Water potential characteristics and yield of summer maize in different planting patterns

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ABSTRACT

A study was conducted in the Shandong province in North China to investigate the effects of different planting patterns on water potential characteristics of soil-plant-atmosphere continuum (SPAC) and yield of summer maize. Three planting patterns were applied, i.e. bed planting (BE), furrow planting (FU) and flat planting (FL). The results showed that although soil moisture content in 0–20 cm soil layer in BE was decreased, soil temperature was increased; as a result, soil water potential in BE was increased. Compared with FL, leaf water potential in BE and FU was enhanced, but water transfer resistance between soil-leaf and leaf-atmosphere was decreased; feasible water supply conditions were thus created for crops colony. Maize yield of BE and FU was significantly (LSD, $P < 0.05$) higher than that of FL, by 1326.45 and 1243.76 kg/ha, respectively. These results obtained in field crop conditions support the idea that planting patterns affect soil water potential, leaf water potential, water transfer resistance between soil-leaf and leaf-gas of summer maize in North China.

Keywords: planting patterns; water potential; water transfer resistance; yield; summer maize

In the Shandong province of Northern China, winter wheat (*Triticum aestivum* L.) is widely planted. Local plant breeders have developed maize (*Zea mays* L.) varieties that grow during summer and are harvested before the winter wheat is planted in fall. This development allows farmers to produce two crops per year. In this planting system, water available for growing crops has become scarce due to an abrupt change in the amount and distribution pattern of natural precipitation and by an increasing demand for water for domestic and industrial use (Zhang et al. 2003, Wang et al. 2004, Kang et al. 2005). In this situation, improving water use efficiency to optimize the benefits of precipitation is of paramount importance for farmers. It was presumed that plants have capacity to sense the amount of water available in the soil and adjust stomatal behaviour and leaf expansion rate accordingly (Stan and Derrick 1990). Hence, some attempts were made to improve the physical environment of the field to favour crop growth and increase maize yield (Dean et al. 2000, Mishra et al. 2001); these include different planting patterns (Abu-Awwad 1999, Agustin et al. 2000). Soil water was necessary to maintain the effective leaf water potential (Ψ_L) under the prevailing evaporative demand in the atmosphere (Wallace et al. 1983). Ψ_L varies to a considerable extent with soil profile water storage, weather conditions, and age of the plant (Misra and Nagarajarao 1980, Singh 1995). Soil potential (Ψ_S) appears to be useful in characterizing soil water status in relation to soil water availability to the plant (Yu et al. 2007). The measurement of soil water content (θ_{act}), which

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is dependent on soil type, is necessary to determine the amount of water for irrigation (Ali et al. 1999); estimation of water transfer resistance of soil-plant-atmosphere continuum (SPAC) is thus important both for describing water movement in the continuum and for adopting practical water-saving measures in agriculture, in order to find solutions to effectively use precipitation in field crop conditions (Zhang et al. 1999, Yang et al. 2003).

The purpose of this study is to investigate the effects of FL, BE and FU on Ψ_L, Ψ_S, water transfer resistance of SPAC and yield of summer maize under rain-fed, field crop conditions in North China.

MATERIAL AND METHODS

Plant culture. Experiments were conducted during the summer season (June–September) of 2005 at the agricultural experimental station of Shandong Agricultural University in Tai'an (36°10'N, 117°09'E), Shandong province, Northern China. The soil in the top 0.6 m was clay loam with mean bulk density of 1.50 g/cm^3. The average field capacity and permanent wilting point of the root zone soil in the crop field were 25.73% and 7.65%, respectively. The readily available N, P and K were 83.1, 13.2 and 78.5 mg/kg, respectively.

