African Journal of Agricultural Research Vol. 7(33), pp. 4698-4707, 28 August, 2012
Available online at http://www.academicjournals.org/AJAR
DOI: 10.5897/AJAR11.1213
ISSN 1991-637X ©2012 Academic Journals

Full Length Research Paper

Estimation of maize evapotranspiration and yield under different deficit irrigation on a sandy farmland in Northwest China

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Accepted 3 September, 2011

A field experiment was conducted on a sandy farmland in Northwest China to estimate on the response of maize evapotranspiration and yield to deficit irrigation. The five irrigation treatments consisted of specific combinations of full irrigation and limited irrigation in different crop growing phases (I, from elongation phase to heading; II, from heading phase to milk; III, from milk phase to physiological maturity) were designed. And for estimation of maize evapotranspiration, reference crop evapotranspiration (ET_0), basal crop coefficient (K_{cb}), soil evaporation coefficient (K_e), and water stress coefficient (K_s) in different treatments were calculated. Results showed that; 1) the crop actual evapotranspiration (ET_c) for treatments SII (deficit irrigation in phase I), ISI (deficit irrigation in phase II), IIS (deficit irrigation in phase III), SIS (deficit irrigation both in phase I and III), and III (full irrigation) were 570, 604, 579, 542, and 607 mm, respectively. (2) The phase II was the most sensitive phase to water deficit, with reductions in leaf area index (LAI), biomass, yield, irrigation water productivity (IWP), and harvest index (HI). In this phase, the effect of water stress on K_e and K_s was slight, and the evapotranspiration has no obvious difference between full irrigation and limited irrigation. (3) Deficit irrigation in phase I can slow down the crop development in early phase, and can also reduce maize biomass and yield. In this phase, water stress obviously reduced K_e and K_s, and the evapotranspiration in limited irrigation treatments were obviously lower than full irrigation treatment in this phase. (4) However, deficit irrigation in phase III has no significant effect on height and leaf area of maize, and did not also significantly reduce maize biomass and yield. In this phase, the evapotranspiration in limited irrigation treatments were also obviously lower than full irrigation treatment. It can be concluded that it was possible to reduce water consumption and maintain the maize yield by adopting deficit irrigations from milk to physiological maturity, then from elongation to heading, but not from heading to milk in this sandy farmland regions.

Key words: Evapotranspiration, deficit irrigation, sandy farmland, maize.

INTRODUCTION

Irrigated agriculture is the primary user of water, but irrigation water supplies are decreasing in many areas of the world (Farré and Faci, 2009; Iniesta et al., 2009). Many regions do not have sufficient water to meet the demands of crop development. (Liu and Jun, 2004). In Northwestern China, since the climate is very dry, irrigation is absolutely necessary for obtaining reliable yields (Wang et al., 2010). In this region, maize is one of the most important crops (Su et al., 2006). Shortage of water resources is forcing farmers to consider the options of deficit-irrigation to reducing agricultural water use (José et al., 2006). However, maize is very sensitive to water stress (Pandey et al., 2000). The effects of water stress on maize include the visible symptoms of reduced growth, delayed maturity and reduced biomass and grain yield. For example, water stress on maize has been shown to reduce plant height (Cakir, 2004), leaf area index (Traore et al., 2000) and root growth (Jama and Ottman, 1993). The high sensitivity of maize to water stress means that under water limiting conditions, it is difficult to implement irrigation management strategies without incurring significant yield losses (Lamm et al., 1994). As a result, many researchers have evaluated the effect of timing of water stress on maize yield (Scheierling et al., 1997) to elect the best phase of deficit irrigation.

Evapotranspiration is a very important parameter in irrigation management and is usually estimated by a reference crop evapotranspiration (ET_0) (Li et al., 2008; Zhang et al., 2008). ET_0 can be estimated by many methods (Zhao et al., 2010; Beyazgül et al., 2000; Kashyap and Panda, 2001; Rivas and Caselles, 2000), but the most popular one is the Penman equation and the modified Penman formula (Goyal, 2004). Much of the past research on crop evapotranspiration on maize has considered a standard condition, where no limitations are placed on crop growth or evapotranspiration from soil water stress (Li et al., 2008). The effect of both crop transpiration and soil evaporation are integrated into a single crop coefficient (K_c) (Tong et al., 2007). In irrigation regions, the dual crop coefficient approach (basal crop coefficient K_c and soil evaporation coefficient K_e) is more complicated and more computationally intensive than the single crop coefficient approach (K_c) (Zhao and Nan, 2007). However, when deficit irrigation was adopted, soil water stress makes it less available for plant root extraction, and the water stress coefficient (K_s) must be taken into account when calculating actual crop evapotranspiration (ET_c) (Kang et al., 2000). It is obvious that water stress as a consequence of deficient irrigation is more likely to occur in sandy soil regions, though few studies have been carried out on it.

Deficient irrigation in some cases could result in water saving by reducing water consumption for little lost in yield (Fereres and Soriano, 2006). Therefore, it is important to know the crop evapotranspiration and yield response to water deficit at growth phases under cropping and irrigation conditions similar to the one experienced by farmers in the area. This paper reports the results of a field experiments performed in 2010 using increased interval between irrigations in different growing phase of maize. The objective was to study the effects of deficit irrigation on maize development, evapotranspiration, and grain yield in a typical sandy farmland.

