The Journal of Animal & Plant Sciences, 23(5): 2013, Page: 1379-1384
ISSN: 1018-7081

SPATIAL ARRANGEMENT EFFECTS ON SOIL AND LEAF WATER STATUS OF WINTER WHEAT

J. Huang, Y. H. Chen[*], X. B. Zhou[*], P. Liu[*], J. J. Bi[*] and Z. Ouyang[**]

Water Conservancy and Civil Engineering College, Shandong Agricultural University, Tai'an, China
[*]College of Agronomy, State Key Laboratory of Crop Biology, Shandong Agricultural University, Tai'an 271018, China
**Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing, P.R. China
Corresponding author email: whyzxb@gmail.com; liup@sdau.edu.cn

ABSTRACT

The effects of row spacing (RS) on soil water content (SMC), leaf relative water content (RWC), leaf water potential (Ψ), and osmotic potential (π) in winter wheat were investigated in Northern China during 2006–2007 and 2007–2008. The experiments consisted of four planting patterns resulting in the same plant density (2.04×10^6 plant ha^{-1}), with RS of 7, 14, 24.5, and 49 cm. A significant negative correlation was observed between RS and yield (Y) during both years ($P < 0.05$). RWC and π correlated positively with Y, and SMC while Ψ had an opposite effect on wheat. SMC decreased with increased RS, and RWC gradually decreased with the growth of crops. RWC and Ψ for RS 14, as well as π for RS 7 were higher than those for RS 24.5 and 49. At the flowering stage, the hourly Ψ of the different RS treatments produced a V-shaped curve trend in 1 day, and the coefficient of variation of RS 14 was relatively stable under different precipitation conditions. The results of this study indicated that the yield of RS 14 was significantly higher than that of RS 49 ($P < 0.05$), and an appropriate narrow RS was able to increase the yield of crops.

Key words: *Triticum aestivum*; soil moisture content; leaf relative water content; leaf water potential; leaf osmotic potential; yield.

INTRODUCTION

Preserving fresh water sources plays a crucial role in sustainable agriculture because water has one of the greatest effects on crop yields and yield parameters. The increasing demand for fresh water sources results in the necessity of saving as much water as possible (Dogan *et al*., 2006). The great challenge lies in increasing food production with less water, particularly in countries with limited water and land resources (Debaeke and Aboudrare, 2004). Studies have shown that planting potatoes (*Solanum tuberosum* L.) in a bed configuration can improve water movement into the potato root zone (Panda *et al*., 2003; Tarkalson *et al*., 2011). Bertram and Pedersen (2004) have reported yield increase of soybean in 0.19 m vs. 0.76 m rows in Wisconsin in a 3-year study. Grain sorghum produced significantly higher yields in 45 cm row spacings (RS) than in 60 and 90 cm RSs using all three planting methods (Bishnoi, 1990). The yield and economic benefits are sufficient to support the production of soybean in narrow rows and at seeding rates below the current seeding rate recommendations (De Bruin and Pedersen, 2008).

At higher rainfall rates, the proportion of rainfall reaching the soil as stemflow decreases. The amount of stemflow has also been found to be correlated with the total leaf area (Bui and Box, 1992). Plant patterns have obvious effects on the population structure and leaf area index of winter wheat (Zhou *et al*., 2011a), so that it can change the distribution of raindrops in the field. The water relations of the plant play a vital role in the phloem translocation of solutes from the source to sink organs and partitioning of assimilates (Mohapatra *et al*., 2003). The partitioning of solutes from the leaf depends on adequate phloem turgor; low water potential under drought conditions reduces the driving force for sap flow into fruits. For most plants, the immediate response to water deficit is the decline in the leaf water potential (Ψ), which leads to stomatal closure and reduced photosynthesis. Prolonged drought can limit plant growth and biomass production, alter the allocation pattern of biomass, and even cause plant death (Puri and Swamy, 2001; Rodiyati *et al*., 2005).