After wheat harvest in 2005, three planting patterns were conducted, namely FL, BE and FU. BE and FU consisted of alternating beds and furrows, the height of the beds was 15 cm, the width of the beds and the furrows were 40 and 20 cm, respectively. For BE, one row of summer maize was planted on beds; similarly, for FU, one row of summer maize was planted in furrows. For both BE and FU, the space between neighboring planting rows was 60 cm. A schematic diagram showing BE and FU is presented in Figure 1. The FL had a row spacing of 60 cm, which is the most frequent practice used by farmers. The summer maize cultivar Nongda 108 is very popular in North China. The maize was sown on 7 June and harvested on 28 September; plant density was 6.6 × 10^4 plants/ha. Weeds were controlled before emergence by application of Bentazon (480 g/l). Nitrogen and potassium fertilization were supplied so as to be non-limiting.

Rainfall and soil water content measurements. Details of the rainfall under natural conditions during the entire cropping season are shown in Table 1. θ_{act} was measured in field crop conditions using the neutron moderation (CNC503DR) method. In the growing seasons of summer maize, θ_{act} for samples taken from every 10 cm of the top 120 cm depth in planting zone was measured by a neutron moisture probe. θ_{act} of the top 20 cm soil layer was measured by the over-drying method. Measurements were made at approximately 7-day intervals; after rainfall, additional measurement was needed. During the growing seasons of summer maize, no additional irrigation was necessary.

Grain yield measurements. Grain yield and yield components were measured at maturity on the area of 8 m^2 corresponding to the two central rows of each plot. The number of maize ears

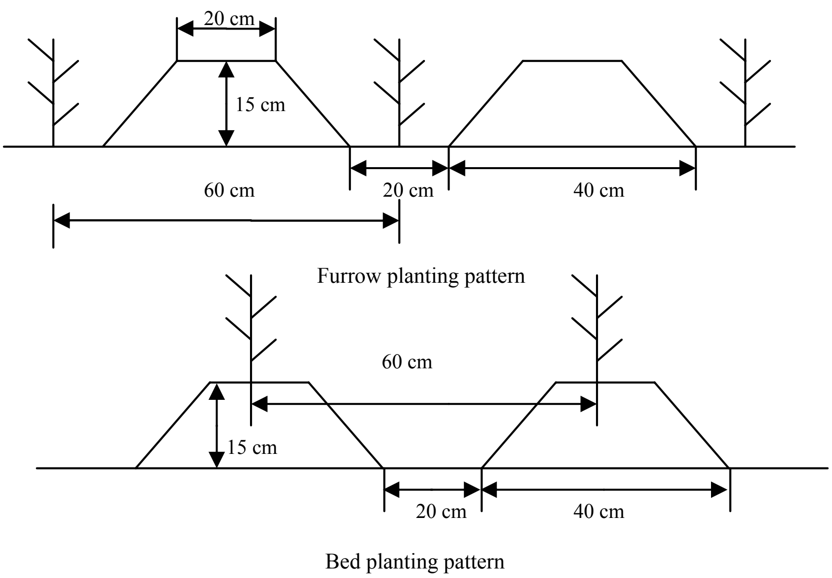

Figure 1. The schematic diagram showing furrow and bed planting patterns

Table 1. Precipitation during the growing season of summer maize in 2005

Month	6	7	8	9
Rainfall (mm)	152.60	119.96	124.00	179.80

per hectare and the number of rows per ear were calculated. The weight of 1000 grains was determined by counting and weighing 100 grains at 3 replicates per plot.

Soil and leaf water potential measurements. Ψ_S and Ψ_L were taken approximately every 7 to 10 days from emergence to maturity, on clear-sky days at 8:00–9:00 with a portable PSYPRO water potential system that measures soil and leaves for each replication in each treatment. Ψ_S was measured with a PCT-55 soil water potential apparatus in the morning at the depth of 20 cm. Meanwhile, soil temperature was observed at the depth of 5, 10, 15 and 20 cm.

Ψ_L was measured with a C-52 sample chamber after the leaf of spike fully expanded. Discs about 6 mm in diameter were cut from the leaves of 3 plants and sealed in the C-52 sample chamber. Samples were equilibrated for 30 min before the readings were recorded by a Wescor HR-33T microvoltmeter in the psychrometric mode.