Field experiments

Site

The experiment was conducted at the Linze inland river basin comprehensive research station (39° 21′N, 100° 07′E, and 1382 m above sea level) located in the Linze town of Gansu Province, Northwest China during the growing seasons of 2010. The site is characterized by a typical semi-arid continental monsoon climate. Average annual temperature was 7.3°C Average annual precipitation was about 116.8 mm, while average annual pan-evaporation was around 2390 mm. In 2010, precipitation during the growing season of grain was 75 mm (Figure 1).

The soil was formed in diluvial-alluvial materials and classified as Calci-OrthicAridosols and Calciorthids according to the Chinese soil taxonomy. The dominant texture is loamy sand with very low nutrient concentration and loose structure. The soil in 0 to 20 cm (plough layer) layer containing organic matter 6.02 g kg^{-1}, total N 0.43 g kg^{-1}, ammonium N 32.5 mg kg^{-1}, available K 108 mg kg^{-1}, Olsen P 8.55 mg kg^{-1}, and its pH and bulk density were 8.8 and 1.43 g cm^{-3}, respectively.

Crop agronomy

A half-bred maize variety (Aoyu3118) was planted in 22nd April and harvested in 23rd September. With row spacing of 45 cm and planting spacing of 25 cm, the planting density was about plants 6.8 × 10^4 ha^{-1}. Fertilizer amounts (350, 100 and 100 kg ha^{-1} of N, P_2O_5 and K_2O, respectively) were based on soil fertility and expected yields, such that nutrients were not limiting. Nitrogen fertilizer was partitioned into one pre-planting application and two post-planting application (150,100 and 100 kg ha^{-1} N, respectively, in the three applications). Irrigation was pumped from a well and applied through water pipes, and the amount was measured with a volumetric flow meter. Weeds, pests and diseases were controlled following best farmers practices in the area.

Irrigation treatments

In our experimental design, we did not aim at treatments with reducing amounts of each irrigation event, but rather, treatments with increasing interval between irrigation events at different growing phases so that amounts of total irrigation water were reduced. Three main growing phases of maize were chosen; I) from elongation to heading; II) from heading to milk; III) from milk to physiological maturity. In each of the three phases, irrigation was applied either to meet the crop water requirements (I = full irrigation treatment), or deficient crop water requirements by increasing the interval between irrigation events (S = stress treatment). The combination of I or S in each of the three phases resulted in five treatments (Table 1). The experimental designed was a randomized block with three replicates. The experimental plot unit was 4 × 5 m (20 m^2). All plots were separated by a rubber barrier down to 100 cm from ground, and 15 cm high concrete barriers were built above that to prevent water movement between contiguous plots.

Data collection and analysis

Leaf areas and height of maize were measured during the different growth phases of maize. The plants in the plots were harvested at maturity and the yield and biomass were recorded. The meteorological data were measured in a standard weather station located in the experiment station. Parameters measured were air temperature, air humidity, and wind speed at 2 m above ground, rainfall and global radiation. Daily values of maximum and minimum temperature, maximum vapor pressure deficit, and average wind speed were also recorded. Statistical significance of difference between treatments was analyzed by analysis of variance (ANOVA) and LSD (least significant deviation) multiple comparison.

Estimation of crop evapotranspiration

The ET_c under different deficient irrigation treatment was calculated

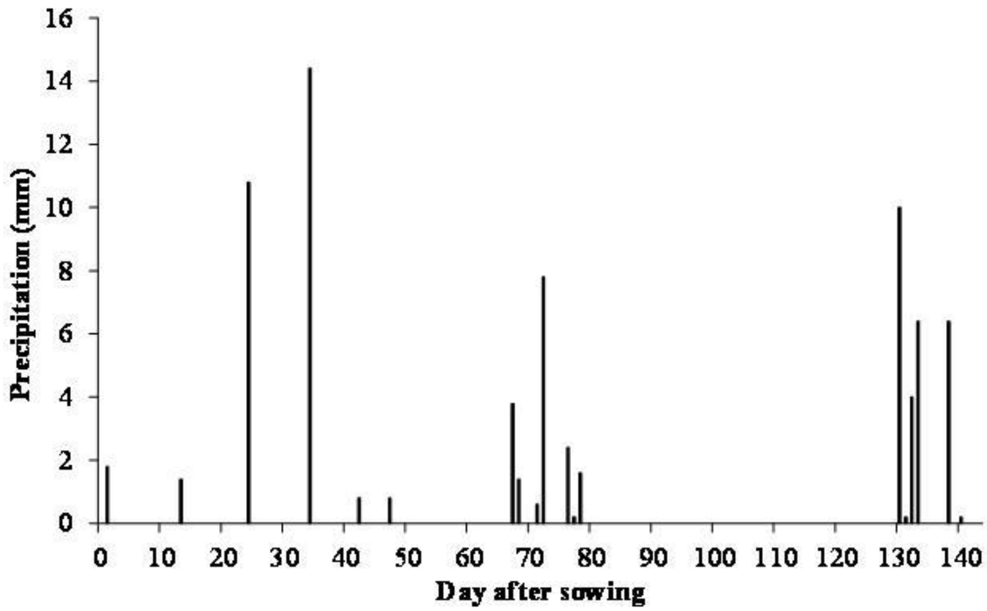

Figure 1. Precipitation in maize growing phase.

