2003) reported that the highest fresh ear yield was obtained using a 2-day irrigation frequency while the minimum yield was with an 8-day irrigation frequency. Yield was reduced with decrease irrigation frequency in both years. The declines in dry matter and grain yields could be attributed to an increased soil water deficit (Darusman *et al.*, 1997; Yazar *et al.*, 1999).

A reduction in yield was observed with decrease irrigation frequency, the rate of yield reduction was less than water savings which indicate that the increase of dripper discharge would improve grain yield. The aim of irrigation is to enhance economic returns while optimizing yields by minimizing damage caused by water deficiency as the crops develop (Stone *et al.*, 2001a). Deficiency at an irrigation frequency of 6 days and a dripper discharge rate of 3L/h can be acceptable for maize production in the Loess Plateau of northwestern China. Ersel *et al.,* (2010) reported a linear relationship existed between seasonal water use and grain yield.

IWUE in the T4 was higher than in other treatments and the values were 3.247 and 3.283 kg m^{-3} in 2010 and 2011. Similar result has been reported showing IWUE increased with a more severe deficit (Dagdelen *et al.*, 2009). The highest grain yield which IWUE was not as high as expected based on available information on yield and seasonal evapotranspiration, because seasonal evapotranspiration was variation. Wang *et al.,* (2012) reported deficit irrigation results in reduced grain yield, kernel numbers and straw yield, but increased IWUE. The highest rate of economical IWUE was 2.85 kg m^{-3} that obtained from optimum irrigation treatments (Lack *et al.*, 2012).

Conclusions

The highest grain yield was obtained of 8.78 and 8.84 t ha^{-1} under T1 in both years, and the minimum yield was obtained with 8.15 and 7.78 t ha^{-1} under T4 in 2010 and 2011, respectively. The maximum irrigation water use efficiency (IWUE) was 3.247 and 3.283 kg m^{-3} in both years under T4. Despite the reduction of growth and grain yield of T3, the dripper discharge was 3L/h, 6 days irrigation frequency and 80% of evaporation was still high and acceptable for corn production and water use efficiency in Loess Plateau of Northwest China.

Acknowledgments

We are grateful to Professor Li (Xi'an University of Technology) for his assistance in revising this paper. We also thank the technicians in Farmland ecosystem of Changwu county national field scientific observation research station Laboratory for their analyses of root activity and other helps. This research was supported by National Natural Science Foundation (41330858), National science and technology support plan (2011BAD31B01).

References

Abdullah, O. 2006. Effect of different irrigation intervals to drip irrigated dent corn (*Zea mays* L. Indentata) water-yield relationship. *Pak. J. Bio.Sci.*, 9(8): 1476-1481.

Abdullah, O. 2008. Effect of deficit irrigation on some yield characteristics of sweet corn. *Bangladesh. J. Bot.*, 37(2): 127-131.

Amanullah, M. and W. Khan. 2010. Interactive effects of potassium and phosphorus on phenology and grain yield of sunflower in Northwest Pakistan. *Pedosphere.,* 20(5): 674-680.

Amanullah, K.B., P. Marwat, N. Shah, S. Maula and Arifullah. 2009. Nitrogen levels and its time of application influence leaf area, height and biomass of maize planted at low and high density. *Pak. J. Bot.,* 41(2): 761-768.

Ayars, J.E., C.J. Phene, R.B. Hutmacher, K.R. Davis, R.A. Schoneman, S.S. Vail and R.M. Mead. 1999. Subsurface drip irrigation of row crops: A review of 15 years of research at the water management research laboratory. *Agr. Water. Manage.*, 42: 1-27.

Bhattaral, S.P., M.C. Palada, D.J. Midmore, D. Wu and R. Salas. 2011. On-farm evaluation of fertilizer briquettes and low-cost drip irrigation for smallholder vegetable production in cambodia. *Irrig. Drain.*, 60: 318-329.

Boote, K.J., J.W. Jones and N.B. Pickering. 1996. Potential uses and limitations of crop models. *Agron. J.*, 88: 5704-716.

