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SOIL MOISTURE, ELECTRIC CONDUCTIVITY AND TEMPERATURE DYNAMICS AND MAIZE GROWTH UNDER ALTERNATE FURROW IRRIGATION

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ABSTRACT To investigate the effect of alternate furrow irrigation (AFI) on water saving and yield in northeastern China, a field experiment was carried out to study the dynamics of soil water, electric conductivity temperature, grain yield and water use efficiency (WUE) of maize with AFI in Shenyang region in 2005. Field experiment comprised of three treatments: CFI (conventional furrow irrigation), AFI1 and AFI2. Results showed that AFI had more space for lateral seepage of soil water and lower evaporation loss. Higher irrigation amount of single furrow in AFI treatment decreased surface soil electric conductivity, i.e. surface soil temperature was higher in AFI treatment, especially in non-irrigated furrow and ridge, which was beneficial for crop growth at the seedling stage. AFI2 increased WUE and grain yield by 22.2% and 4.8%, respectively. Although AFI1 improved WUE by 28.5%, it significantly decreased grain yield. Therefore, the AFI with appropriate irrigation quota (AFI2) can increase both grain yield and WUE and achieve water saving and yield increasing simultaneously.

Keywords: alternate furrow irrigation, maize, electric conductivity, temperature, water use efficiency

INTRODUCTION Currently, surface irrigation is still the main irrigation method and accounts for 90 percent of global irrigation area (Crevoisier *et al*. 2008). In China, surface irrigation even accounts for 98 percent of national irrigation area. Furrow irrigation and border irrigation are mostly adopted for main dry land crops such as wheat, maize and cotton (Li *et al*. 2003). Surface irrigation can achieve higher water use efficiency (WUE) with better management (Kang 1991; Maihol 2007). Facing the scarcity of water resources and lower efficiency of irrigation water, new surface irrigation such as deficit irrigation, limited irrigation and regulated deficit irrigation had been conducted by many experts to improve grain yield and WUE simultaneously, but these irrigation methods only considered optimal water allocation timely and did not take optimal distribution of irrigation water in crop root zone, regulation function of abscisic acid (ABA) on leaf stomatal aperture and WUE into account. Therefore, based on physiological function of the integrated effect of crop roots and ABA theory on WUE improvement, alternate partial root zone irrigation (APRI) was proposed with relationship between photosynthesis, transpiration and stomatal aperture by Kang *et al*. (1997), which improved the traditional furrow irrigation. Many studies on wine grape (De souza *et al*. 2003), tomato (Zegbe *et al*. 2004), soybean (Wakrim *et al*. 2005), cotton (Du *et al*. 2006) and potato (Shahnazaria *et al*. 2007) with alternate furrow irrigation (AFI) were carried out in recent years. The results showed that AFI was a promising water-saving irrigation method. Du *et al.* (2006) indicated that AFI increased cotton yield and WUE, and it respectively increased cotton WUE by 17.2% and 18.6% when compared to CFI (conventional furrow irrigation) and FFI (fixed furrow irrigation). Du *et al*.(2008) studied on table grape irrigated with ADI (alternate drip irrigation), and indicated that ADI reduced irrigation water, improved WUE and fruit quality without detrimental effect on yield. Liang *et al.* (2000) pointed out that AFI significantly reduced evaporation loss and improved irrigation water efficiency, saved water by 33.3% without detrimental effect on maize yield. Pan *et al.* (2000 and 2002) also indicated that AFI could save water by 33.3% and reduce deep percolation.

Since AFI was proposed, many researchers mainly focused on the effects of AFI on grain yield and WUE, but furrow irrigation had certain influences on soil salt and energy budget in surface soil (Xie *et al.* 1997□. Soil electric conductivity could represent salt content in the soil (Liu *et al*.2001). Plenty of radiation heat was dissipated during water evaporation, surface soil characteristics affected radiation absorption (Wang 2000). Soil heat with furrow irrigation was affected by meteorological factors such as wind direction (Yang 1996). Ren *et al*. (2008) showed that furrow irrigation significantly increased soil temperature, which promoted maize growth. Li *et al.* (2001) indicated that surface soil temperature and nutrient use efficiency were improved with suitable proportion of furrow to ridge under furrow irrigation. Up to now, there are few studies on surface soil electric conductivity and energy budget with AFI.

Therefore, maize, as one of main food crop in northeastern China, was selected as an experimental crop. The objectives of this study were to: (1) investigate the distribution of soil water, electric conductivity and temperature with AFI, and analyze water use and consumption, and variation of electric conductivity resulted from water transfer with AFI; (2) investigate the effect of AFI on maize growth, grain yield and WUE.

MATERIALS AND METHODS

Experimental site description Experiment was conducted from June to September in 2005 in an experimental field of Water Conservancy College of Shenyang Agricultural University (N 41°44′, E 123°27′, altitude 44.7 m). Climatic records in maize growing season in the region yielded the maximum temperature of 32.2 □, the minimum temperature of 6.4 □, and the mean temperature of 21.6 □, the sunshine duration of 815 h and rainfall of 595.5 mm. The soil is classified as brown soil, with the bulk density of 1.38 g cm^{-3}, the field capacity of 0.33-0.41 cm^3 cm^{-3}, and PH-value of 7.9. The soil was sampled for the 0-30 cm depth before sowing in 2005 with 10.75 g kg^{-1} soil organic matter, 60.84 mg kg^{-1} available N, 48.10 mg kg^{-1} available P and 140.84 mg kg^{-1} available K. The water table was about 4.8 m during the experimental period.