As follows: $ET_c=(K_sK_{cb}+K_e)ET_0$ (1)

Where K_s is water stress coefficient, K_{cb} is the basal crop coefficient, K_e is the soil evaporation coefficient, and ET_0 is the reference crop evapotranspiration. The FAO Penman Monteih method was used to estimate the ET_0 in the study (Allen et al., 1998):

$$ET_0 = \frac{0.408\,\Delta(R_n - G) + \gamma \frac{900}{T + 273} U_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34U_2)} \quad (2)$$

Where; R_n is the radiation at the crop surface (MJ m^{-2} day^{-1}); G is the soil heat flux density; T is the mean daily air temperature at 2 m height (°); U_2 the wind speed at 2 m height (m s^{-1}); e_s and e_a are the saturation vapor pressure (kPa) and the actual vapor pressure (kPa); Δ is the slope of the saturation vapor pressure-temperature curve ($kPa°^{-1}$); and γ is the psychrometric constant ($kPa°^{-1}$).

The basal crop coefficient (K_{cb}) is defined as the ratio of ET_c to ET_0 when the soil surface is dry but transpiration is occurring at a potential rate, that is, water is not limiting transpiration (Allen et al., 1998). The values of K_{cb} of maize used the recommended values (0.15, 1.15, and 0.5, respectively, in the initial, mid-season, and late season stages) and were adjusted using the following equation:

$K_{cb}=K_{cb(tab)}+[0.04(U_2\text{-}2)\text{-}0.004(RH_{min}\text{-}45)](h/3)^{0.3}$ (3)

Where; $K_{cb\ (tab)}$ is the value of K_{cb} taken from Table 17 of FAO-56 (Allen et al., 1998); RH_{min} the mean value for daily minimum relative humidity; h is the mean plant height.

The soil evaporation coefficient (K_e) described the evaporation component of ET_c. K_e is maximal when the topsoil is wet, following rain or irrigation. When the soil surface is dry, K_e is small and even zero when no water remains near the soil surface for evaporation. K_e is expressed as:

$K_e = K_r\,(K_{cmax} - K_{cb})$ (4)

where K_{cb} is the basal crop coefficient, $K_{c\ max}$ is the maximum value of K_{cb} following rain or irrigation, ranges from about 1.05 to 1.30 when using the grass reference ET_0, and is calculated as follows:

$K_{cmax}=max(\{1.2+[0.04(U_2\text{-}2)\text{-}0.004(RH_{min}\text{-}45)]((h/3))^{0.3},K_{cb}+0.05\})$ (5)

K_r is dimensionless evaporation reduction coefficient depending on the cumulative depth of water depleted (evaporated) from topsoil, following rain or irrigation K_r is 1. As the soil surface dries, K_r is calculated as follows:

$$K_r = \frac{TEW - D_{e,i-1}}{TEW - REW} \quad (6)$$

Where $D_{e,i-1}$ is the cumulative depth of evaporation from the soil surface layer at the end of day i-1 (the previous day), TEW is the maximum depth of water and can be evaporated from the soil when the topsoil has been initially completely wetted, and REW is the cumulative depth of evaporation at the end of stage 1. TEW and REW can been taken from Table 19 of FAO-56 (Allen et al., 1998) according to soil characteristic, and $D_{e,i-1}$ can be calculated through daily water balance equation.

K_s is described as the effect of water stress on crop transpiration. For sufficient soil water conditions, where there is no soil water stress, K_s = 1. For soil water limiting conditions, K_s<1, and is calculated as follows:

$$K_s = \frac{TAW - D_i}{(1 - p)TAW} \quad (7)$$

Where; D_r is root zone depletion, TAW is total available soil water in the root zone, and *p* is fraction of TAW that a crop can extract from the root zone without suffering water stress. TAW and *p* can be taken from Table 22 of FAO-56 (Allen et al., 1998) according to soil characteristic and crop, and D_r can be calculated through a daily

Table 1. Irrigation water amounts applied (mm) in different irrigation treatments.

Treatments	Phase I					Phase II					Phase III				Total
	6/8	6/13	6/18	6/24	6/26	7/8	7/19	7/22	7/26	7/31	8/3	8/11	8/15	8/21	
SII		180		135		112.5	112.5		112.5		112.5	112.5		112.5	990
ISI	180		135		112.5	112.5		112.5		112.5		112.5		112.5	990
IIS	180		135		112.5	112.5	112.5		112.5		112.5		112.5		990
SIS		180		135		112.5	112.5		112.5		112.5		112.5		878
III	180		135		112.5	112.5	112.5		112.5		112.5	112.5		112.5	1103

Table 2. Temporal variation of height of maize under different treatments.

Treatments	Date (month/day)					Logistic regression between H and D
	5/27	6/23	7/20	8/19	9/10	
SII	0.2 ± 0.03^{a}	0.91 ± 0.09^{b}	2.15 ± 0.05^{b}	2.2 ± 0.11^{ab}	2.26 ± 0.20^{ab}	$H = \frac{2.4}{1+e^{(6.6-0.10D)}}$
ISI	0.2 ± 0.03^{a}	1.23 ± 0.06^{a}	2.28 ± 0.09^{ab}	2.3 ± 0.11^{ab}	2.32 ± 0.13^{ab}	$H = \frac{2.4}{1+e^{(5.8-0.09D)}}$
IIS	0.2 ± 0.03^{a}	1.20 ± 0.06^{a}	2.35 ± 0.08^{a}	2.39 ± 0.07^{a}	2.42 ± 0.13^{a}	$H = \frac{2.5}{1+e^{(5.9-0.09D)}}$
SIS	0.2 ± 0.03^{a}	0.93 ± 0.03^{b}	2.14 ± 0.11^{b}	2.14 ± 0.19^{b}	2.16 ± 0.11^{b}	$H = \frac{2.2}{1+e^{(7.0-0.11D)}}$

In the same column, values followed by the same letter are not significantly different ($p < 0.05$).

water balance computation for the root zone.