Cai, X., D.C. Mckinney and M.W. Rosegrant. 2003. Sustainability analysis for irrigation water management in the aral sea region. *Agr. Syst.*, 76(3): 1043-1066.

Caviglia, O.P. and V.O. Sadras. 2001. Effect of nitrogen supply on crop conductance, water- and radiation- use efficiency of wheat. *Field. Crop. Res.*, 69: 259-266.

Connell, M.G.O., G.J.O. Leary, D.M. Whitfield and D.J. Connor. 2004. Interception of photosynthetically active radiation and radiation-use efficiency of wheat, field pea and mustard in a semi-arid environment. *Field. Crop. Res.*, 85: 111-124.

Dagdelen, N., H. Basal, E. Yilmaz, T. Gurbuz and S. Akcay. 2009. Different drip irrigation regimes affect cotton yield, water use efficiency and fiber quality in western turkey. *Agr. Water. Manage.*, 96: 111-120.

Dagdelen, N., E. Yilmaz, F. Sezgin and T. Gurbuz. 2006. Water-yield relation and water use efficiency of cotton (gossypium hirsutum l.) and second crop corn (*Zea mays* L.) in western turkey. *Agr. Water. Manage.*, 82(1-2): 63-85.

Dang, T.H., C. G.X, S.L. Guo, M.D. Hao and L.K. Heng. 2006. Effect of nitrogen management on yield and water use efficiency of rainfed wheat and maize in northwest china. *Soil. Sci. Society. China*, 16(4): 495-504.

Darusman, A.H., L.R. Khan, Stone and R.L. Freddie. 1997. Water flux below the root zone vs. Drip-line spacing in drip-irrigated corn. *Soil. Sci. soc. Am. J.,* 61(6): 1755-1760.

Dukes, M.D. and J.M. Scholberg. 2005. Soil moisture controlled subsurface drip irrigation on sandy soils. *Appl. Eng. Agric.*, 21(1): 89-101.

Ersel, Y., A. Selin, G. Talih, D. Necdet and S. Fuat. 2010. Effect of different water stress on the yield and yield components of second crop corn in semiarid climate. *J. Food. Agirc. Environ.*, 8(3-4): 415-421.

Fereres, E. and M.A. Soriano. 2007. Deficit irrigation for reducing agricultural water use. *J. Exp. Bot.*, 58(2): 147-159.

Hussein, F., M. Janat and A. Yakoub. 2011. Assessment of yield and water use efficiency of drip-irrigated cotton (gossypium hirsutum l.) as affected by deficit irrigation. *Turk. J. Agric. For.,* 35: 611-621.

Hussain, J., N. ur Rehman, A.L. Khan, H. Hussain, A. Al-Harrasi, L. Ali, F. Sami and Z.K. Shinwari. 2011. Determination of macro-and micro-nutrients and nutritional prospects of six vegetable species of Mardan, *Pakistan. Pak. J. Bot.,* 43: 2829-2833.

Kang, S.Z., L. Zhang, Y.L. Liang, X.T. Hu, H.J. Cai, B.J. Gu and A.W.M. 2002. Effects of limited irrigation on yield and water use efficiency of winter wheat in the loess plateau of china. *Agr. Water. Manage.*, 55: 203-216.

Lack, S., H. Dashti, G. Abadooz and A. Modhej. 2012. Effect of different levels of irrigation and planting pattern on grain yield, yield components and water use efficiency of corn grain (*Zea mays* L.) hybrid sc. 704. *Afr. J. Agr. Res.*, 7(18): 2873-2878.

Lal, R. 2009. Soil degradation as a reason for inadequate human nutrition. *Food. Secur.*, 1: 45-47.

Lehmann, J. 2003. Subsoil root activity in tree-based cropping systems. *Plant. Soil.*, 255: 319-331.

Liu, T., F. Song, S. Liu, X. Zhu and A.J.o.C.S. 2012. Light interception and radiation use efficiency response to narrow-wide row planting patterns in maize. *Aust. J. Crop. Sci.*, 6(3): 506-513.