Experimental design The experiment comprised of three treatments with three replications. Three treatments included CFI (conventional furrow irrigation, CFI), alternate furrow irrigation (AFI1 and AFI2). Irrigation quota of each treatment was shown in Table 1.

Table 1 Irrigation quota of each treatment

Treatment	Before jointing		Jointing-tasseling		After tasseling	
	Irrigation quota (m^3/hm^2)	Irrigation for single furrow (m^3)	Irrigation quota (m^3/hm^2)	Irrigation for single furrow (m^3)	Irrigation quota (m^3/hm^2)	Irrigation for single furrow (m^3)
CFI	300	0.018	450	0.027	500	0.030
AFI$_1$	150	0.018	225	0.027	250	0.030
AFI$_2$	200	0.024	300	0.036	330	0.040

The lower limit of irrigation was 65% of the field capacity. Maize needed to be irrigated when soil water content at the root zone of the ridge reached to the lower limit. Field experiment was conducted in cuboid lysimeters under a movable rain shelter. Length, width and depth of the lysimeters are 1.2 m, 1.0 m and 1.0 m, respectively. Ridge planting and furrow irrigation were adopted in the lysimeters with north-south direction. The cross section was trapezoidal, and the dimension was shown in Fig. 1. In each lysimeter, 4 plants of maize (*Zea mays* L. cv. Shenyu 17□1.2 plants m^{-2}) were planted on May 28, 2005 and harvested on September 28, 2005. The row spacing is 60 cm and the plant spacing is 40 cm.

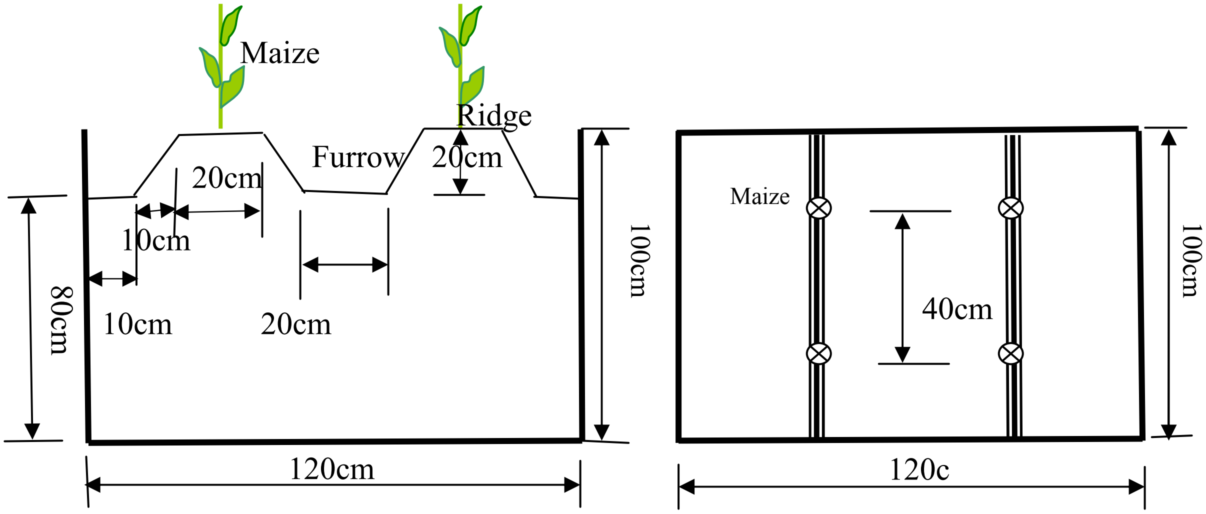

Fig. 1 Profile diagram of the lysimeter (a) and lay out of maize (b) in the lysimeter

Measurements

<u>Soil water content and electric conductivity</u> Soil water content (θ) was measured with time domain reflector (TDR) every six days. TDR access tubes were located in the irrigation furrow and ridge of CFI treatment, respectively. For AFI1 and AFI2 treatment,

the tubes were located in the irrigated furrow, ridge and non-irrigated furrow, respectively. Soil water content were measured every 20 cm in 20-80 cm soil layer. The surface soil water content and electric conductivity in 0-20 cm soil layer were measured by probe type TDR (10 cm).

Surface soil temperature Surface soil temperatures were measured using the portable infrared thermometer. Soil temperatures of furrow and ridge in each location were measured four replications, and then mean values were calculated.

Soil evaporation and evapotranspiration Soil evaporation (E) was measured by micro-lysimeter with inner and outer tubes. The tube was made of iron sheet of galvanize with 1 mm thickness. The diameter of the inner tube had two types: 10 cm and 8 cm. The corresponding diameters of the outer tube were 12 cm and 10 cm, respectively. The former was placed in furrow and the latter in ridge. Replacement of soil core and weight was performed at 16:00 everyday.

Evapotranspiration (ET) is estimated based on soil water balance equation as follows (Hillel 1998):

$$ET = P_e + I + U - R - D_w - \Delta S \tag{1}$$

Where, ET is crop evapotranspiration (mm), ΔS the change of soil water stored in 0-80 cm soil layer (mm), P_e the effective precipitation (mm), determined by USDA soil conservation services method, I irrigation quota (mm), U the upward capillary flow into the root zone (mm), R the runoff (mm), D_w the downward drainage out the root zone (mm).

