Original Paper Open Access

Planting pattern effects on soil water and yield of summer maize

Xing Ya Wang[1,2], Xun Bo Zhou[1,2]*, Yu Hai Chen[2]

[1]Agricultural College of Guangxi University, Nanning 530004, China
[2]State Key Laboratory of Crop Biology, Shandong Agricultural University, Tai'an 271018, China
*Corresponding author: E-mail: whyzxb@gmail.com

Abstract

Productivity and water use efficiency are important problems in sustainable agriculture, especially in high-demand water resource crops such as maize (*Zea mays* L). The aims of this research were to study plant and row spacing in maize, evaluating soil water content (SWC), yield and water use efficiency (WUE). A 3-year field experiment (2011–2013) was carried out in the north of China. The summer maize experiment consisted of five types of row spacing under the same planting density. The results showed that the SWC in 90–120 cm was higher than 0–30 cm, and soil water storage was a significant regression with advancing growth stage. A negative correlation was observed among yield, WUE and row spacing. The average yield of RS50 and RS40 was by 9.6% higher than that of RS70 and RS80, and the WUE of the RS40 and RS50 were significantly higher than RS60, RS70, and RS80. The study also indicated that increased productivity and WUE of rainfed summer maize can be reached via row spacing reduction and plant spacing widening under same planting density, and RS50 cm is regarded as the best planting system selection for the plains of Northern China.

Keywords: Zea mays, rainfed, row spacing, soil water content, water use efficiency

Introduction

Plants compete among themselves for some resources. The main competition factors can be identified as light, temperature, water, nutrients and weed (Brant et al, 2009). One plant was sufficiently close to another to influence its soil or atmospheric environment and thereby decrease its rate of growth (De Bruin and Pedersen, 2008). Many planting patterns and agricultural practices have been used to make full use of resources, and by adjusting the row spacing can promote crop growth and improve efficiency of resource use. Different row spacings changed the local environment of individual plant. In Alabama, USA, the sorghum grain yield of row spacing 45 cm was significantly higher than that of row spacing 60 and 90 cm when the seeding rate was 20 grain per meter (Bishnoi et al, 1990). Under the same summer soybean plant population density, yields of narrow row spacing were significantly higher than that of wide row spacing (Zhou et al, 2015).

Global demand for agricultural products is expected to double in the coming decades (Godfray et al, 2010). Maize is one of the staple food crops, and China is currently the world's second largest maize producer (Meng et al, 2006). Summer maize in north China is not irrigated during the growing season, and water supply is an important factor to the yield. Zhou et al (2010) indicated that enhanced productivity and water use efficiency of rainfed summer soybean can be achieved via row spacing reduction under same planting density. For rainfed crops, relatively uniform row spacing would made reasonable absorb moisture inter-plant, minimize unproductive consumption caused by the soil evapotranspiration (Debaeke and Aboudrare, 2004). Water loss, due to evapotranspiration, was also significantly greater in the row position than in the interrow position (Timlin et al, 2001).

Many previous researches have focused on the water use efficiency (WUE) under the condition of water restrict, but only a few have studied the effects of crop row spacing on yield and WUE (Bowers et al, 2000). The aim of this study was to explore the effects of row spacing on soil evaporation, water-consumption characteristics, grain yield and WUE for rainfed summer maize in the North China Plain.

Materials and Methods

Experimental design and weather data collection

The study was conducted at Agronomy Experimental Station, Shandong Agricultural University, which located in Tai'an, China (36°09'N;117°09'E). The soil type in this region was a silt loam with the average soil organic matter of 16.3 g kg^{-1}, N 1.3 g kg^{-1}, P 35 mg kg^{-1}, K 95 mg kg^{-1}, and pH of 6.9. The long-term yearly average (1971-2010) rainfall was 693.5 mm, and the average temperature was 13.1°C. Data on monthly rainfall through the year are shown in Figure 1. Precipitation during the summer maize growing season was 572.5 mm in 2011, 337.1 mm in 2012, and 461.8 mm in 2013.