Atmosphere water potential (Ψ_a) was calculated by Zhang et al. (1999):

$$\Psi_a = \frac{RT}{V_w} \ln RH$$

where: R = 8.3127 Pa m^3/mol K is the constant of general gas; T is the absolute humidity (K); V_w = 1.8 × 10^{-5} m^3/mol is the partial Moore volume content; RH is relative humidity (%)

Water transfer resistance was calculated by Zhang et al. (1997):

$$E = \frac{\Psi_S - \Psi_L}{\Psi_{SL}} = \frac{\Psi_L - \Psi_a}{\Psi_{La}}$$

where: E is the transpiration rate (μg/cm^2/s), which was measured similarly with water potential of leaves and soil by CIRAS-2 photosynthetic system; Ψ_S (Pa), Ψ_L (Pa), and Ψ_a (Pa) are the water potentials of soil, leaves and atmosphere; Ψ_{SL} (s) and Ψ_{La} (s) are the water transfer resistances between soil-leaves and leaves-atmosphere

Climate data. A weather station (ET106) was established near the experiment site. The operation of weather station was automatic. Hourly and 24 h values of weather data were stored in the datalogger for a month. Every month, the data from the datalogger were first electronically transferred to a cassette tape and then transferred from the cassette to a personal computer.

Experimental design and statistical analyses. The experiments were laid out in a randomized block design, and all the treatments were replicated sequentially three times. For the treatments an analysis of variance (ANOVA) was used; it was performed at α = 0.05 level of significance to determine whether significant differences existed among treatments means. The multiple comparisons were done for significant effects with the LSD test at α = 0.05.

RESULTS AND DISCUSSION

Soil water potential (Ψ_S). The studies were performed under three planting patterns: FL, BE and FU. The Ψ_S within the range 0 to –0.14 MPa were determined in different planting patterns (Figure 2). The Ψ_S all maintained at upper level between 12 July to 25 August; however, a fast decrease was observed afterwards; it was related to the rainfall during the entire cropping season. Thus the differences between the three planting patterns in the decrease of Ψ_S were related to the difference in the soil water character. Ψ_S in the BE was higher than FU and FL. This indicates that the presence of soil water supply in BE mostly excelled the other two planting patterns.

Leaf water potential (Ψ_L). From Figure 3, it is clear that neither of the three planting patterns showed regular relation to Ψ_L before 18 August. However, after 18 August, similar to the results for Ψ_S (Figure 2), the values of Ψ_L of the three patterns showed considerable differences; that is, the highest Ψ_L value for BE, next for FU, and the lowest for FL. The analysis of the results for Ψ_L revealed an osculating relation between Ψ_L and yield. Thus, it appears that at the key period for yield, i.e. later growth stage of summer maize, it was necessary to maintain a higher Ψ_L.

Water transfer resistance of SPAC. These differences were further elucidated by relating the responses in the three planting patterns to water transfer resistance of SPAC (Table 2). The water transfer resistance of SPAC from leaf to atmosphere was 100 times higher than from soil to leaf; hence, water transfer resistance from leaf to atmosphere was the key resistance of SPAC. The difference in water transfer resistance from leaf to atmosphere was the main factor of water supply condition of soil

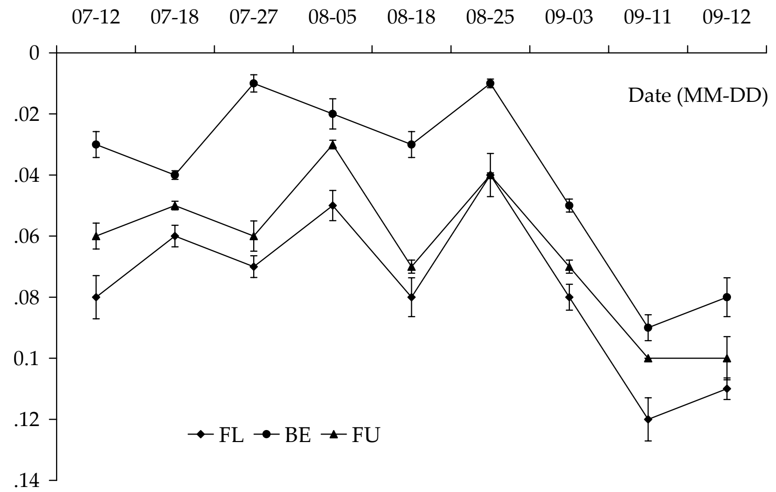

Figure 2. Variation of soil water potential during the growing season of summer maize