The upward and downward flow estimated using Darcy's law (Kar *et al*. 2007; Medeiros e*t al*. 2005) indicated that the two items were negligible at the experimental site. Runoff was also negligible because of lower irrigation quota and sheltering from rainfall during the growing season.

Growth index, yield and yield components Leaf length, leaf width, plant height and stem diameter after emergency were measured using the ruler at 7-10 days intervals. Two plants were sampled in each plot. Leaf area was determined by following formula: leaf area = leaf length × the greatest leaf width × 0.75 (Zhang *et al*. 2006).

Three representative plants for each treatment were selected at the commencement of filling stage. Ten seeds, sampled in one row of the ear at each sampling, were taken from the ear of the samples at four days intervals, After sampling, the ear was wrapped carefully, so that effects of sampling on other seeds were reduced. The seeds were dried at 80℃ to constant dry weight.

At harvesting, eight plants were selected to measure grain weight per ear, 100-seed weight, ear length, bare top length, ear diameter, row number per ear, and so on for each treatment.

Water use efficiency and harvest index Water use efficiency (WUE) can be calculated as follows:

$$WUE = \frac{Y_{grain}}{ET} \tag{2}$$

$$WUE_{biomass} = \frac{Y_{biomass}}{ET} \tag{3}$$

Harvest index (HI) is calculated as follow:

$$HI = \frac{Y_{grain}}{Y_{biomass}} \tag{4}$$

where, Y_{grain} is grain yield at harvest (kgm^{-2}), $WUE_{biomass}$ water use efficiency by crop biomass (kgm^{-3}),$Y_{H\text{-}biomass}$ biomass at harvest (kgm^{-2}), ET total actual evapotranspiration over the growing season (mm).

Data analysis Data were analyzed with SAS (Statistical Analysis System) soft package (SAS Institute, 1999), and significance test was conducted with LSR (least significant range test) method.

RESULTS

Dynamics of soil water, electric conductivity and temperature

Soil water content dynamic in the profile Soil water content (θ) at jointing stage was chosen to analyze soil water dynamic in the irrigation furrow after the irrigation (Fig. 2).

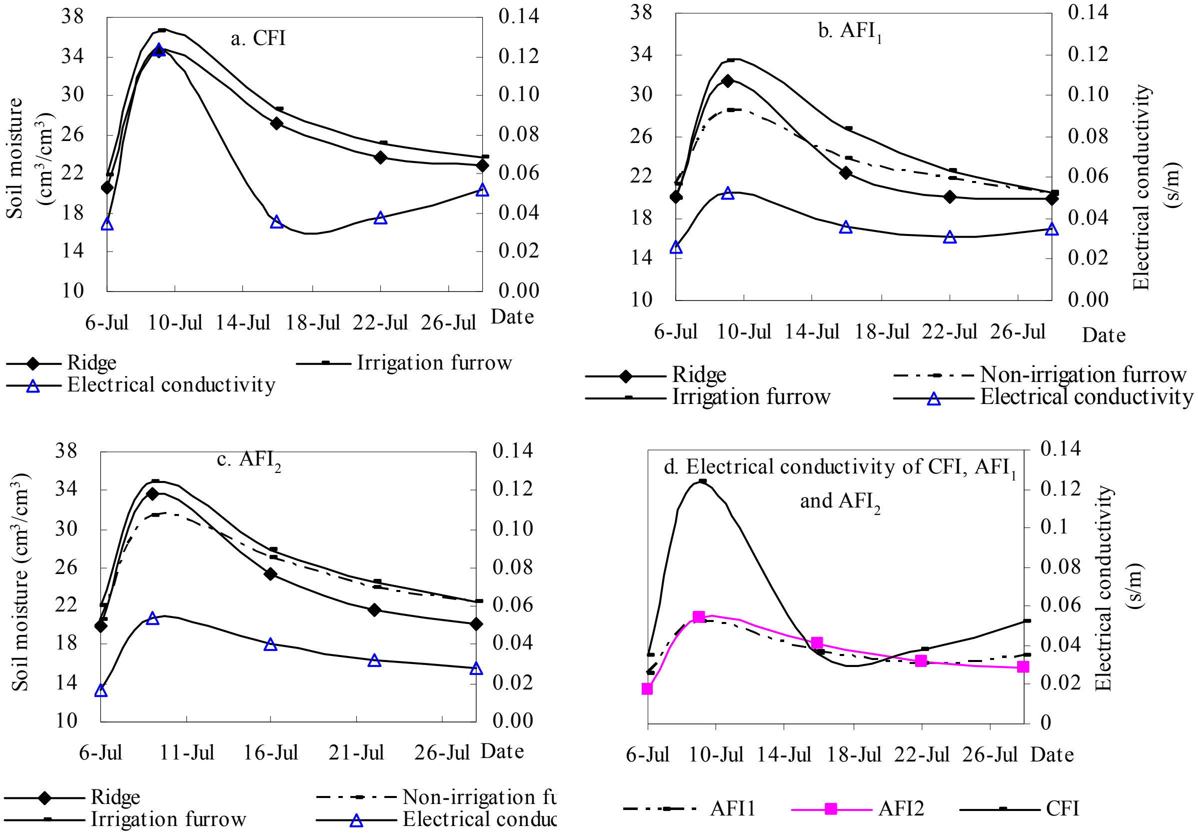

Fig. 2 Changes of soil water content and electric conductivity at surface soil layer (0-10 cm)