Experiments were established in 2011, 2012, 2013 and consisted of 5 planting patterns under the same planting density (6.25 × 104 plant ha^{-1}); row spacing (RS, cm) × plant spacing (cm) was 40 cm ×

 RECEIVED 03/17/2015

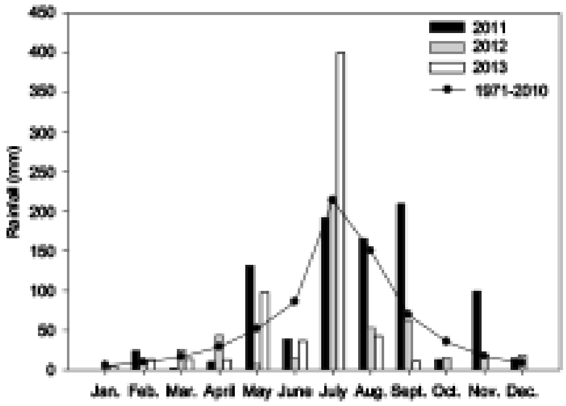

Figure 1 - The monthly rainfall average in 1971–2010 and monthly rainfall in 2011–2013.

40 cm (RS40), 50 cm × 32 cm (RS50), 60 cm × 27 cm (RS60), 70 cm × 23 cm (RS70), 80 cm × 20 cm (RS80). Treatments were randomized plot design and replicated three times. Non-irrigated summer maize (cv Luyu14) was hand planted on June 18, 2011, June 17, 2012, June 19, 2013, and harvested on September 24, 2011, October 2, 2012, and October 2, 2013. The experiment plot area was 4 m × 4 m. The growth stage of VE, V6, R0, R2, R3, R4, and R5 were measured in this experiment (Ritchie et al, 1996).

Soil water content (SWC, v/v) was measured every 10 d using a neutron moisture meter (CNC503B, Super Energy Nuclear Technology, Ltd, Beijing, China) throughout the summer maize growing season at 10 cm intervals in the 0–120 cm soil profile.

Computation and statistical analyses

The evapotranspiration (ET) was calculated using the following equations (Zhang et al, 2011): ET= ΔW + R – SI – Q, where ΔW is change of soil water stored (SWS, mm), R is rainfall (mm), SI is deep percolation (mm), and Q is surface run-off (mm). SI was estimated using the approach proposed by Gong and Li (1995): SI = ΔW – FK, where FK is field capacity, ΔW = Σ(ΔØi × Zi), where ΔØi is change in soil volumetric water content (m^3 m^{-3}) and Zi is depth of the soil layer (mm). Q = $(R – 0.2S)^2/(R + 0.8S)$, where S is potential maximum retention after runoff begins (mm) (Bosznay, 1989). S = (25400/CN) – 254, where: CN is runoff curve number. The WUE formula is as follows (Neal et al, 2011): WUE = Y/ET, where Y is grain yield (kg ha^{-1}) of summer maize, ET is total seasonal evapotranspiration.

All graphs were prepared from means and drawn using SigmaPlot 10.0 (SPSS Inc, Chicago, IL). All

