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ROW SPACING EFFECT ON SOIL AND LEAF WATER STATUS OF SUMMER SOYBEAN

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ABSTRACT

The effects of row spacing (RS) on soil water content (SWC), leaf relative water content (RWC), leaf water potential (Ψ), and osmotic potential (π) were investigated in summer soybean crops in Northern China during the 2007 and 2008 growing seasons. The experiment consisted of five planting patterns resulting in the same plant population density (3.09×10^5 plant·ha^{-1}), with RS of 18, 27, 36, 45, and 54 cm. A significant negative correlation was observed between RS and SWC, RWC, Ψ, π, Y in both years ($P < 0.05$). SWC, RWC, Ψ, and π correlated positively with Y in soybean. The daily rainfall caused fluctuations in SWC. In 2007 and 2008, the mean values of RWCs, Ψ, and π for RS 18 and 27 were significantly higher than that of RS 54 ($P < 0.05$). At the grain-filling stage, the hourly Ψ of the different RS treatments produced a V-shaped curve trend in one day, and the minimum of the curve appeared in midday. These results indicated that this was a beneficial response for yield under the high SWC, RWC, Ψ, and π conditions. Therefore, narrow RS improved soil and leaf water status and could increase yield of crops.

Key words: Glycine max; soil water content; leaf relative water content; leaf water potential; leaf osmotic potential; yield.

INTRODUCTION

Water deficit, defined as the lack of adequate moisture necessary for a plant to grow normally and complete its life cycle (Zhu, 2002), is often a key factor limiting plant growth, productivity, and survival (Namirembe et al., 2009; Kamiloğlu, 2011). For most plants, the immediate response to water deficit is leaf water potential decline, which leads to stomatal closure and reduced photosynthesis. Furthermore, 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). Drought avoidance involves rapid phenological development, leaf rolling, leaf shading, reduced leaf area, and increased stomatal and cuticular resistance (Turner, 1986). Nevertheless, the water relations of the plant play a vital role in the phloem translocation of solutes from source to sink organs and partitioning of assimilates (Mohapatra et al., 2003). Partitioning of solutes from the leaf is dependent on adequate phloem turgor; low water potential under drought reduces the driving force for sap flow into the fruits.

The fractions of available and transpirable soil water have been widely documented (Wahbi and Sinclair, 2007). Reduction in 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). In rainfed areas, the lack of adequate moisture leading to water stress is a common occurrence caused by infrequent rains and poor irrigation (Wang et al., 2005).

Most annual summer crops in north China are not irrigated during the growing season. These crops are subjected to various degrees of water stress that reduce biomass and seed yields. The lack of adequate soil moisture leads to water deficits in leaf tissue, which affect many physiological processes, and ultimately reduce yield. Rainfall and soil moisture mediate the effect of row spacing (RS) on soybean yield, and yield tends to increase as RS decreases in years of average rainfall (Zhou *et al*., 2010, 2011). Water loss from evapotranspiration is also significantly greater in the row position than in the inter-row position (Timlin *et al*., 2001).

This study aimed to investigate the effects of RS-induced water stress, to compare water stress tolerance strategies, and to select the most tolerant planting pattern. For these purposes, the moisture content of leaves and soil were determined so that proper information could be provided 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 (36º09′N, 117º09′E) in Northern China. This site is representative of the main summer soybean-growing region of the Huanghuaihai Plain in China. The long-term yearly average (from 1971 to 2008) rainfall was 696.6 mm, and rainfall was approximately 500 mm from June to September. The soil was a silt loam with an average soil organic matter (SOM) of 16.3 g·kg^{-1}, with N, P and K of 92.98, 34.77, and 95.45 mg·kg^{-1}, respectively, and pH of 6.9. The SOM content was determined by the dichromate oxidation-titration method, and the total N content in the soil was determined by the Kjeldahl method (Nelson and Sommers, 1982). For the total K content of soil was determined by atomic absorption spectrophotometry, and P was determined colorometrically using the molybdenum blue method (Aarnio *et al*., 2003). Soil pH was measured in soil-water suspensions (1:2, vol/vol). The monthly amounts of rainfall during the summer soybean-growing seasons (June–September) were 203.4, 120.4, 186.0, and 29.3 mm in 2007, and 7.9, 273.3, 107.6, and 59.0 mm in 2008.