Soil water movement and redistribution occurred in the irrigation furrow within 20 days after the irrigation. Soil depth with maximal water content in the profile was different at the 1st day after irrigation, AFI at the 0-10 cm and CFI at 40-60 cm soil layer. Irrigation water can move to the dry area in AFI plot because of lateral infiltration. Because two adjacent furrows in the CFI plot were irrigated, water was rapidly moved to the deep layer because of lower soil water potential. At the 1st day after irrigation, the depth of the wet front was 40-60 cm for CFI and AFI2 treatments and 20-40 cm for AFI1 treatment. At the 8th day after irrigation, the depth with maximal water content was 60-80 cm. Soil water content was gradually decreased due to the evaporation and root uptake. At the 20th day after irrigation, the average soil water content in the whole profile of CFI treatment was 26.4%, while that of AFI treatment reached to the lower limit of irrigation□Fig.3□.

Seeing from the dynamic of averaged water content in the soil profile, from the 1st day to the 20th day after irrigation, soil water content varied from 38.1% to 26.4% in CFI, 32.9% to 24.1% in AFI_2 and 31.1% to 23.8% in AFI_1. Therefore, CFI can maintain higher soil water content after irrigation, but its soil water content varied greatly at each time interval. Soil water content in AFI varied slightly at each time interval, especially at 60-80 cm soil layer.

Soil electric conductivity dynamic in surface soil layer Soil electiric conductivity at 0-10 cm layer at the jointing stage was chosen to analyze the change of soil electiric conductivity within 20 days after irrigation. Soil electiric conductivity was firstly higher and then decreased to be relatively constant with the change of soil water and the peak soil electiric conductivity occurred at the 3rd day after irrigation for all water treatments. Soil electiric conductivity in the AFI1 and AFI2 treatments varied slightly during the measurement period. The electric conductivity in the CFI treatment was higher than those of AFI1 and AFI2 treatments.

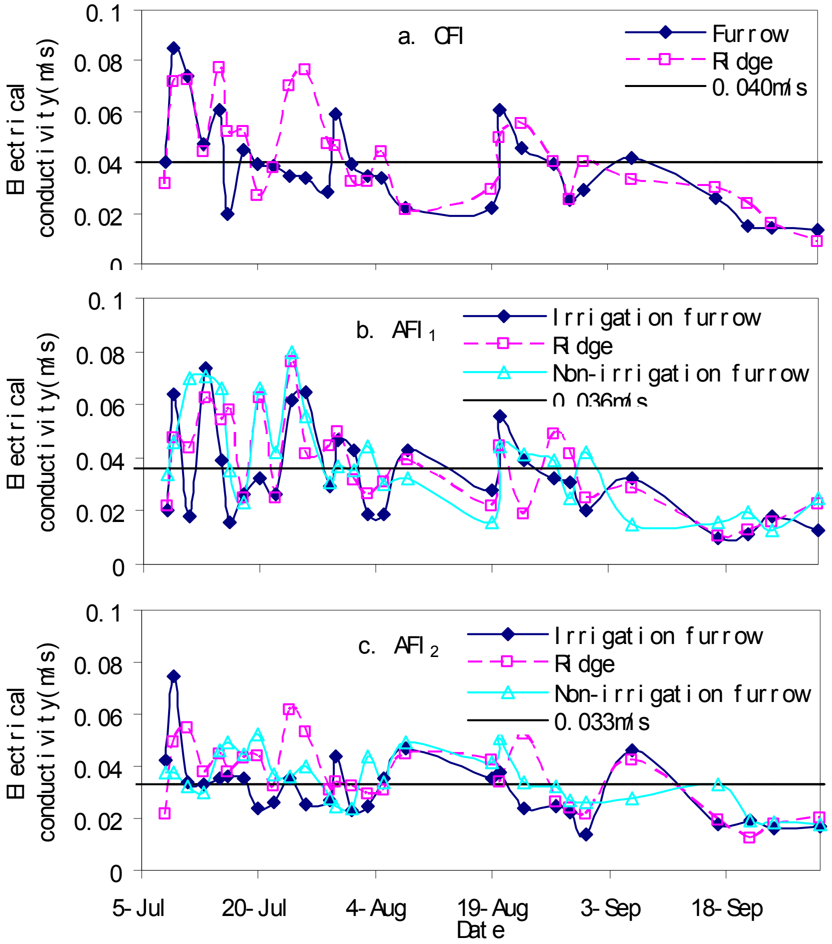

Fig. 3 Soil water content of CFI (a), AFI_1 (b) and AFI_2 (c)

In the CFI treatment, the electric conductivity of the irrigation furrow was the maximum at the 1st day after irrigation. Occurrence of the maximal electric conductivity in the ridge lagged behind in the furrow, the electric conductivity in the ridge reached its maximum value at the 4th to 6th day after irrigation, thus soil salt content in the ridge was higher than that of the furrow. Average electric conductivities of both ridge and furrow were 0.043 and 0.037 sm-1 over the whole growing season, respectively.