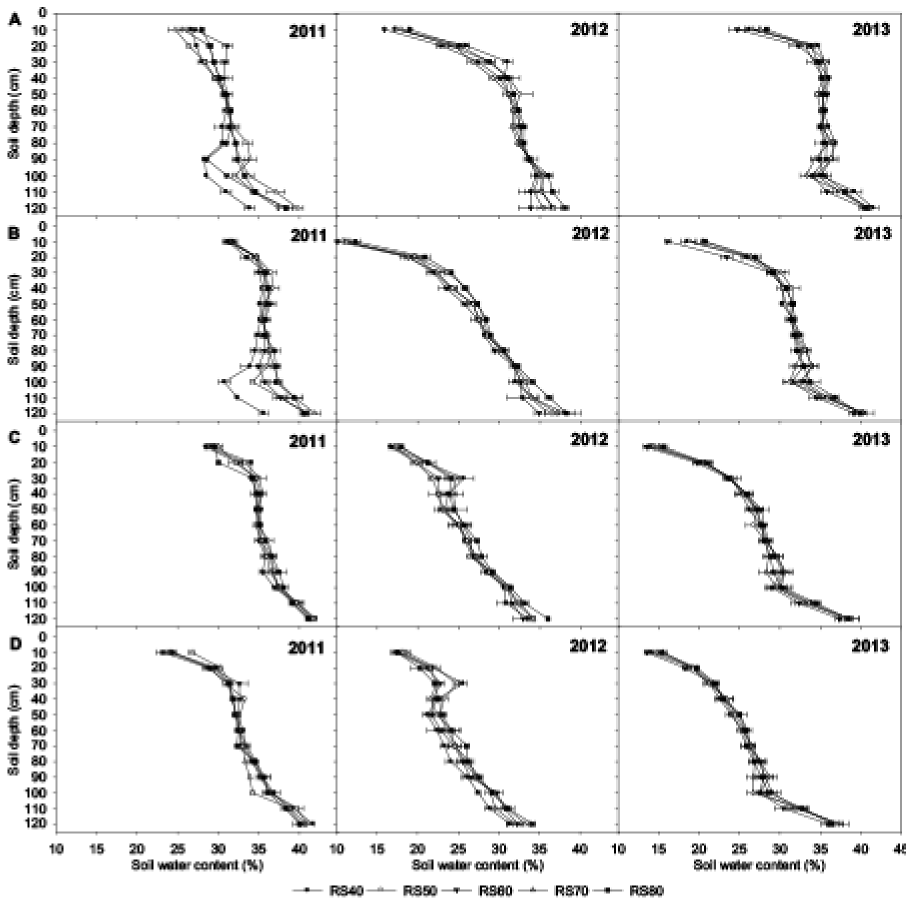

Figure 2 - Soil water content at 0–120 cm layer in 2011–2013. A, B, C, D are V6, R0, R2, R3 respectively; the bars are the SE.

data were analyzed using SAS 9.2 (SAS Institute Inc, Cary, USA). Multiple comparisons were conducted for significant effects with the least significant difference test at P = 0.05.

Results

Change of SWC

The means of SWC (0-120 cm) were 34.0% (2011), 27.3% (2012), and 29.8% (2013), respectively. The SWC of 2011 was obviously higher than those of 2012 and 2013, and presented an irregular Z-shaped curve within the 0–120 cm soil layer. The SWC in the deeper layer (90–120 cm) was higher than upper layer (0-30 cm); the SWC of 40-80 cm soil layer increased with the increasing soil depth, but the fluctuation was small (Figure 2).

The SWC had a large difference in the different growth stages. At V6, the fluctuation of SWC in 2011 was smaller than those of 2012 and 2013 at 0–120 cm layer, and the SWC in 0–30 cm layer was 28.1% (2011), 23.5% (2012), and 31.7% (2013), respectively. At R0, the SWC in 0–30 cm layer was highest in 2011 and the value was 33.9%, but it was lowest in 2012 and the value was 17.8%. The SWC of 2012 was lower than those of other two years in 0–120 cm layer. At R2, the SWC in 0–120 cm layer were 35.6% (2011), 26.1% (2012), 27.3% (2013), and were lower than R0. The SWC of R3 was 6.3% (2011), 4.3% (2011) and 6.5% (2011) lower than those of R2, respectively. At R2 and R3, the SWC of 2013 was lower than that of 2012 in 0–30 cm layer.