Experimental design: The experiments were established during the growing seasons of June to September in 2007 and 2008. As part of a continuous winter wheat-summer soybean [*Glycine max* (L.) Merr.] rotation experiment, winter wheat plants were first hand-harvested and the stubble removed. Then, determinate summer soybean seeds (cv. Ludou 4) were hand-sown to a plant density of 6.18×10^5 plant·ha^{-1} on June 13, 2007 and June 18, 2008. The experiment consisted of five planting patterns under the same plant population density (RS × plant spacing): 18 × 18 cm (RS 18), 27 × 12 cm (RS 27), 36 × 9 cm (RS 36), 45 × 7.2 cm (RS 45), and 54 × 6 cm (RS 54). All plots were thinned to one plant per hill 5 d after soybean emergence to obtain the same final population density (3.09×10^5 plant·ha^{-1}).

Each experiment plot was 3.5 × 6 m with three replications in a randomized block design. The crops were harvested on September 25, 2007 and September 24, 2008. Other cultural practices were similar to those generally used for non-irrigated summer soybean in the Huanghuaihai Plain; pests and weeds were adequately controlled.

Soil water measurements: The aluminum access tubes (diameter 45 mm) of the neutron moisture meter were installed between the rows at each location to a depth of 1.2 m prior to sowing (one per treatment-replicate). Soil volumetric water content (SWC) was monitored every 10 cm between depths of 0–120 cm. This were performed every 10 d during the summer soybean-growing season using a local field-calibrated CNC503B (DR) Neutron Moisture Probe (Super Energy Nuclear Technology Ltd., Beijing, China).

Leaf water relations measurements: The measurement of leaf relative water content (RWC) was performed every 10 d from branching to maturity, on clear-sky days at 08:00. Nine leaves per treatment were obtained from different individual plants. The sampled leaves were the fully expanded No. 7 ternate pinnate leaf with normal physiological status. RWC was calculated using 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 leaf samples. Leaves were excised, weighed fresh, and placed in distilled water to rehydrate in the dark at 4^0C to minimize respiration losses until they reached a constant weight (full turgor, typically after 12 h). Leaf turgid weight was measured, and leaves were then dried at 80^0C for 48 h, after which dry weight was determined.

At the start of the experiment, concomitant leaf water potential (Ψ) and osmotic potential (π) were measured. The Ψ was measured with 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. Discs approximately 6 mm in diameter were cut from the leaves and sealed in the sample chamber. Samples were equilibrated for 20 min before the readings were recorded. During the grain filling stage, Ψ was measured every hour from 08:00 to 17:00.

The π was measured cryoscopically with 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 (-20^0C), and was later thawed at the time of measurement in the laboratory (Guenni *et al*., 2004).

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

RESULTS

Soil moisture content and rainfall: SWC was related to daily rainfall of the current season and RS. In 2007, daily rainfall was relatively uniformly distributed, and fluctuation of SWC was small (Fig. 1a). However, in 2008, daily rainfall had obvious effects on SWC during the course of the study, and SWC had evident fluctuation (Fig. 1b). SWC decreased with RS increments. For RS 18, 27, 36, 45, and 54, the SWC averages were 35.2%, 34.6%, 34.6%, 34.3%, and 34.1%, respectively, in 2007, and SWC of RS 18 was significantly higher than that of RS 54. In 2008, SWC averages were 32.6%, 32.3%, 32.3%, 31.8%, and 31.9%, respectively, and the SWC of RS 18 was significantly higher than that of RS 45 ($P <$ 0.05).