In the AFI_2 treatment, the maximum electric conductivities occurred at the 1st, 4th and 7th day after irrigation for the irrigated furrow, ridge, and non-irrigated furrow, respectively. After the maximum value, soil electiric conductivity in each site gradually decreased to be constant. Average electric conductivities during the whole growing season were 0.031, 0.036 and 0.035 sm^{-1} for the irrigated furrow, ridge and non-irrigated furrow, respectively

Variation of soil electric conductivities in AFI_1 was similar to that of AFI_2. Average electric conductivities over the whole growing season was 0.033, 0.037 and 0.039 sm^{-1} for the irrigation furrow, ridge and non-irrigation furrow, respectively (Fig.4).

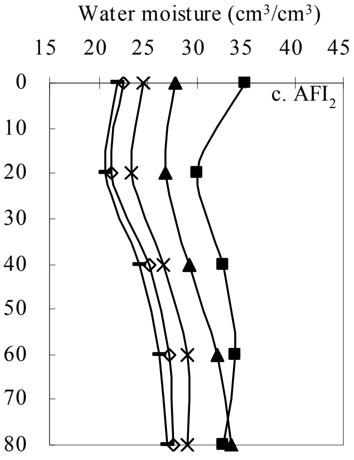

Fig. 4 Changes in electric conductivity and mean values at different sites of each treatment

Dynamic of surface soil emperature Variation of temperature over surface soil Variation of temperature over surface soil in the irrigated furrow, ridge and non-irrigated furrow and mean soil temperatures of all irrigation treatments were shown in Fig.5, respectively. Mean soil temperature of each treatment was in order of CFI<AFI_2<AFI_1. And mean soil temperatures over the whole growing stage were 24.21□ and 25.22□ for the furrow and ridge of the CFI treatment, 25.21 □, 25.85□ and 25.86 □, and 25.64□, 26.20□ and 26.34 □ for the irrigated furrow, ridge and non-irrigated furrow of AFI_2 and AFI_1, respectively.

Soil temperature in the irrigated furrow reduced after irrigation. In the CFI treatment, the difference in mean soil temperature between the furrow and ridge was about 1. In the AFI_2 treatment, the difference in mean soil temperature was 0.64 between the furrow and ridge, and 0.65 between the irrigated and non-irrigated furrows, respectively. In the AFI_1 treatment, the difference in mean soil temperature was 0.56 between the furrow and ridge, 0.70 between the irrigated and non-irrigated furrows, respectively. Thus AFI can increase soil temperature, but reduce the difference of soil temperature between the furrow and ridge when compared to CFI.

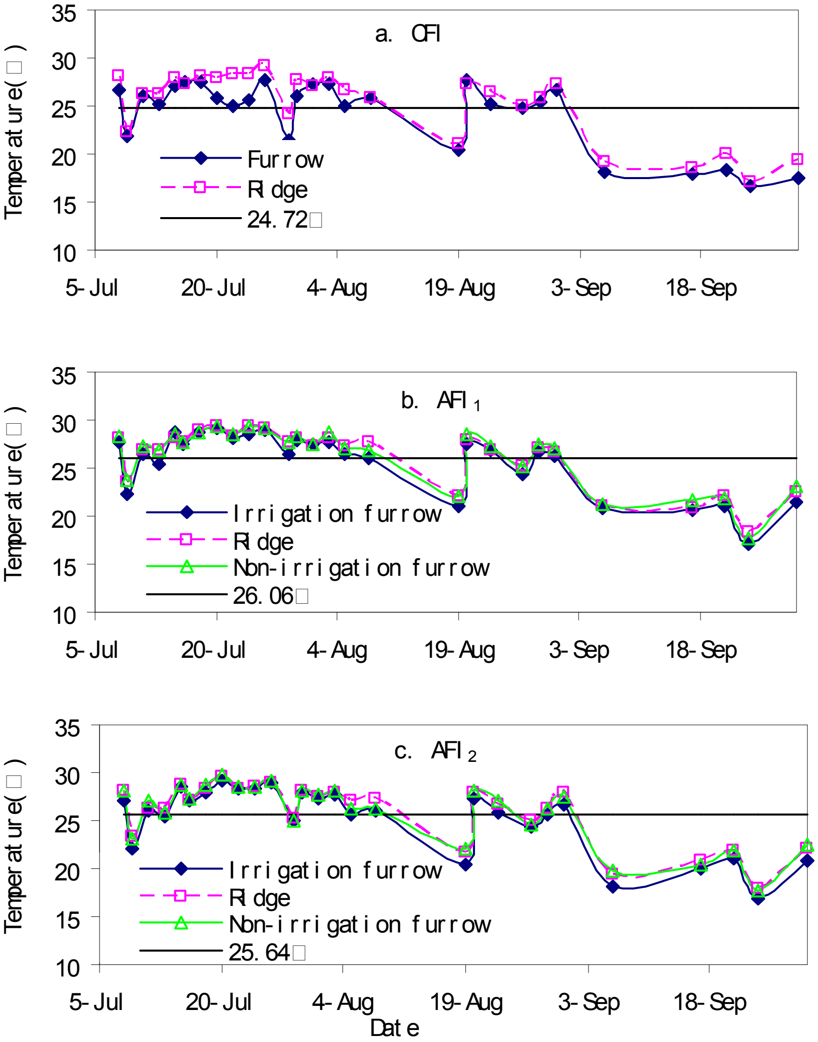

Fig. 5 Changes in soil temperature and mean values at different sites of each treatment

SOIL EVAPORATION Soil evaporation and irrigation quota of each treatment were shown in Fig. 6. Total irrigation over the whole growing season was 373 mm, 248 mm and 314 mm for the CFI, AFI1 and AFI2 treatments, respectively. And total soil evaporation over the whole growing season was 81.6 mm, 42.9 mm and 55.8 mm for CFI, AFI1 and AFI2, respectively, indicating that AFI can reduce soil evaporation.