The SWC changed with different RSs. At V6 and R0, the SWC in 90–120 cm layer of RS40 was lower than those of other RS treatments in 2011, which maybe attributed to more rainfall in the early growth stage, and was growing quickly and had a higher consumption under RS40. The SWC averages of RS40, RS50, RS60, RS70, RS80 were 33.3%, 34.3%, 34.1%, 34.2%, and 34.2% (2011), 27.2%, 27.5%, 26.7%, 27.1%, and 28.0% (2012), 30.0%, 29.9%, 29.4%, 29.6%, and 30.0% (2013), respectively; the means of three years were 30.1%, 30.6%, 30.0%, 30.3%, and 30.7%, respectively

Change of SWS

In 0–120 cm, the SWS of 2011, 2012, and2013 were 393.9, 304.1, and 334.4 mm, and it may be relate to rainfall; the SWS of VE, V6, R0, R2, R3, and R5 were 286.2, 388.3, 376.5, 356.4, 335.8, and 321.7 mm, respectively; relative low SWS values were observed at VE and R5. In the middle and late summer maize growth seasons (R0–R5) maintained relative high SWS values attribute to more rainfall. A similar trend was observed in 2012 and 2013. The SWS reached to a peak at V6 and decreased gradually which related to less rainfall and intense water consumption (Figure 3).

A correlation analysis showed that there was a significant regression trend between SWS and GS, and the equation can be denoted as y (SWS, mm) = -11.682x2 (GS) + 72.971x + 241.03, with an R2 = 0.4798 (P = 0.0090). The means of RS40, RS50, RS60, RS70, RS80 (2011–2013) were 339.8, 346.7, 340.5, 344.4, and 349.2 mm, respectively. There was no significant regression between RS and SWS, the SWS of RS40 was 2.7% lower than that of RS80, and RS50 and RS80 were higher than those of the other RSs.

ET, yield, and WUE

ET versus grain yield was plotted for all treatment conditions (Figure 4). The ET in 2011, 2012, and 2013 were 465.0, 310.1, and 489.7 mm, respectively; the ET of 2012 was lower than those of 2011 and 2013. In 2011, the results indicated that yields were increased with increased ET; yield and ET were significantly positive correlated, and the correlation coefficient (R2) was 0.4113 (P = 0.0100). In 2012 and 2013, yield and ET were not significantly correlated, and the R2 were 0.1490 (P = 0.2706) and 0.0707 (P = 0.3381). Those results showed that rainfed summer maize was different from irrigated winter wheat due to rainfall, light intensity, temperature and other environmental factors, and high water consumption may not promoting yield. The yields of RS40 (2011) and RS50 (2012) were higher than those of other RS treatments, but ETs were low (Figure 4).

The results show that the order of average WUE

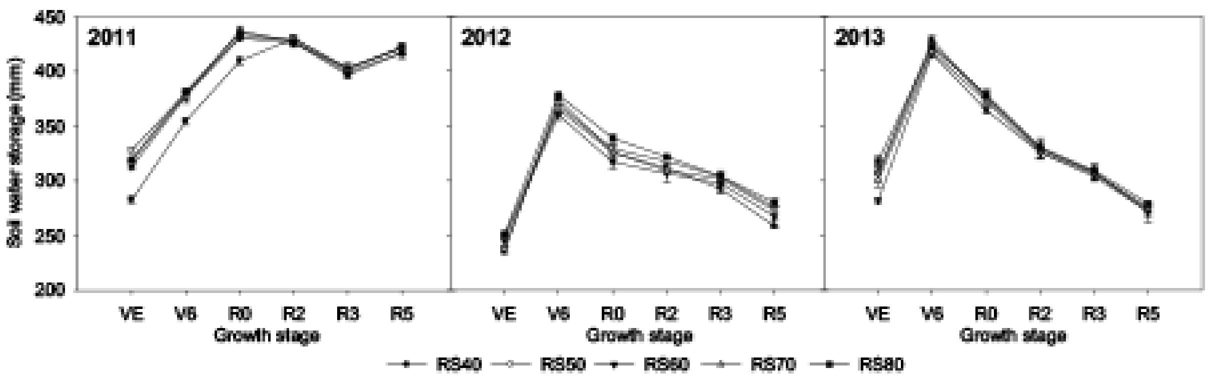

Figure 3 - Effects of row spacing on soil water storage. The bars are the SE.