Maisiri, N., A. Senzanje, J. Rockstrom and S.J. Twomlow. 2005. On farm evaluation of the effect of low cost drip irrigation on water and crop productivity compared to conventional surface irrigation system. *Phys. Chem. Earth.*, 30: 783-791.

Modarres, A.M., R.I. Hamilton, M. Dijak, L.M. Dwyer, D.W. Stewart, D.E. Mather and D.L. Smith. 1998. Plant population density effects on maize inbred lines grown in short-season environments. *Crop. Sci.*, 38: 104-108.

Oktem, A. 2008. Effect of water shortage on yield, and protein and mineral compositions of drip-irrigated sweet corn in sustainable agricultural systems. *Agr. Water. Manage.*, 95(9): 1003-1010.

Oktem, A., M. Simsek and A.G. Oktem. 2003. Deficit irrigation effects on sweet corn (*Zea mays* saccharata sturt) with drip irrigation system in a semi-arid region part i. Water-yield relationship. *Agr. Water. Manage.*, 61: 63-74.

Pandey, R.K., J.W. Maranville and A. Admou. 2000. Deficit irrigation and nitrogen effects on maize in a sahelian environment. Part i. Grain yield and yield components. *Agr. Water. Manage.*, 46: 1-13.

Payero, J.O., S.R. Melvin, S. Irmak and D. Tarkalson. 2006. Yield response of corn to deficit irrigation in a semiarid climate. *Agr. Water. Manage.*, 84(1-2): 101-112.

Perveen, S., Z. Malik and W. Nazif. 2010. Fertility status of vegetable growing area of Peshawar, *Pakistan. Pak. J. Bot.,* 42: 1871-1880.

Phene, C.J. and T.A. Howell. 1984. Soil sensor control of high frequency irrigation. *T. Asae.*, 27(2): 392-396.

Raziuddin, Farhatullah, G. Hassan, M. Akmal, S.S. Shah, F. Mohammad, M. Shafi, J. Bakht and W. Zhou. 2011. Effects of cadmium and salinity on growth and photosynthesis parameters of Brassica species. *Pak. J. Bot.,* 43: 333-340.

Salemi, H., M.A.M. Soom, T.S. Lee, M.K. Yusoff, D. Ahmad and P.J.o.T.A.S. 2011. Effects of deficit irrigation on water productivity and maize yields in arid regions of iran. *Per. J. Tro. Agr. Sci.*, 34(2): 207-216.

Stone, P.J., D.R. Wilson, P.D. Jamieson and R.N. Gillespie. 2001b. Water deficit effects on sweet corn. Part ii. Canopy development. *Aust. J.Agr.Resour. Ec.*, 52: 115-126.

Stone, P.J., D.R. Wilson, P.D. Jamieson, R.N. Gillespie and A.J.o.A.a.R.E. 2001a. Water deficit effects on sweet corn. Part i. Water use, radiation use efficiency, growth, and yield. *Aust. J. Agr. Resour. Ec.*, 52: 103-113.

Vazquez, N., A. Pardo, M.L. Suso, M. Quemada and E.a.E. Agriculture. 2006. Drainage and nitrate leaching under processing tomato growth with drip irrigation and plastic mulching. *Agr. Ecosyst, Environ.*, 112: 313-323.

Wang, F.X., Y.H. Kang and S.P. Liu. 2006. Effects of drip irrigation frequency on soil wetting pattern and potato growth in north china plain. *Agr. Water. Manage.*, 79: 248-264.

Wang, Q., F. Li, E. Zhang, G. Li and M. Vance. 2012. The effects of irrigation and nitrogen application rates on yield of spring wheat (longfu-920), and water use efficiency and nitrate nitrogen accumulation in soil. *Aust. J. Crop. Sci.*, 6: 662-672.

White, R.G. and J.A. Kirkegaard. 2010. The distribution and abundance of wheat roots in a dense, structured subsoil-implications for water uptake. *Plant. Cell. Environ.*, 33: 133-148.

Yazar, A., T.A. Howell, D.A. Dusek and K.S. Copeland. 1999. Evaluation of crop water stress index for lepa irrigated corn. *Irrig. Sci.*, 18: 171-180.

(Received for publication 27 September 2012)