RESULTS AND DISCUSSION

Biological characteristics of maize

Because of the indistinguishing water application in May 27th, the heights and leaf area indexes of maize under different treatments were all same in this phase. Compared with sufficient water application (treatment III), height of maize were lower in treatments SII and SIS in June 23th, July 20th, August 19th, and September 10th (Table 2). Height difference between treatments SIS and III were all significant. Compared with treatment III, leaf area index of maize in treatments ISI and IIS were significantly lower in June 23rd, but the difference was not significant when measured in July 20th and August 19th (Table 3). Leaf area index in treatment ISI were significantly lower than treatment III in July, 20th and August, 19th. Water stress has been shown to reduce leaf area leaf of maize in many studies (Farré and Faci, 2009). In our study, water stress in phase I (S--) has significantly reduced height of maize, and water stress in phase II (-S) has significantly reduced leaf area index of maize. However, water stress in phase III has no significant effect both in height and leaf area index of maize.

Reference crop evapotranspiration (ET_0)

The model (Equation 2) could be used after the calculation of the variables (R_n, Δ, γ, e_s) based on or directly obtained from the meteorological data (U_2, T e_a). Finally, the ET_0 was temporally estimated (Figure 2). In general, ET_0 range from 1.59 to 6.30 mm day^{-1} during maize growing

Table 3. Temporal variation of leaf area index under different treatments.

Treatments	Leaf area index			
	5/27	6/23	7/20	8/19
SII	0.27 ± 0.06[a]	1.4 ± 0.1[b]	3.2 ± 0.5[ab]	3.7 ± 0.2[ab]
ISI	0.27 ± 0.06[a]	2.7 ± 0.3[a]	2.9 ± 0.4[b]	3.5 ± 0.3[b]
IIS	0.27 ± 0.06[a]	2.6 ± 0.1[a]	3.5 ± 0.5[a]	4.2 ± 0.3[a]
SIS	0.27 ± 0.06[a]	1.3 ± 0.3[b]	3.1 ± 0.3[ab]	3.9 ± 0.1[ab]
III	0.27 ± 0.06[a]	2.7 ± 0.3[a]	3.6 ± 0.2[a]	4.3 ± 0.4[a]

In the same column, values followed by the same letter are not significantly different ($p < 0.05$).

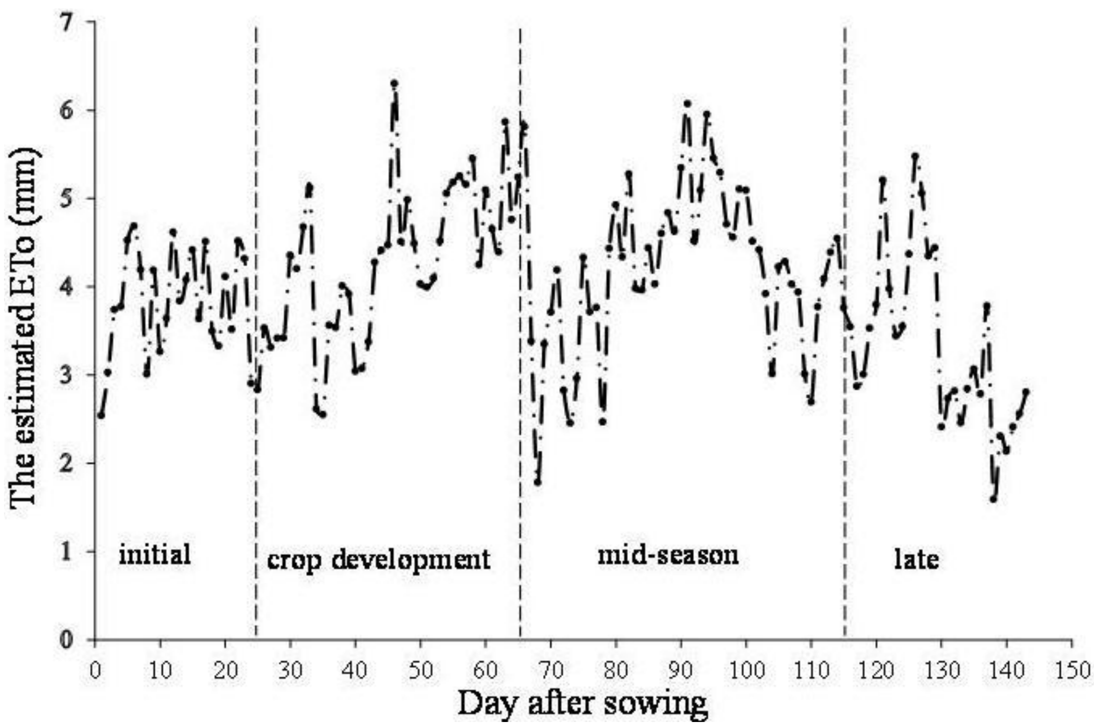

Figure 2. Temporal variation of the estimated ET_0 at the experimental site in 2009.

season. The totals of ET_0 was 570 mm in the entire growing season of maize, and were 95, 172, 210 and 93 mm, respectively in initial stage, crop development stage, mid-season stage, and late stage. Similar result was reported by Zhao et al. (2010). Their result showed that the total ET_0 was 567.5 mm during maize growing season.