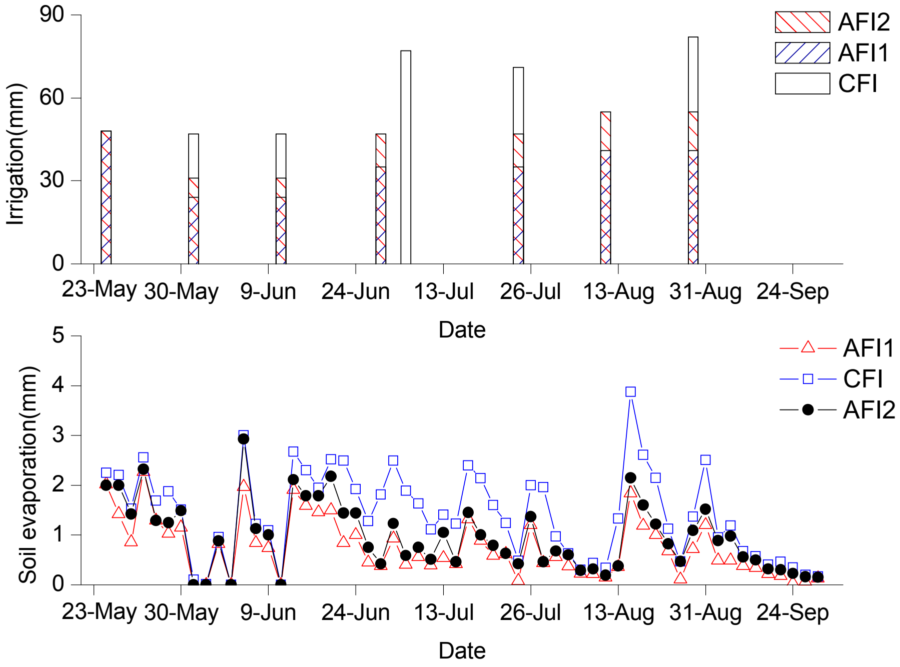

Fig. 6 Soil evaporation and irrigation of each treatment

Soil evaporation over the growing season was influenced by many factors, e.g. crop canopy, meteorological factors and soil water content. In order to eliminate the effect of meteorological factors on soil evaporation, the relative soil evaporation intensity, E/ET, was introduced to substitute soil evaporation. ET was the reference crop evapotranspiration, estimated using Penman-Monteith equation recommended by FAO (Allen *et al*. 1998). The E/ET increased with the increasing θ for all irrigation treatments, which was in order of $AFI_2 > AFI_1 > CFI$. Based on the measured data, the relationships between E/ET and θ can be expressed exponentially as follows:

$$\text{CFI:}\quad E/ET = 0.0016e^{10.800\theta},\ R^2 = 0.7493 \qquad (5)$$

$$\text{AFI}_2\text{:}\quad E/ET = 0.0095e^{5.686\theta},\ R^2 = 0.7127 \qquad (6)$$

$$\text{AFI}_1\text{:}\quad E/ET = 0.0004e^{17.242\theta},\ R^2 = 0.8228 \qquad (7)$$

where, ET is the reference crop evapotranspiration (mm), θ soil water content (cm^3cm^{-3}).

LAI had less effect on E/ET in CFI than that of AFI. The relationships between E/ET and LAI can be expressed in the negative exponential function as follows:

$$\text{CFI:}\quad E/ET = 0.0727e^{-0.2897LAI},\ R^2 = 0.8203 \qquad (8)$$

$$\text{AFI}_2\text{:}\quad E/ET = 0.0571e^{-0.2757LAI},\ R^2 = 0.9594 \qquad (9)$$

$$\text{AFI}_1\text{:}\quad E/ET = 0.1301e^{-0.3788LAI},\ R^2 = 0.7745 \qquad (10)$$

MAIZE GROWTH AND DEVELOPMENT Changes in stem diameter, plant height and LAI over the whole growth stage were showed in Table 2. Leaf growth speed, leaf length and width mainly depended on the division and extension of cells that were affected by soil water (Xin 1992). During the vegetative growth stage (before July 3), the stem diameter, LAI and plant height were significantly increased. After the vegetative growth stage, the growth indices went successively into the stable growth stage. At the maturity stage, AFI2 was the greatest stem diameter, while AFI1 was the lowest. And CFI had the greatest plant height and LAI. The growth rate of stem diameter in CFI lagged behind that of AFI, indicating that AFI was beneficial for strong seedling and lodging resistance. The CFI treatment had greater plant height and leaf area, but AFI was helpful for controlling the redundant growth.