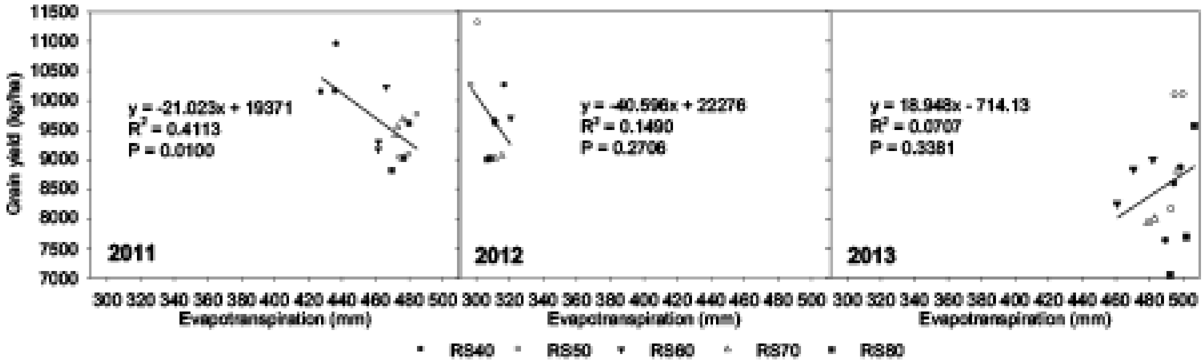

Figure 4 - Regression of evapotranspiration vs. grain yield for the rainfed summer maize in 2011–2013.

was 2012 > 2011 > 2013. The WUE of 2012 was the highest although least amount of rainfall, which indicated that WUE was related to rainfall of the current season (Table 1). In 2011–2013, the WUE of RS40, RS50, RS60, RS70, and RS80 were 24.2, 24.8, 23.2, 22.0, and 21.6 kg ha^{-1} mm^{-1}, respectively. In 2011, RS40 was significantly higher than RS50, RS60, RS70 and RS80; in 2012, RS50 was significantly higher than RS40, RS60, RS70 and RS80, whereas RS70 was significantly lower than those of RS40 and RS50 ($P < 0.05$). In 2013, there was no significant difference for WUE between RS ($P > 0.05$).

The means of three years results showed that the order of yield was RS50 > RS40 > RS60 > RS70 > RS80, and the average yield of RS50 and RS40 was 9.6% higher than that of RS70 and RS80. In 2011, the grain yield of RS40 was significantly higher than that of RS80; in 2012, RS50 was significantly higher than those of RS60, RS70, and RS80; in 2013, RS50 was significantly higher than those of RS40, RS70, RS80 ($P < 0.05$).

Soil water relations with yield

The study over 3 years showed that a significant negative correlation was observed between RS and yield, and the correlation coefficient (r) was -0.9020 ($P < 0.05$); a significant positive correlation was observed between ET and SWC, and the r was 0.9017 ($P < 0.05$). The result indicated that the increased SWC would improve crop transpiration and soil evaporation, increased ET. There was a positive correlation between ET, SWC and RS, and the r was 0.7169 and 0.5067, respectively; the ET and SWC increased with the increasing of RS. A negative correlation was observed between ET and yield, and high ET did not increase the yield of summer maize. The results indicated that the natural rainfall was not consistent with crop water demand, and relative low water resource utilization was observed under rainfed condition (Table 2).

Discussion

The SWC of summer maize was greatly influenced by rainfall. For SWC, 2011 was evidently higher than that of 2012 and 2013, and the deeper layer (90–120 cm) was higher compared to upper layer (0–30 cm). The density and depth of root penetration are greatly affect by the soil profile water status and the factor can aslo limit crops full use of available soil water (Angadi and Entz, 2002; Zuo et al, 2006). An upward capillary flux and hydraulic gradient would appear in the deeper soil layers of the crop root zone (Bandyopadhyay et al, 2005; Li et al, 2010).