Basal crop coefficient (K_{cb}), soil evaporation coefficient (K_e) and water stress coefficient (K_s)

Three point values were required to describe and to construct the crop coefficient curve. After dividing the growing period into four general growth stages and selecting and adjusting the K_{cb} values corresponding to the initial ($K_{cb,\ ini}$), the mid-season ($K_{cb,\ mid}$) and the end of the late season stage ($K_{cb,\ end}$), the crop coefficient curve can be drawn (Figure 3) and the K_{cb} coefficients can be derived. K_{cb} of maize in the initial, mid-season, and late season stages on the conditions of this study were 0.18, 1.21, 0.45, respectively. The K_{cb} was larger than that measured by (Zhao and Nan, 2007) in the start stage, where the differences were most likely to be caused by the high plant and the behavior of climatic conditions. Moreover, the K_{cb} during the mid-season and late-season stage was smaller than that reported by (Zhao and Nan, 2007). This is caused by the short growing stage and early maize harvest compared with the study of (Zhao and Nan, 2007). Although, there were height and leaf area index difference between the different water application treatments, the value of K_{cb} showed no

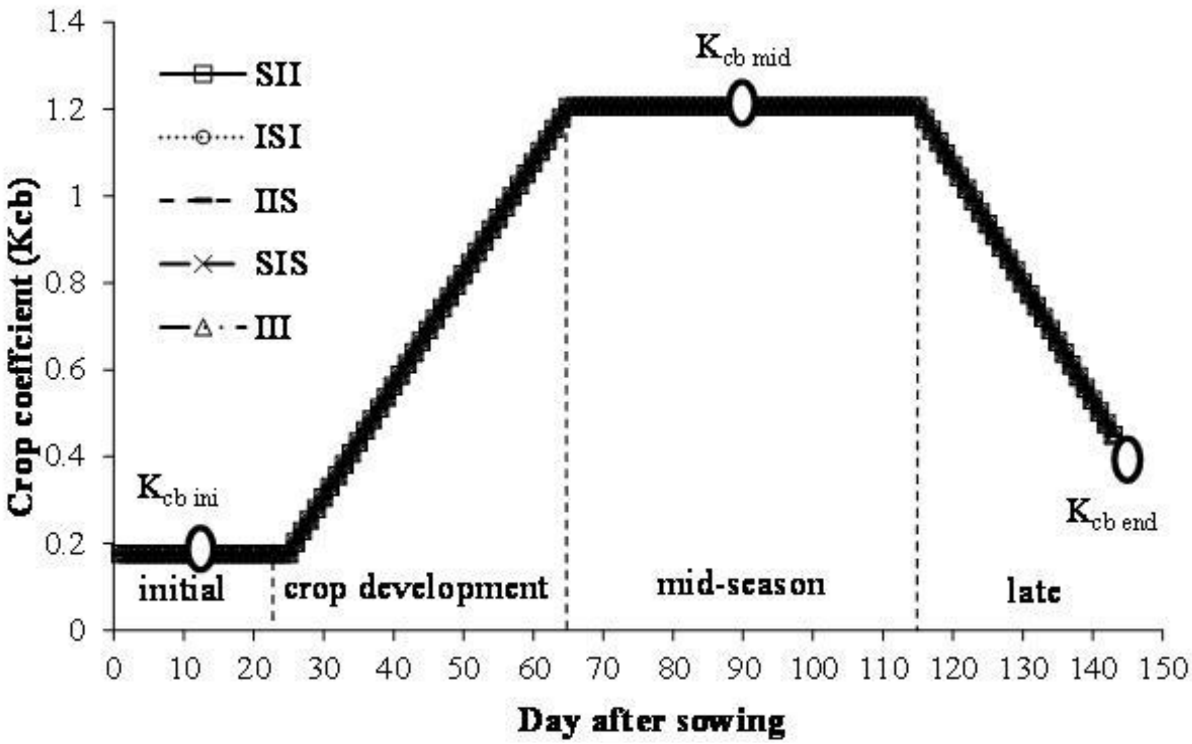

Figure 3. K_{cb} curve of maize under different irrigation treatments.

obvious difference between the different irrigation treatments. This indicated that water stress do not have effect on crop transpiration obviously in this study.

The estimation of K_e in the calculation procedure requires a daily water balance computation for the surface soil layer for the calculation of the cumulative evaporation or depletion from the wet condition. As a result, it can be affected by the precipitation, irrigation, and exposed and wetted soil fraction. Figure 4 shows the variation of K_e in the growing season of maize. In the initial stage, the effective fraction of soil surface covered by maize was small, and thus, soil evaporations were severe and easily influenced by precipitation. Following precipitation, K_e was greater and reached a peak value, and later had a sharp fall because the cumulative depth of evaporation from the topsoil layer was decreasing and water retention capacity of the soil was low. So a peak of K_e was presented. There were no differences on K_e between the different irrigation treatments, because applications of water on maize were not distinguished in this stage. In the crop development stage, the effective fraction of soil surface covered by maize gradually increased, hence, the K_e decreased. Following precipitation, K_e also significantly increased and later sharply decreased. Following irrigation, a peak value was also reached, but due to different irrigation schedule, the peal values in different irrigation treatments appeared in different date. In III, ISI, and IIS treatments, there were two K_e peak values that appeared in June 8th and 18th, but in SII and SIS treatments, there was only one K_e peak value that appeared in June 13th. In the mid-season stage, the effective fraction of the soil surface covered by maize reached 0.9. The soil water losses mainly depended on the crop transpiration. The small exposed soil faction resulted in a small K_e value. Although, there were still different irrigation schedules, the different of K_e between different irrigation treatments were tiny. In the late season, the K_e value was greater than in the mid-season stage because of the drooping of the maize leaves. The K_e peak that appeared in IIS and SIS treatments were early, and the value were low than that in III, ISI, and SII treatments. The effect of soil water stress on ET_c is described by reducing the value for the crop coefficient. This is accomplished by multiplying the crop coefficient by the water stress coefficient. Figure 5 shows the variation of K_s in the growing season of maize. In the initial stage, crops were still not growing up, so soil water decrease has no effect on water taken up by plant roots. Where there is no soil water stress, K_s=1. In the development stage, mid-season stage, and late stage, when the soil is wet, the water has a high potential energy and is relatively free to move and easily taken up by the plant roots. In dry soils, the water has a low potential energy and is strongly bound by capillary and absorptive forces to the soil matrix, and is less easily extracted by the crop. For water deficient treatments, soil water stress limited crop evaporation, Ks < 1. Because of irrigation schedule difference, K_e appeared different in