Reduced soil water availability leads to low plant water potential. Consequently, among the first plant responses to avoid excessive transpiration, the leaves lose turgescence, the stomata close, and cell elongation is halted (Souza *et al*., 2010). There is a negative relationship between the net photosynthetic rate and water stress expressed (Peri *et al*., 2011). Water stress induces decrease in the shoot dry weight and relative water content (RWC) (Martìnez *et al*., 2004). Inadequate soil moisture leads to water deficits in leaf tissues, which affects many physiological processes and ultimately reduces the yield (Mahmood *et al*., 2012). Rainfall and soil moisture mediate the effect of RSs on the soybean yield, and the yield tends to increase with decreased RS in years of average rainfall (Zhou *et al*., 2010).

This study aimed to investigate the effects of

RS-induced water stress by comparing water stress tolerance strategies, and to select the most tolerant planting pattern. For these purposes, the moisture contents of leaves and soil were determined to provide relevant information for the selection and management of RS in the region.

MATERIALS AND METHODS

Site description: This research was conducted at the experimental farm of Shandong Agricultural University, Taian (36°09' N, 117°09' E) in northern China. The site is representative of the main winter wheat-growing region of Huanghuaihai Plain. Long-term (years 1971 to 2008) average rainfall and temperature were 696.6 mm and 12.8 °C, respectively, whereas the rainfall was about 200 mm during the winter wheat growth season. The soil is characterized as silt loam with an average soil organic matter of 16.3 g kg^{-1}, N of 92.98 mg kg^{-1}, P of 34.77 mg kg^{-1}, K of 95.45 mg kg^{-1}, and pH of 6.9.

Experimental design: The experiments were conducted during the growing seasons from October to June during 2006–2007 and 2007–2008. As part of the continuous winter wheat (*Triticum aestivum*)–summer soybean [*Glycine max* (L.) Merr.] rotation experiment, post-summer soybean plants were hand harvested and their stubbles were removed. Winter wheat (cv. Shannong 919) was hand planted according to the plant density (4.08×10^6 plant ha^{-1}) on October 6, 2006 and October 10, 2007. The experiments consisted of four planting patterns under irrigation and rainfed conditions. RS × plant spacing was 7 × 7 cm (RS 7, a uniform grid pattern), 14 × 3.5 cm (RS 14), 24.5 × 2 cm (RS 24.5), and 49 × 1 cm (RS 49).

Each experiment plot was 3 m × 3 m in size and replicated thrice in randomized block designs. Concrete slabs were inserted into a depth of 2.0 m and a width of 15 cm on four sides of each plot. Plastic films (0.1 mm thick) were also placed along the concrete wall. Hence, the lateral flow of soil water was prevented. Seedling thinning was performed by hand 5 days after wheat emergence to obtain the same final population density (2.04×10^6 plant ha^{-1}). The crops were harvested on June 5, 2007 and June 13, 2008. The yields were measured on a 2 m^2 per plot. The weather data were collected from the Taian Agrometeorological Experimental Station located 500 m from the experimental site. Data on the long-term monthly rainfall from October to June (from 1971 to 2008) are shown in Figure 1. During the winter wheat growth season, the total rainfall values during 2006–2007 and 2007–2008 were 212.5 and 169.9 mm, respectively.

Soil moisture measurements: Neutron moisture meter access tubes (one per treatment replicate) were installed between rows at each location at a depth of 1.3 m prior to sowing. The soil moisture content (SMC) was monitored every 7–10 days throughout the winter wheat growing season at 10 cm intervals from 20 cm to 120 cm depths using a locally field-calibrated CNC503B (DR) Neutron Moisture Probe (Super Energy Nuclear Technology Ltd., Beijing, China). The moisture content of the top 20 cm soil profile was determined using a portable time domain reflectometry CS620 system (Campbell Scientific Australia Ptv. Ltd., Townsville).