The changes of the SWC curve of different growth stages had related reports (Wang et al, 2014). In 0–30 cm soil layer, the high SWC at V6 in 2013 growing season may attribute to 399.8 mm of rainfall in July, and the high SWC at R2 and R3 in 2012 growing season might have been affected with 115.0 mm of rainfall in August and September. In the three years, the SWC average of RS50 and RS80 was higher than that of other treatments, this result indicate that changes of row spacing of summer maize effected extracting water in soil. There was a descending trend with the

Table 1 - Effects of row spacing on the water use efficiency (WUE) of summer maize in 2011–2013.

Row spacing (cm)	2011		2012		2013	
	Yield (kg ha^{-1})	WUE (kg ha^{-1} mm^{-1})	Yield (kg ha^{-1})	WUE (kg ha^{-1} mm^{-1})	Yield (kg ha^{-1})	WUE (kg ha^{-1} mm^{-1})
40	10415 a*	24.0 a	9948 ab	31.6 b	8352 b	16.9
50	9288 ab	19.4 b	10779 a	36.0 a	9443 a	19.0
60	9569 ab	20.7 b	9660 b	30.6 bc	8693 ab	18.4
70	9551 ab	20.2 b	9035 b	28.8 c	8238 b	16.9
80	9152 b	19.3 b	9011 b	29.3 bc	8099 b	16.2
LSD (0.05)	941	2.04	993	2.78	1586	2.95

* Values followed by the same letter in a column are not significantly different according to $LSD_{0.05}$

Table 2 - Correlation coefficients between row spacing (RS), yield, evapotranspiration (ET), and soil water content (SWC) of summer maize in 2011–2013.

	RS	Yield	ET	SWC
RS	1.0000	-0.9020*	0.7169	0.5067
Yield		1.0000	-0.4392	-0.2621
ET			1.0000	0.9017*
SWC				1.0000

* r values presented at $P < 0.05$.

advance of the GS, which may be relative to less rainfall in September and more water consumption in the middle and late periods of GS.

In 2011, the overall yield trend indicated that yields were increased with increased ET. The result is similar to previous findings (Schneider and Howell, 1997; Huang et al, 2004). But significant correlation was not found in 2012 and 2013, which time and amount of rainfall was difficult to completely consistent with crop water requirement under the rainfed condition.

The WUE of RS40 and RS50 were significantly higher than RS60, RS70 and RS80, which attributed to greater early-season light interception for narrow row spacing and accelerated crop growth. Relative narrow row was the important factor to increase light interception when the key period of yield formation, and this was the crucial factor to make a high yield (Andrade et al, 2002). It was negative correlation between WUE and RS and positive correlation between WUE and yield, which were alike to the research of soybean study (Ethredge et al, 1989).

Conclusion

The study 3 years has shown that high yields and WUE of summer maize can be gained by reducing row spacing under the same planting density in the plains of northern China. The conclusion of the study was that RS50 may be an optimum planting pattern to improve WUE and yield of summer maize under rainfed conditions.

Acknowledgements

The authors especially thank Huang Juan, Feng Zhibo, Wang Guoyun and Han Yuanyuan for his valuable contributions. This research was supported by the National High Technology Research and Development Program of China (2013AA102903) and Guangxi Natural Science Foundation (2015GXNSFAA139049).