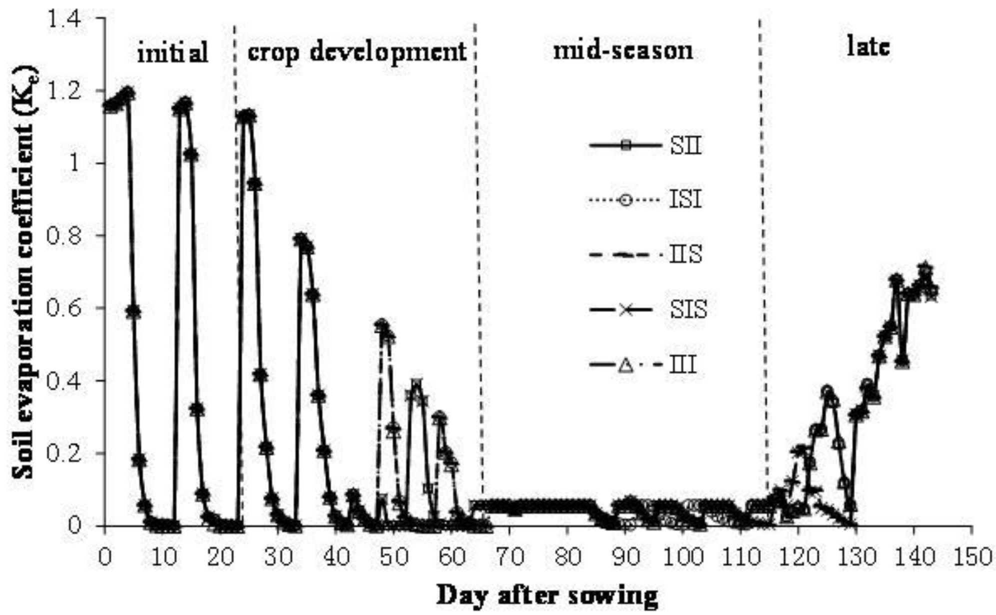

Figure 4. K_e curve of maize under different irrigation treatments.

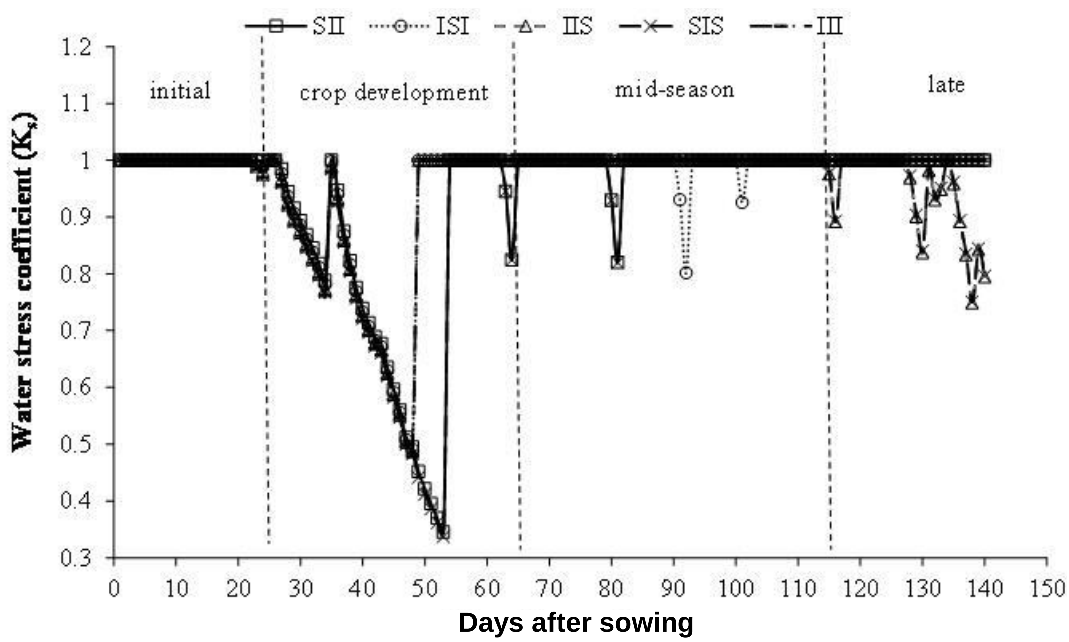

Figure 5. K_s curve of maize under different irrigation treatments.

temporal variation under different irrigation treatments.