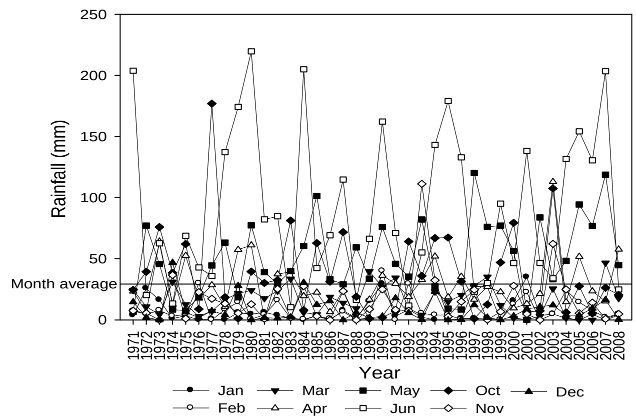

Fig. 1 The average monthly rainfall during October–June (1971-2008).

Leaf water relation measurements: The leaf RWC was measured every 10 days from jointing to maturity on clear-sky days at 08:30 h. Sixteen leaves per treatment were obtained from different individual plants. The sampled leaves were fully expanded no. 6 leaves at the jointing stage, and the flag leaf since the flag leaf stage with normal physiological status. RWC was calculated by the equation RWC (%) = (Fw – Dw) / (Tw – Dw) × 100 (Galmés *et al*., 2007; Aydi *et al*., 2008), where Fw is the fresh weight, Dw is the dry weight, and Tw is the turgid weight of the leaf samples. The leaves were excised, weighed fresh, and placed in distilled water to rehydrate in the dark at 4 °C to minimize respiration losses until they reached a constant weight (full turgor, typically after 12 h). The leaf turgid weight was measured and the leaves were dried at 80 °C for 48 h, after which the dry weight was determined.

At the start of the experiment, the concomitant Ψ and osmotic potential (π) were measured. Ψ was measured using a PSYPRO Water Potential System (Wescor, Inc., Logan, UT USA) with eight Model C-52-SF sample chambers [7 (diameter) × 1.25 (depth) mm], measuring three leaves for each treatment. Water loss was minimized during the transfer of each leaf to the sample chamber by enclosure in a black plastic bag immediately after excision. Approximately 6 mm-diameter discs were cut from the leaves and sealed in the sample chamber. The samples were equilibrated for 20 min before the readings were recorded. During the flowering stage, Ψ was measured every hour from 07:00

h to 18:00 h.

π was measured cryoscopically using a 5520 Vapor Pressure Osmometer (Wescor, Inc., Logan, UT USA) with a sample holder. The discs were immediately wrapped in a black plastic bag and frozen in an icebox (-20 °C), and later thawed at the time of measurement in the laboratory (Guenni *et al*., 2004).

Statistical analysis: All data were analyzed using the SPSS 16.0 Statistical Software Package. The least significant difference test was used. The effects were considered significant in all statistical calculations if the *P* values were ≤ 0.05 (Mishra *et al*., 2001).

RESULTS AND DISCUSSION

SMC: SMC decreased with the growing process (Figure 2). The fluctuation of SMC was evidently related to the rainfall. In 2007, the high SMC average value at the 0–120 cm soil layer on 24 May might have been affected by 104.7 mm of rainfall on May 20–23. For RS 7, 14, 24.5, and 49, the SMC averages were 25.4%, 24.3%, 24.6%, and 23.7%, respectively, in 2007, and SMC of RS 7 was significantly higher than that of RS 49. In 2008, the SMC averages were 25.6%, 25.6%, 25.6%, and 27.0%, respectively, and SMC of RS 49 was significantly higher than those of the other treatments (P < 0.05). The opposite changes were observed with RS 49 during 2007. Ibt