(Yang et al. 2003). Table 2 shows water transfer resistance of SPAC both from soil to leaf and from leaf to atmosphere; in BE and FU these were evidently lower than in FL at the metaphase and anaphase of summer maize. Water transfer resistance plays the key role in the course of water dissipation from leaf to atmosphere, which determines the water supply conditions of the crops colony.

Grain yield and yield components. Table 3 shows the grain yields and yield components of the three planting patterns. Yield and yield components differed very little between BE and FU. The average grain yield was only 2.5% higher in BE than in FU. Conversely, grain yield was significantly (LSD, $P < 0.05$) lower in FL, the yield reductions were 15.6% and 13.5% of BE and FU, respectively. The number of grains per row was also significantly (LSD, $P < 0.05$) lower in FL than in BE and FU. The weight of 1000 grains, the number of maize ears per hectare and the number of rows per ear were not significantly (LSD, $P < 0.05$) different among the planting patterns.

Some researchers reported that as soil moisture content increased, soil water potential increased (Mishra et al. 1999); some authors also discovered that soil water potential increased with increasing soil temperature (Zhang 1997). In this study, during the growing seasons of summer maize, Ψ_S of BE was higher than those of FU and FL, but θ_{act} measured at 0–20cm depth in BE was lower than those of FU and FL (Figure 4). However, the results of soil temperature were opposite (Figure 4). During the growing season of summer maize, θ_{act} in 0–20cm always retained higher level due to sufficient rainfall, and so soil water was not the key factor restricting the growth and develop-

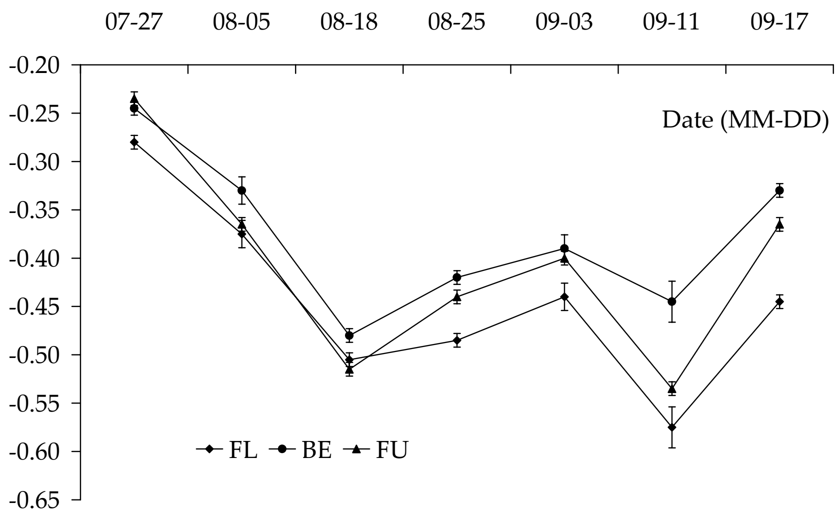

Figure 3. Variation of leaf water potential during the growing season of summer maize

Table 2. Water transfer resistance of SPAC during the growing season of summer maize

Treatments	07–27			08–25			09–12		
	BE	FU	FL	BE	FU	FL	BE	FU	FL
Soil-leaf (10^8 S*)	0.668	0.496	0.603	1.142	1.310	1.446	0.685	0.730	0.931
Leaf-atmosphere (10^{10} S)	0.897	0.865	0.875	1.163	1.170	1.194	1.499	1.506	1.516