Table 2 Plant height, stem circumference and leaf area index of each treatment

Date	Plant height (cm)			Stem circumference (cm)			LAI (cm)		
(dd/mm)	CFI	AFI$_1$	AFI$_2$	CFI	AFI$_1$	AFI$_2$	CFI	AFI$_1$	AFI$_2$
06/06	13.2 a	13. 2 a	13. 2 a	2.3 a	2.3 a	2.3 a	0.1 a	0.1 a	0.1 a
14/06	28.33 a	27.9 a	28.3 a	4.0 a	3.8 b	3.9 ab	0.3 b	0.4 a	0.3 b
20/06	58.77 a	61.9 a	59.3 a	6.2 c	7.5 a	6.9 b	0.7 b	0.9 a	0.9 a
27/06	72.0 b	73.4 b	82.0 a	10.0 a	9.5 b	9.2 b	2.1 a	2.2 a	2.1 a
03/07	88.8 b	89.7 b	92.6 a	11.0 a	10.6 b	11.1 a	3.2 b	3.4 a	3.3 ab
16/07	190.2 a	176.4 c	182.6 b	11.1 a	10.6 b	11.2 a	6.4 a	5.8 b	6.3 a
24/07	258.0 a	249.6 bc	255.0 b	11.1 a	10.7 b	11.3 a	6.7 a	6.4 b	6.5 ab
08/08	264.6 a	259.7 b	263.8 a	11.2 b	10.8 c	11.4 a	7.1 a	6.6 c	6.7 b
27/08	270.7 a	260.7 c	266.0 b	11.2 b	10.8 c	11.4 a	7.1 a	6.7 b	6.9 ab

Different small letters (a, b, c) in the same column indicate significant difference at $P_{0.05}$ level.

Crop reproductive growth and senescence were affected by water stress. The filling speed of maize firstly increased, then decreased for all irrigation treatments, and CFI firstly reached the maximum value. AFI$_2$ had higher filling speed than CFI, and AFI$_1$ had the lowest filling speed. The average filling speed was 0.091, 0.092 and 0.084 g day^{-1} for CFI, AFI$_2$ and AFI$_1$. Changes of yellow leaves per plant during the growing season were shown in Fig. 7(b). AFI$_2$ had the lowest yellow leaves per plant, but AFI$_1$ had the highest.

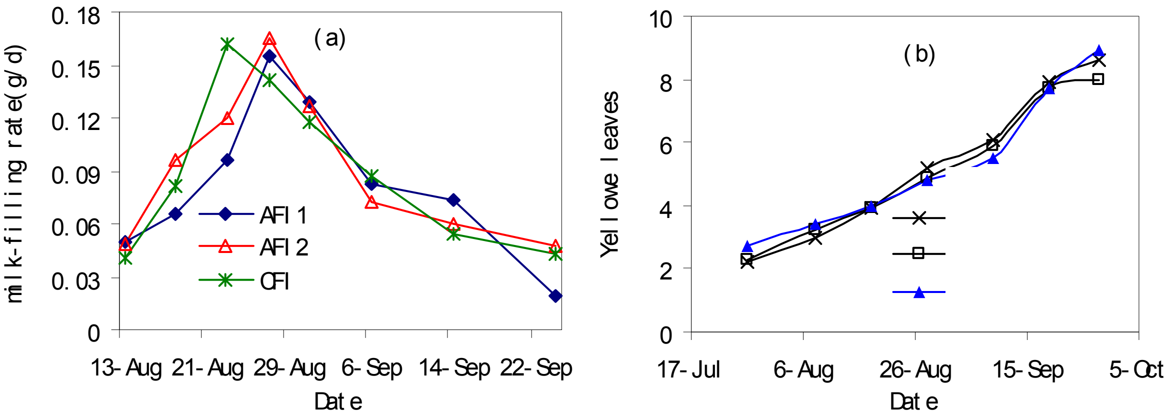

Fig. 7 Effect of different irrigation treatments on the progress of milk-filling rate (a) and leaf senescence rate (b) of maize

MAIZE YIELD COMPONENTS AND YIELD Compared to AFI_1 and CFI, AFI_2 significantly increased the 100-seed weight and yield (Table 3). The ear length, grain number per plant, seed weight per plant, core weight per plant, 100-seed weight and yield in AFI_1 were significantly lower than those of AFI_2. Compared to CFI, AFI_2 increased grain yield of maize by 4.7%, and AFI_2 and AFI_1 increased harvest index (HI) by 8.5% and 5.2%, respectively, indicating that AFI can improve grain output ratio.

Table 3 Maize yield, yield components and HI of each treatment

Treat-ment	Ear length (cm)	Ear circumfere-nce (cm)	bald head length (cm)	Ear rows (rows)	Row grains	Grain number per spike
CFI	23.4 aAB	18.6 A	2.3 bB	15.6 A	44.9 aA	700.8 aA
AFI_2	23.9 aA	19.6 A	2.9aAB	16.5 A	42.7 aAB	704.9 aA
AFI_1	22.4 aB	18.7 A	3.3 aA	15.5 A	40.3 aB	624.7 aB

Treat-ment	Grain weight per plant (g)	Ear axsis weight per plant (g)	100-seed weight (g)	Y_{grain} (kg/hm^2)	$Y_{biomass}$ (kg/hm^2)	HI
CFI	272.3 aAB	34.6 aAB	39.2 bB	9156.0 aB	23154.2 aA	0.39b
AFI_2	288.0 aA	40.2 aA	40.8 aA	9599.7aA	22354.2 aB	0.43a
AFI_1	254.0 aB	30.3 aB	39.4 bB	8466.4bC	20354.17 aB	0.42a

Different small letters (a,b,c) and capital letters(A,B,C) in the same line indicate significant difference at $P_{0.05}$ and $P_{0.01}$ level, respectively.

WATER USE EFFICIENCY (WUE) Compared to CFI, AFI significantly increased WUE and $WUE_{biomass}$, AFI_2 and AFI_1 increased WUE by 22.2% and 28.5% and WUE $_{biomass}$ by 12.4% and 22.3%, respectively, indicating that AFI can improve water use efficiency of maize. In summary, AFI_2 may improve the contribution of irrigation water to grain production (Tables 3 and 4).