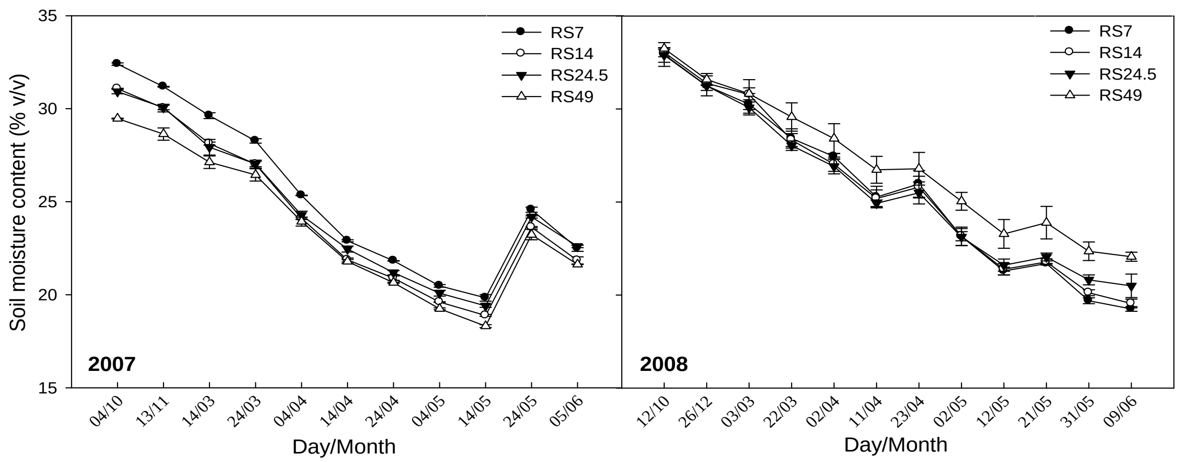

Fig. 2 Soil moisture content during 2007 and 2008. The values are averages of measurements made at 10 cm increments between 0 and 1.2 m depth. Error bars are standard error (±SE).

Leaf RWC: RS had a significant effect on the leaf RWC of (Figure 3). RWC gradually decreased during the cropping season for the six measurement dates, although RWC slightly recovered under rainfall. There was an overall trend of higher RWC values with narrow rows during both growing seasons. The RWC averages of RS 7, 14, 24.5, and 49 were 87.47%, 88.48%, 86.23%, and 84.40% in 2007, and 91.44%, 91.85%, 89.88%, and 89.08% in 2008, respectively. RWC of the RS 14 treatment was significantly higher than those of the RS 24.5 and 49 treatments (P < 0.05).

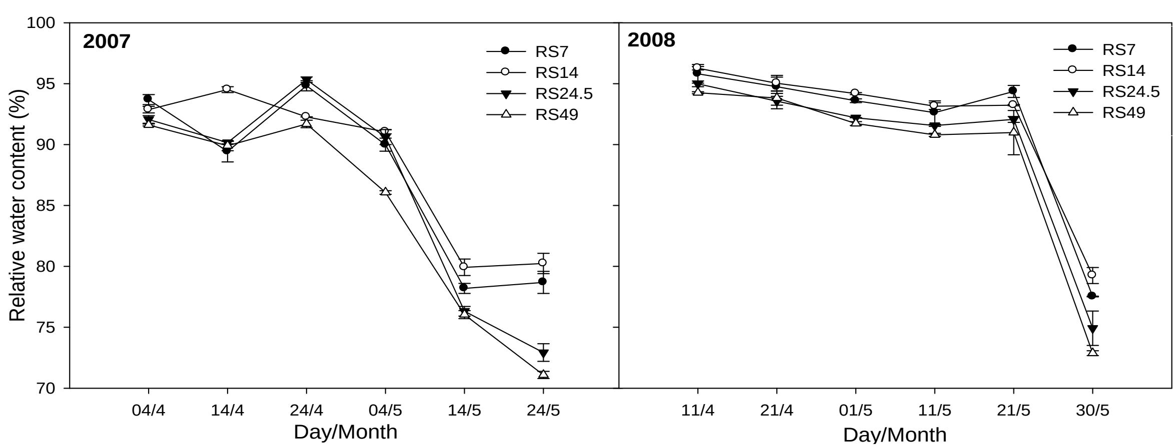

Fig. 3 Leaf relative water content of wheat under different row spacings. Error bars are standard error (±SE).