*1 S = 1 Pa/μg cm^2 s

Table 3. Maize yield and yield components of each treatment

Treatment	Number of maize ears per hectare	Number of grains per row	Number of rows per ear	Weight of 1000 grains (g)	Yield (kg/ha)
FL	65790^a	35.43^b	15.20^a	287.63^a	10177.37^b
FU	65895^a	38.83^a	15.50^a	332.23^a	11421.13^a
BE	65955^a	39.13^a	15.60^a	327.46^a	11503.82^a

Treatment or yield means followed by the same letter are not significantly different (LSD test, $P \leq 0.05$)

ment of summer maize. Under these conditions, a change of planting patterns of summer maize could increase soil temperature, which could result in an increase in Ψ_S. This result was similar to the findings of Zhang (1997). Hence, the authors believe that BE could play an important role in areas characterized by prolonged water logging as a result of excessive rainfall.

It appears that some effective water was not utilized by crops in the root zone at the harvest stage (Passiourad 1983). Only about 30% of roots of crops absorb effective water. Furthermore, due to a great water transfer resistance in the root zone, roots are incapable to absorb soil water (Yang et al. 2003), especially deeper soil water. The aim of this paper was demonstrate that at the metaphase and anaphase of summer maize, both BE and FU could decrease water transfer resistance of SPAC from soil to leaf and leaf to atmosphere, which will contribute to an increase of the ability to utilize deep soil moisture. In the scope of 40–120 cm soil layer, the soil moisture content of BE and FU was lower than that of FL (Li 2006), which suggests that maize under the BE and FU planting patterns used more deeper soil moisture than that of FL.

The growth stage of summer maize was very short, its roots were mostly centralized no less than 1 m, about 60% of them were in 0–20cm (Zhang 1997). Under the condition of sufficient rainfall, both BE and FU could enhance Ψ_S in 0–20 cm, compared to FL. As a result, feasible water supply conditions were created for crops colony.

To conclude, the primary role of agricultural scientists should be providing farmers with viable

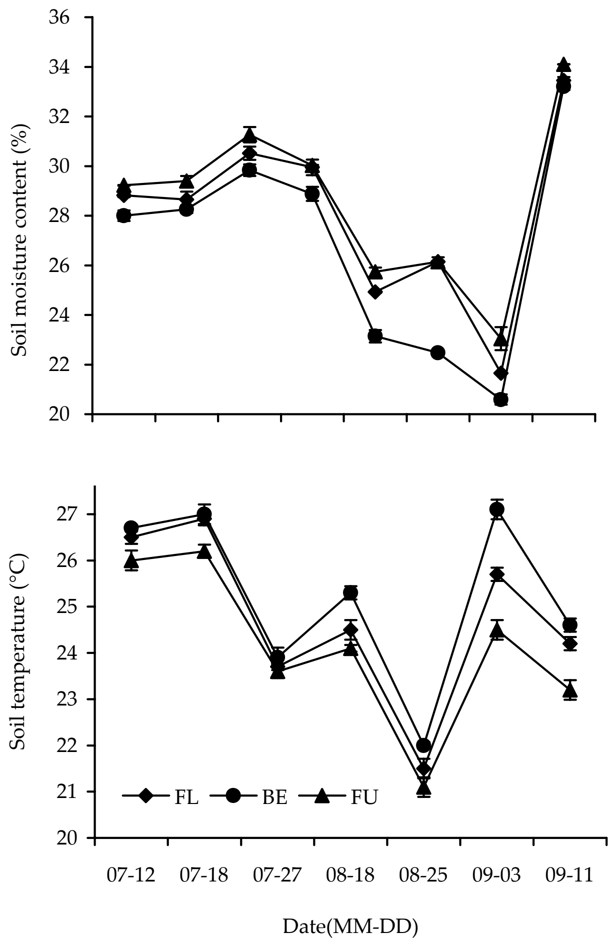

Figure 4. Variation of soil moisture content and soil temperature in the growing season of summer maize

management alternative. Both BE and FU appear suitable planting patterns for growing maize, still, further studies will be necessary.

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