Actual crop evapotranspiration

In general, the evapotranspiration (ET_c) values ranged from 0.56 to 7.74 mm day^{-1} (Figure 6). During the initial stage of crop growth, which is the period from sowing through 25 days, the crop is small and water is predominately lost by soil evaporation. So, the ET_c values are very low except during precipitation events in this stage. The ET_c values increases during the crop development stage (25 to 65 days) especially after irrigation events. It reach peak stage during the mid-season stage (65 to 115 days) mainly due to crop completely covering the soil and intensive irrigations

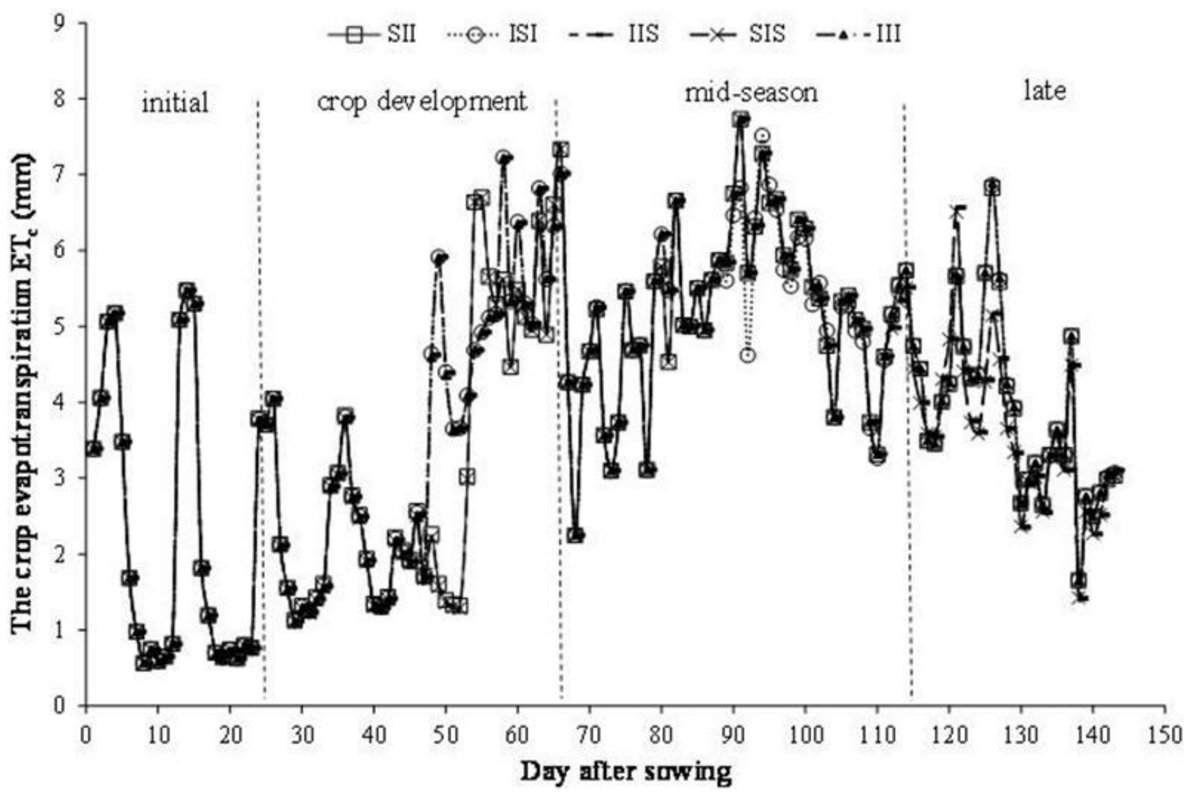

Figure 6. Temporal variation of the estimated ET_c at the experimental site in 2009.

being able to supply water fast enough to satisfy the crop transpiration demand. With crop withered and crop transpiration weakened, the ET_c values decline rapidly during the last crop growth stage, the period from 125 to 143 days. For estimating the calculated result, we measured data through lysimeter to validated evaporation component ($K_e \times ET_0$), correlation coefficient reached 0.78 (Figure 7).

The ET_c in the complete growing season were 570, 604, 579, 542, and 607 mm in treatments SII, ISI, IIS, SIS, and III, respectively. The ET_c was 58 mm in the initial stage of crop. There was no significant difference between the different irrigation treatments, because the irrigation application was all same in this stage. The ET_c under crop development stage was 124 mm in treatments SII and SIS, and was 160 mm in treatments ISI, IIS, and III. Because water stress, ET_c reduced 36 mm in deficit water supply treatments than in sufficient water supply treatments. The totals ET_c under crop mid-season stage were 261, 259, 261, 260, and 262 mm in treatments SII, ISI, IIS, SIS, and III, respectively. There were little differences between deficit and sufficient water supply treatments in this stage. The totals ET_c under crop late stage were 127 mm in treatments SII, ISI, and III, and were 100 mm in treatments IIS and SIS. ET_c reduced 27 mm in deficit water supply treatments than in sufficient water supply treatments.

Yield, harvest index and irrigation water productivity

Final above-ground biomass in treatment III was higher than that in treatments SII, ISI, IIS, and SIS, but there were no significant differences between treatments III and IIS. Grain yield in treatment III was also higher than that in treatments SII, ISI, IIS, and SIS and there was still no significant difference between treatments III and IIS. IWP in different treatment was in sequence of treatment IIS > III > SII > SIS > ISI. IWP in treatment ISI was significantly lower than other treatments. HI in treatment SII was higher than that in other treatments, and the lowest values of HI was reached in treatment ISI (Table 4)