Ψ: It was observed that RS had a significant effect on Ψ. As expected, the changes in Ψ closely paralleled those of RMC (Figures 3 and 4). The values of Ψ during both growing seasons ranged from -0.82 MPa to -2.43 MPa regardless the amount of rainfall (Figure 4). During 2007, Ψ averages of RS 7, 14, 24.5, and 49 were -1.65, -1.84, -1.61, and -1.32 MPa, respectively; the average of RS 49 was 27.9% higher than that of RS 14. During 2008, Ψ averages were -1.14, -1.12, -1.23, and -1.23 MPa, respectively; the averages of both RS 7 and 14 were 8.3% higher than those of RS 24.5 and 49.

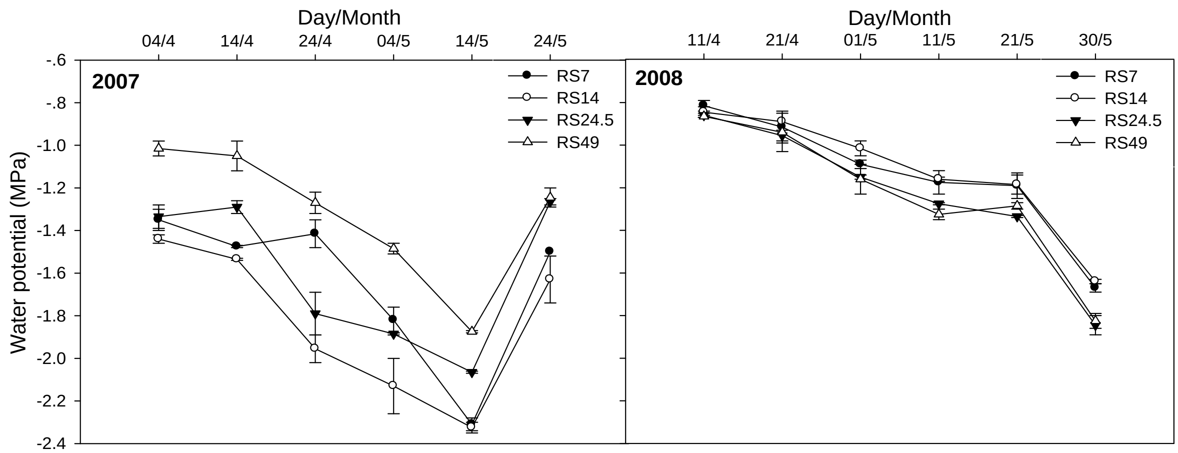

Fig. 4 Effect of row spacing on the leaf water potentials of wheat plant. Error bars are standard error (±SE).

Ψ changed with the time of day (Figure 5). The hourly Ψ of the different treatments produced a V-shaped curve during the flowering stage (May 6, 2007 and 2008), and the minimum of the curve appeared in midday (from 11:00 h to 13:00 h). The RS had obvious effects on Ψ. During 2008, the order of Ψ averages in 1 day was RS 7 ≈ 14 > 24.5 > 49, and the averages of both RS 7 and 24.5 were 4.6% higher than those of RS 24.5 and 49. However, there was no obvious change regulation among the RS treatments in 2007. The range of Ψ fluctuations of RS in 1 day was wider. The coefficients of variation (CVs) of RS 7, 14, 24.5, and 49 were -19.0%, -13.8%, -19.3%, and -25.1% in 2007, and -13.7%, -14.9%, -13.2%, and -12.6% in 2008, respectively. The result showed that the CV of the RS 14 treatment was relatively stable under different climate conditions, especially during rainfall.