References

Andrade FH, Calvino P, Cirilo A, Barbieri P, 2002. Yield responses to narrow rows depend on increased radiation interception. Agron J 94: 975-980

Angadi SV, Entz MH, 2002. Root system and water use patterns of different height sunflower cultivars. Agron J 94: 136-145

Bandyopadhyay PK, Mallick S, Rana SK, 2005. Water balance and crop coefficients of summer-grown peanut (*Arachis hypogaea* L) in a humid tropical region of India. Irrig Sci 23: 161-169

Bishnoi UR, Mays DA, Fabasso MT, 1990. Response of no-till and conventionally planted grain sorghum to weed control method and row spacing. Plant Soil 129: 117-120

Bosznay M, 1989. Generalization of SCS curve number method. J Irrig Drain Eng 155: 139-144

Bowers GR, Rabb JL, Ashlock LO, Santin JB, 2000. Row spacing in the early soybean production system. Agron J 92: 524-531

Brant V, Neckář K, Pivec J, Duchoslav M, Holec J, Fuksa P, Venclová V, 2009. Competition of some summer catch crops and volunteer cereals in the areas with limited precipitation. Plant Soil Environ 55: 17-24

De Bruin JL, Pedersen P, 2008. Effect of row spacing and seeding rate on soybean yield. Agron J 100: 704-710

Debaeke P, Aboudrare A, 2004. Adaptation of crop management to water-limited environments. Eur J Agron 21: 433-446

Ethredge WJ, Ashley DA, Woodruff JM, 1989. Row spacing and plant population on yield components of soybean. Agron J 81: 947-951

Godfray HCJ, Beddington JR, Crute IR, Haddad L, Lawrence D, Muir JF, Pretty J, Robinson S, Thomas SM, Toulmin C, 2010. The challenge of feeding 9 billion people Science. Food Secur 327: 812-818

Gong YS, Li BG, 1995. Using field water balance model to estimate the percolation of soil water. Adv Water Sci 6: 16-21 (In Chinese).

Huang M, Gallichand J, Zhong L, 2004. Water-yield relationships and optimal water management for winter wheat in the Loess Plateau of China. Irrig Sci 23: 47-54

Li F, Wei C, Zhang F, Zhang J, Nong M, Kang S, 2010. Water-use efficiency and physiological responses of maize under partial root-zone irrigation. Agric Water Manage 97: 1156-1164

Meng E, Hu R, Shi X, Zhang S, 2006. Maize in China: production systems, constraints, and research priorities. CIMMYT, Mexico

Neal JS, Fulkerson WJ, Sutton BG, 2011. Differences in water-use efficiency among perennial forages used by the dairy industry under optimum and deficit irrigation. Irrig Sci 29: 213-232

Ritchie SW, Hanway JJ, Benson GO, 1996. How a corn plant develops. Spec Rep 48. Rev e. Iowa State Uni Coop Ext Serv, Ames

Schneider AD, Howell TA, 1997. Methods, amounts, and timing of sprinkler irrigation for winter wheat. Trans ASAE 40: 137-142

Timlin D, Pachepsky Y, Reddy VR, 2001. Soil water dynamics in row and interrow positions in soybean (*Glycine max* L). Plant Soil 237: 25-35

Wang GY, Han YY, Zhou XB, Chen YH, Ouyang Z, 2014. Planting pattern and irrigation effects on

water-use efficiency of winter wheat. Crop Sci 54: 1166-1174
Zhang Y, Kang S, Ward EJ, Ding R, Zhang X, Zheng R, 2011. Evapotranspiration components determined by sap flow and microlysimetry techniques of a vineyard in northwest China: Dynamics and influential factors. Agric Water Manage 98: 1207-1214
Zhou XB, Chen YH, Ouyang Z, 2015. Spacing between rows: effects on water-use efficiency of double-cropped wheat and soybean. J Agric Sci 153: 90-101
Zhou XB, Yang GM, Sun SJ, Chen YH, 2010. Plant and row spacing effects on soil water and yield of rainfed summer soybean in the northern China. Plant Soil Environ 56: 1-7
Zuo Q, Shi J, Li Y, Zhang R, 2006. Root length density and water uptake distributions of winter wheat under sub-irrigation. Plant Soil 285: 45-55