The contrast analysis between treatments with full irrigation (I) and deficit irrigation (S) in the different growth phases provided a better insight into the effect of the irrigation treatments. The contrast analysis showed that deficit irrigation in phase III (--S) did not significantly reduced both final above-ground biomass and grain yield, and increased IWP and HI when compared to full irrigation in the entire growing phase (treatment III). Above-ground biomass and grain yield was significantly reduced in deficit irrigation in phase II, IWP and HI were also significantly low than other treatments. The period around flowering has also been reported to be the most sensitive to water deficit in maize in numerous studies (Farré and Faci, 2009). Deficit irrigation in phase I

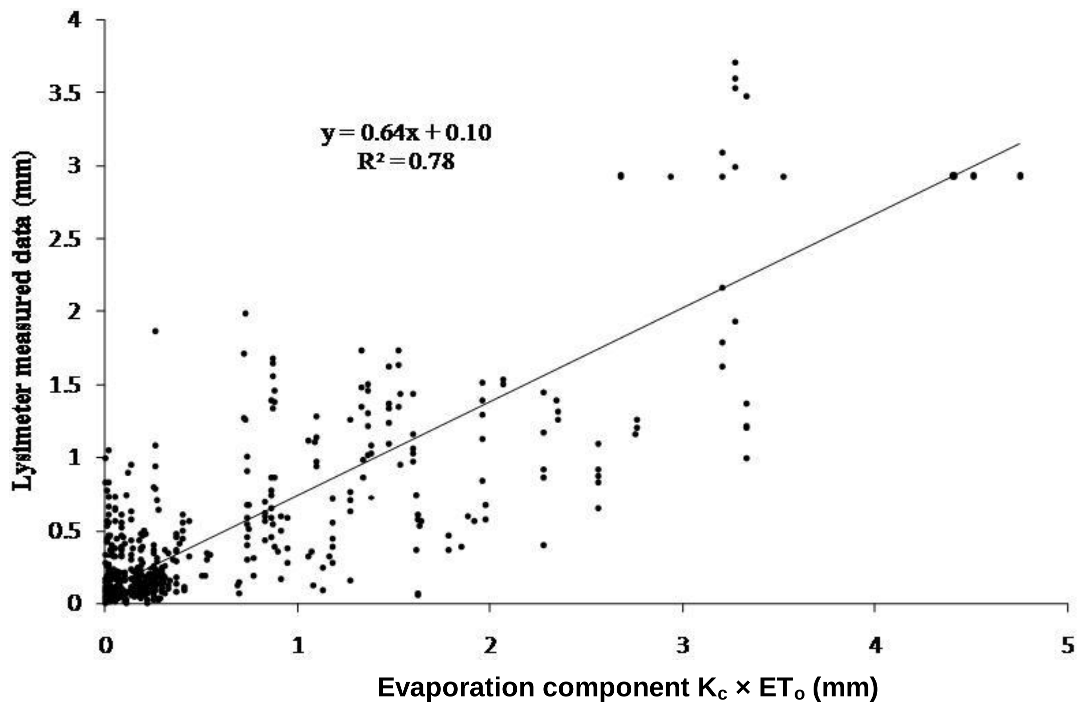

Figure 7. Comparison between the evaporation component and lysimeter measured data.

Table 4. Above-ground biomass (AGB), grain yield, Irrigation water productivity (IWP), and Harvest index (HI) in the different irrigation treatments.

Treatments	AGB (kg/hm2)	Yield (kg/hm2)	IWP (kg/m3)	HI
SII	19388 ± 1664[b]	8824.7 ± 206.0[b]	1.42 ± 0.02[a]	0.46
ISI	17797 ± 1663[b]	7548.1 ± 197.4[c]	1.14 ± 0.03[b]	0.42
IIS	21592 ± 1953[ab]	9551.8 ± 380.8[ab]	1.45 ± 0.06[a]	0.44
SIS	18889 ± 1414[b]	8316.9 ± 146.0[bc]	1.34 ± 0.04[a]	0.44
III	24850 ± 1797[a]	10283.7 ± 120.6[a]	1.40 ±0 .01[a]	0.43

In the same column, values followed by the same letter are not significantly different ($p < 0.05$).

(treatment SII) reduced above-biomass and grain yield compared with full irrigation treatment (III), but increase HI. Deficit irrigation in both phase I and phase III reduced above-biomass and grain yield compared with full irrigation treatment (III), however, amount of irrigation water in whole growing phase was reduced significantly as compared to full irrigation treatment (III).

Conclusions

Results indicated that at the sandy farmland in Linze town of Gansu Province, Northwest China, deficit irrigation effect crop development, evapotranspiration, and yield of maize obviously. Water stress in phase I (S--) has significantly reduced height of maize, and water stress in phase II (-S-) has significantly reduced leaf area of maize. Water stress in phase III (--S) has no significant effect both in height and leaf area of maize. Water stress has no obvious effect on K_{cb}. Different irrigation schedules between different treatments affect the dynamic variation of K_e and K_s. It leads to evapotranspiration difference in different maize growing phase. Deficit irrigation in phase II has no obvious effect on ET_c. Deficit irrigation in phases I and III obviously reduced ET_c of maize. It can be seen that it was not possible to apply deficit irrigation created by increasing the interval between irrigations around flowering without incurring significant yield penalties. On the other hand, deficit irrigation or higher interval between irrigations during the grain filling phase did not reduce significantly the crop growth and yield, and IWP was significantly increased compared with fully irrigation. Based on the results, we can conclude that it is possible to implement deficit irrigation strategies for reducing agricultural water consumption by increasing the interval between irrigations during the periods other than around flowering.

ACKNOWLEDGMENTS

This work was supported by The National Basic Research Program of China (no. 2009CB421302) and Foundation for Excellent Youth Scholars of CAREERI, CAS (51Y084881).

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