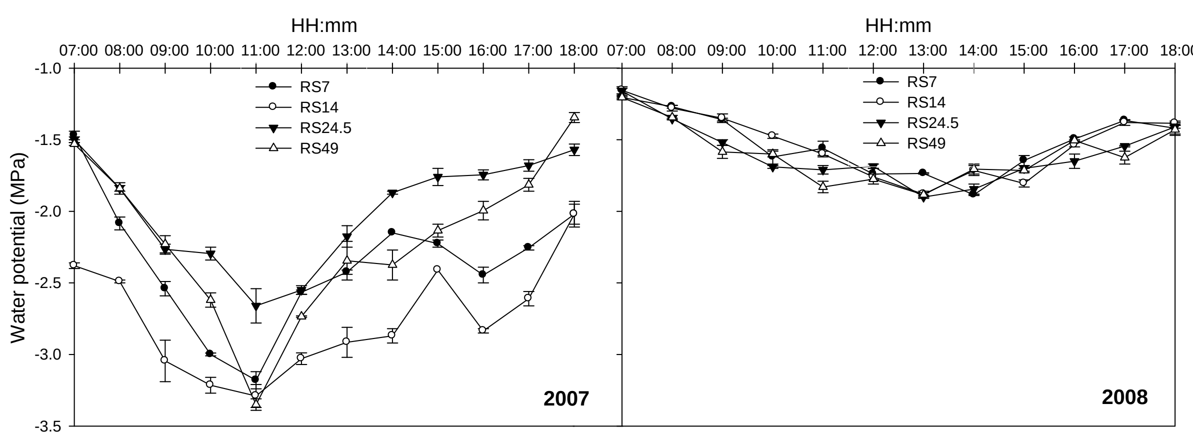

Fig. 5 Daily variation of leaf water potential under different treatments. The data was measured on 6 May 2007 and 2008. Error bars are standard error (±SE).

π: The changes in π closely paralleled those of Ψ. There was an overall trend of higher π values with narrow rows in 2007. During both growing seasons, the CVs were -16.3% and -18.1%, respectively, which might have been affected by rainfall. During the experiment, the π values of RS 7 were higher than those of RS 24.5 and 49 (Figure 6), and the percentages were 2.5% and 4.6% in 2007, as well as 4.3% and 6.2% in 2008, respectively. The π averages of RS 7, 14, 24.5, and 49 were -1.68, -1.78, -1.72, and -1.76 MPa (in 2007), and -1.36, -1.35, -1.42 and -1.45 MPa (in 2008), respectively.

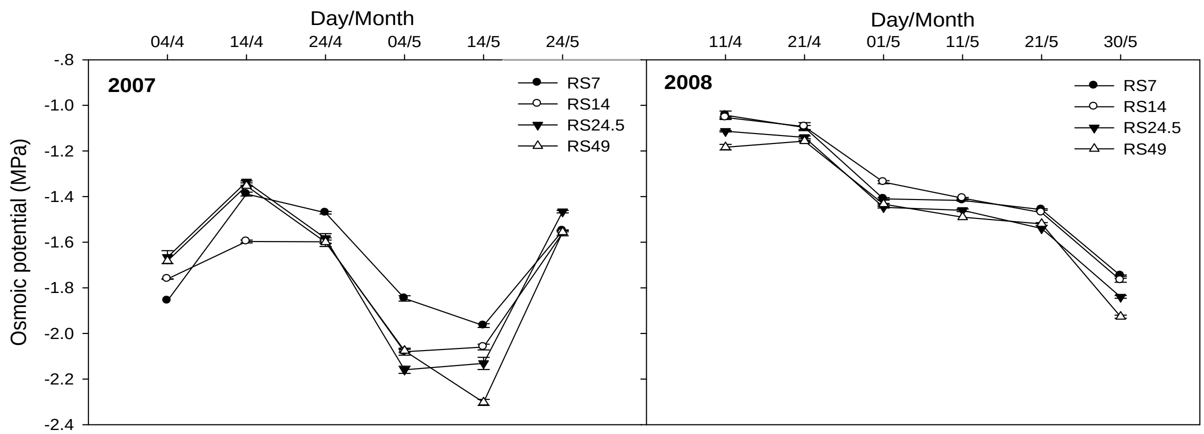

Fig. 6 Effect of row spacing on the leaf osmotic potential of wheat plant. Error bars are standard error (±SE).