Table 4 The evapotranspiration and water use efficiency of each treatment

Treatment	ET (mm)	WUE (kg/m^3)	$WUE_{biomass}$ (kg/m^3)
CFI	247.7a	2.07 a	5.23c
AFI_2	231.8b	2.53b	5.89b
AFI_1	192.6c	2.66c	6.40a

Different small letters (a, b, c) in the same column indicate significant difference at $P_{0.05}$ level

DISCUSSION Soil electric conductivity could represent water and salinity content in the soil (Liu and Yang, 2001), and is an important index of soil productive potentiality. On one hand, excessive fertilization and irrigation increased accumulation and migration amount of salt in the soil; on the other hand, frequent irrigation and crop transpiration increased the transport of soil salt to the surface soil by evaporation, which could influence soil electric conductivity in the soil (Xie *et al.* 1997). In this study, soil electric conductivity in surface soil layer increased at the 1st day after irrigation, and then soil electric conductivity in surface soil layer decreased as the result of soil water infiltration. Water infiltration and soil evaporation in CFI was greater than these in AFI, because CFI had more irrigation. Mean value of soil electric conductivity in furrow and ridge was 0.040 s m^{-1} during whole growing season. Mean value of soil electric conductivity in AFI_1 and AFI_2 was 0.033 and 0.036 s m^{-1}, respectively. The results indicated that the increase of soil electric conductivity in surface soil layer in CFI maybe result from greater evapotranspiration force. There was more space for water lateral movement in AFI with lower evapotranspiration pull. Water transported to the ridge and dry furrow with lower water potential, which resulted soil electric conductivity in ridge and dry furrow higher than that in wet furrow (Fig.4).

In a pot maize experiment, soil salinity had inhibitory effect on maize LAI and height 35 days after emergence, but soil salinity had slight effect on LAI during the later growing season (Liu 2004). Zhang *et al.* (1999) indicated that soil salinity affected the growth of maize seedlings when salt content was 3 g L^{-1}. In this study, the growth rate of plant height, LAI and stem diameter in the AFI treatments was faster than those of the CFI treatment within 36 days from sowing and after 81 days from sowing, which may result from the combined effect of water and salinity.

Soil temperature is an important factor influencing biological activity and crop growth, and it represents soil heat condition. In agricultural production, soil temperature in the cultivated horizon not only affects the growth of roots and seedlings, but also directly and indirectly influences the transport and transform of water and nutrients (Lei *et al*. 1988). And soil temperature is related to soil heat transport, crop growth and yield etc. Under full irrigation and fertilizer, there was a linear relationship between leaf elongation rate and soil temperature (Zhang *et al*. 2001). In this study, AFI increased the temperature over surface soil, which can provide adequate heat at the seedling stage and reduce frost injury at the later growing season.

Liang *et al*.(2000) indicated that alternate drying and wetting in the soil had the compensatory effect on leaf growth of maize. Yang *et al*. (2003) showed that alternate irrigation could save irrigation water, and had slight effect on maize height and leaf growth. In this study, the stem diameter of AFI_2 was significantly greater than that of CFI at the seedling and maturity stages, which was beneficial for strong seedling and lodging resistance. Compared to CFI, AFI_2 had slight difference in plant height but significant difference in LAI at the maturity stage. Thus CFI promoted the growth of maize height and LAI. However, AFI inhibited the redundancy growth of maize. At the early growth stage, maize with CFI firstly reached the maximum filling rate, however, at the later growth stage, maize with AFI_2 had greater filling rate than CFI. Moreover, AFI_2 had lower yellow leaves, indicating AFI can keep more green leaves and higher filling rate at the later growth stage.

In the CFI treatment, soil water mainly infiltrated to the deep layer and soil water content in the same depth was the maximum at the same stage, indicating that soil water may increase the deep percolation. But in the AFI treatment, the infiltration and lateral leaching simultaneously after irrigation may reduce the deep percolation and improve WUE, which was in agreement with the result of Pan *et al*. (2000). Liang *et al*. (2000) and Kang *et al*. (2001) suggested that AFI could save water by more than 33.3% without yield reduction when compared to CFI. This study indicated that alternate drying and wetting in the soil significantly reduced evapotranpiration but improved yield components and significantly increased maize yield. Compared to CFI, AFI_2 increased WUE, $WUE_{biomass}$ and yield by 22.2%, 12.4% and 4.8%, respectively. However, AFI_1 significantly reduced grain yield although it saved irrigation water and improved WUE.

Soil salt content and temperature were separately analyzed for different irrigation methods in this study. However, crop growth and yield were influenced by the interaction of water, heat and electric conductivity, which needs further research.

CONCLUSIONS Alternate furrow irrigation increased the space for water infiltration and reduced soil evaporation loss. Relationships between soil evaporation and soil water content and LAI were shown in the exponential functions. AFI had lower electric conductivity in the 0-10 cm soil layer. Heat resource was efficiently utilized by maize with AFI, which was beneficial for crop growth. The redundant growth was inhibited, maize-lodging tolerance was improved, and WUE was significantly increased under AFI with suitable irrigation amount. Compared to the CFI treatment, AFI_2 increased yield and WUE by 4.8% and 22.2%, respectively.

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