Leaf relative water content: RS had a significant effect on the RWC of leaf (Table 1). RWC gradually decreased during the cropping season for the seven measured dates, although RWC had some recovery under rainfall. There was an overall trend of higher RWC values with narrow rows during both growing seasons. RWC averages of RS 18, 27, 36, 45, and 54 were 88.16%, 88.91%, 87.52%, 85.99%, and 85.41% in 2007, and 91.11%, 91.01%, 90.22%, 88.87%, and 87.85% in 2008, respectively. The RWCs of RS 18 and 27 treatments were significantly higher than those of RS 36, 45, and 54 treatments ($P < 0.05$).

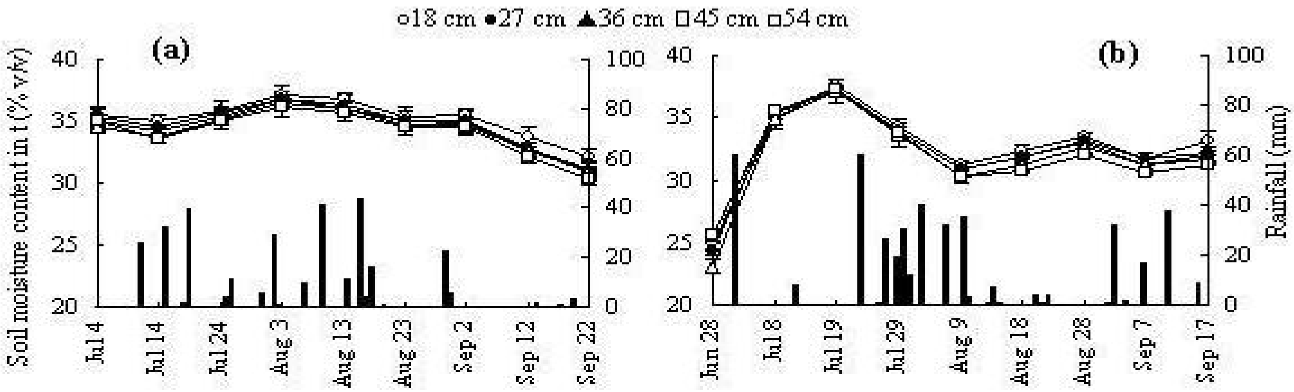

Fig. 1 Rainfall and soil moisture content in (a) 2007 and (b) 2008. Soil water content values are averages of weekly measurements made at 10 cm increments between 0 and 1.2 m depth. Error bars are standard deviation.

Table 1. Leaf relative water content of summer soybean under different row spacings (%)

2007	RS (cm)	Jul 4	Jul 14	Jul 24	Aug 3	Aug 13	Aug 23	Sep 2
	18	96.36a*	87.32ab	99.26a	80.76bc	85.98a	83.47ab	83.99a
	27	96.52a	89.27a	99.61a	82.58a	85.67ab	84.43a	84.29a
	36	95.64ab	87.27b	99.21a	81.19ab	84.96ab	82.90abc	81.48b
	45	95.34b	86.20b	96.91b	79.94bc	83.46bc	81.03c	79.07bc
	54	95.03b	85.64b	95.13c	79.58c	82.29c	82.03bc	78.18c
2008	**RS (cm)**	**Jul 9**	**Jul 19**	**Jul 29**	**Aug 8**	**Aug 18**	**Aug 28**	**Sep 7**
	18	88.34a	94.08a	85.96a	91.18a	96.09a	93.02a	89.10a
	27	87.22ab	94.41a	86.14a	91.24a	96.33a	92.39ab	89.34a
	36	86.53ab	92.68b	85.63ab	91.09a	95.19ab	92.03ab	88.36ab
	45	85.26b	92.50b	83.17c	89.41b	94.52ab	91.41b	85.84b
	54	85.60b	92.21b	82.50c	87.45b	93.83b	89.88c	83.48c

* Means within column groupings with similar letters are not significantly different from each other at the 0.05 probability level.