Plant water relations with yield: During both years, the yield averages of RS 7, 14, 24.5, and 49 were 7333, 7241, 7204, and 6391 kg ha^{-1} (data not shown), respectively, and the yield of RS 14 was significantly higher than that of RS 49 (P < 0.05). A significant negative correlation was observed among Y and RS in both years (P < 0.05). RWC and π correlated positively with Y in wheat, whereas SMC and Ψ correlated negatively with Y, especially in Ψ (Table 1). These results indicated that the wide RS was adverse to the yield of crop.

Table 1. Correlation coefficients between row spacing (RS), soil moisture content (SMC), leaf relative water content (RWC), leaf water potential (Ψ), leaf osmotic potential (π), and yield (Y) of wheat in 2006–2008

	SMC	RWC	Ψ	π	Y	RS
SMC	1					
RWC	-0.343	1				
Ψ	0.679	-0.867	1			
Π	0.287	0.741	-0.508	1		
Y	-0.381	0.912	-0.937	0.773	1	
RS	0.108	-0.918	0.801	-0.921	-0.954*	1

*, Correlation is significant at the 0.05 level.

The daily rainfall caused the fluctuation of SMC, and the RS also affected SMC. SMC and soil storage water decreased with increased evapotranspiration (ETa) and soil evaporation (Es) after the reproductive stage; the wide RS increased the ETa and Es. In this study, SMC decreased with increased RS, and these results were similar to that of summer soybean under rainfed conditions (Zhou *et al*., 2010).

Water from leaves is usually viewed as important information on living plants (Yu *et al.*, 2000). In this study, the RS obviously affected the leaf water status. RWC gradually decreased with the crop growth. During the cropping season, RWC and Ψ for RS 14 were significantly higher than those for RS 24.5 and 49 (P < 0.05). In 1 day, the CV of RS 14 was relatively stable under different precipitation conditions. The changes in π closely paralleled those in Ψ. The π average of RS 7 was higher than those of RS 24.5 and 49 during both growing seasons.

Vegetative growth continues during the reproductive stage and exacerbated the competition for the limited production of photoassimilates. The translocation of assimilates from the source leaf to the grain in crop plant is exposed to factors, such as impairment of water supply (Ohashi *et al*., 2000). The results of this study indicated that the yield of RS 14 was significantly higher than that of RS 49 (P < 0.05). SMC and Ψ correlated negatively with Y in wheat, which was inconsistent with the result of a soybean experiment (Zhou *et al*., 2011b). These results indicated that wide RSs were adverse to the crop yield, and that narrow RSs enabled resistance to drought stress, leading to increased crop yield.

Acknowledgments: This study was funded by the National High Technology Research and Development Program of China (2013AA102903), the Special Fund for Agro-scientific Research in the Public Interest (200903040, 201103001), the National Key Technology Support Program of China (2011BAD16B14), and by the Special Fund for Meteorologic-scientific Research in the Public Interest (GYHY201306046).

REFERENCES

Aydi, S. S., S. Aydi, E. Gonzalez, and C. Abdelly (2008). Osmotic stress affects water relations, growth, and nitrogen fixation in Phaseolus vulgaris plants. Acta Physiol. Plant 30: 441–449.

Bertram, M. G. and P. Pedersen (2004). Adjusting management practices using glyphosate-resistant soybean cultivars. Agron. J. 96: 462–468.

Bishnoi, U. R., D. A. Mays, and M. T. Fabasso (1990). Response of no-till and conventionally planted grain sorghum to weed control method and row spacing. Plant Soil 129:117–120.

Bui, E. N. and J. E. J. Box (1992). Stemflow, rain throughfall and erosion under canopies of corn and sorghum. Soil Sci. Soc. Am. J. 56: 242–247.

Cox, W. J. and J. H. Cherney (2011). Growth and yield responses of soybean to row spacing and seeding rate. Agron. J. 103:123–128.

De Bruin, J. L. and P. Pedersen (2008). Effect of row spacing and seeding rate on soybean yield. Agron. J. 100: 704–710.

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

Dogan, E., G. A. Clark, D. H. Rogers, V. Martin, and R. L. Vanderlip (2006). On farm scheduling studies and CERES-Maize simulation of irrigated corn. Appl. Eng. Agric. 22: 509–516.

Galmés, J., J. Flexas, R. Savé, and H. Medrano (2007). Water relations and stomatal characteristics of Mediterranean plants with different growth forms and leaf habits: responses to water stress and recovery. Plant Soil 290: 139–155.

Guenni, O., Z. Baruch, and D. Marín (2004). Responses to drought of five Brachiaria species. II. Water relations and leaf gas exchange. Plant Soil 258: 249–260.

Mahmood, N., B. Ahmad, S. Hassan, and K. Bakhsh (2012). Wheat yield response to physiological limitations under water stress condition. The J. Anim. Plant Sci. 22: 773–780.

Martìınez, J. P., S. Lutts, A. Schanck, M. Bajji, and J. M. Kinet (2004). Is osmotic adjustment required for water stress resistance in the Mediterranean shrub *Atriplex halimus* L? J. Plant Physiol. 161: 1041–1051.

Mishra, H. S., T. R. Rathore, and U. S. Savita (2001). Water-use efficiency of irrigated winter maize under cool weather conditions of India. Irrigation Sci. 21: 27–33.

Mohapatra, P. K., N. C. Turner, and K. H. M. Siddique (2003). Assimilate partitioning in chickpea (*Cicer arietinum* L.) in drought prone environment. In: Saxena NP (ed) Management of agricultural drought: agronomy and genetic options. Science Publishers Inc., Enfield, pp 173–188.

Ohashi, Y., H. Saneoka, and K. Fujita (2000). Effect of water stress on growth, photosynthesis, and photoassimilate translocation in soybean and tropical pasture legume siratro. Soil Sci. Plant Nutr. 46: 417–425.

Panda, R. K., S. K. Behera, and P. S. Kashyap (2003). Effective management of irrigation water for wheat under stressed conditions. Agr. Water Manage. 63: 37–56.

Peri, P. L., M. Arena, G. M. Pastur, and M. V. Lencinas (2011). Photosynthetic response to different light intensities, water status and leaf age of two *Berberis* species (Berberidaceae) of Patagonian steppe, Argentina. J. Arid. Environ. 75: 1218–1222.

Puri, S. and S. L. Swamy (2001). Growth and biomass production in Azadirachta indica seedling in response to nutrients (N and P) and moisture stress. Agroforest. Syst. 51: 57–68.

Rodiyati, A., E. Arisoesilaningsih, Y. Isagi, and N. Nakagoshi (2005). Responses of *Cyperus brevifolius* (Rottb.) Hassk. and *Cyperus kyllingia* Endl. to varying soil water availability. Environ. Exp. Bot. 53: 259–269.

Souza, B. D., M. V. Meiado, B. M. Rodrigues, and M. G. Santos (2010). Water relations and chlorophyll fluorescence responses of two leguminous trees from the Caatinga to different watering regimes. Acta Physiol. Plant 32: 235–244.

Tarkalson, D. D., B. A. King, D. L. Bjorneberg, and J. P. Taberna Jr (2011). Evaluation of in-row plant spacing and planting configuration for three irrigated potato cultivars. Am. J. Potato Res. 88: 207–217.

Yu, G. R., T. Miwa, K. Nakayama, N. Matsuoka, and H. Kon (2000). A proposal for universal formulas for estimating leaf water status of herbaceous and woody plants based on spectral reflectance properties. Plant Soil 227: 47–58.

Zhou, X. B. and Y. H. Chen (2011a). Yield response of winter wheat to row spacing under irrigated and rainfed conditions. Bulg. J. Agric. Sci. 17: 158–166.

Zhou, X. B., G. M. Yang, S. J. Sun, and Y. H. Chen (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.

Zhou, X. B., L. Qi, G. M. Yang, and Y. H. Chen (2011b). Row spacing effect on soil and leaf water status of summer soybean. The J. Anim. Plant Sci. 21: 680–685.