Table 2. Effect of row spacing on the leaf water potentials of soybean plant (MPa)

2007	RS (cm)	Jul 4	Jul 14	Jul 24	Aug 3	Aug 13	Aug 23	Sep 2
	18	-0.80a*	-0.83ab	-0.63bc	-1.12ab	-0.81a	-0.88b	-1.00a
	27	-0.82a	-0.80a	-0.59ab	-1.08a	-0.84ab	-0.83a	-0.97a
	36	-0.79a	-0.86bc	-0.54a	-1.14ab	-0.98c	-0.99c	-1.03ab
	45	-0.86a	-0.91c	-0.67c	-1.29c	-0.99c	-0.88b	-1.07bc
	54	-0.84a	-0.92c	-0.64bc	-1.20bc	-0.86b	-0.85a	-1.10c
2008	**RS (cm)**	**Jul 9**	**Jul 19**	**Jul 29**	**Aug 8**	**Aug 18**	**Aug 28**	**Sep 7**
	18	-0.69a	-0.68a	-0.52a	-0.66b	-0.71a	-0.73a	-0.90a
	27	-0.69a	-0.68a	-0.54ab	-0.59a	-0.72a	-0.73a	-0.89a
	36	-0.72ab	-0.70ab	-0.54ab	-0.76b	-0.76ab	-0.74ab	-0.90a
	45	-0.72ab	-0.70ab	-0.55ab	-0.84d	-0.77ab	-0.79b	-0.98b
	54	-0.73b	-0.71b	-0.58b	-0.90e	-0.81b	-0.82b	-1.03c

* Means within column groupings with similar letters are not significantly different from each other at the 0.05 probability level.

Leaf water potential: We found that RS had a significant effect on the Ψ. Changes in Ψ, as expected, closely paralleled trends in RWC (Tables 1 and 2). Values of Ψ in both growing seasons ranged from -0.52 to -1.29 MPa regardless of the rainfall (Table 2). During the cropping season, the Ψ averages of RS 18 and 27 were significantly higher than those of others ($P < 0.05$). In 2007, the Ψ averages of RS 18, 27, 36, 45, and 54 were -0.87, -0.85, -0.90, -0.95, and -0.92 MPa, respectively; the averages of RS 18 and 27 were 8.9% and 10.9% higher, respectively, than that of RS 45. In 2008, the Ψ averages were -0.70, -0.69, -0.73, -0.76, and -0.80 MPa, respectively; the averages of RS 18 and 27 were 12.4% and 13.3% higher, respectively, than that of RS 54.

The Ψ changed with the time of day. The hourly Ψ of the different treatments produced a V-shaped curve trend at the grain-filling stage (on August 19, 2007 and August 24, 2008), and the minimum of the curve appeared in midday (from 11:00 to 13:00), especially in RS 54 (Fig. 2). RS had obvious effects on Ψ in the course of this study. During both growing seasons, the order of the Ψ averages in one day was RS 18 ≈ 27 > 36 > 45 > 54, and averages of RS 18 and 27 were significantly higher than those of RS 45 and 54 ($P < 0.05$). The range of Ψ fluctuations of RS 54 in one day was greater compared to other treatments. In 2007 and 2008, the daily fluctuations were 0.43 and 1.46 MPa for RS 54, in contrast to merely 0.23 and 0.29 MPa for RS 18, and 0.24 and 0.35 MPa for RS 27.

Leaf osmotic potential: The changes in π closely paralleled trends in Ψ. There was an overall trend of higher π values with narrow rows during both growing seasons. In 2007 and 2008, the coefficients of variance were 14.5% and 17.5%, respectively, which might have been affected by rainfall. During the experiment, the π values of RS 18 and 27 were higher than those of RS 45 and 54 (Table 3), and the π averages of RS 18, 27, 36, 45, and 54 were -0.97, -0.96, -1.02, -1.07, and -1.07 MPa (in 2007) and -0.86, -0.90, -0.93, -0.98, and -1.00 MPa (in 2008), respectively. During both growing seasons, the π averages of RS 18 and 27 were significantly higher than that of RS 54 ($P < 0.05$), and the percentages were 10.2% and 11.2% in 2007, 16.7% and 10.6% in 2008, respectively.

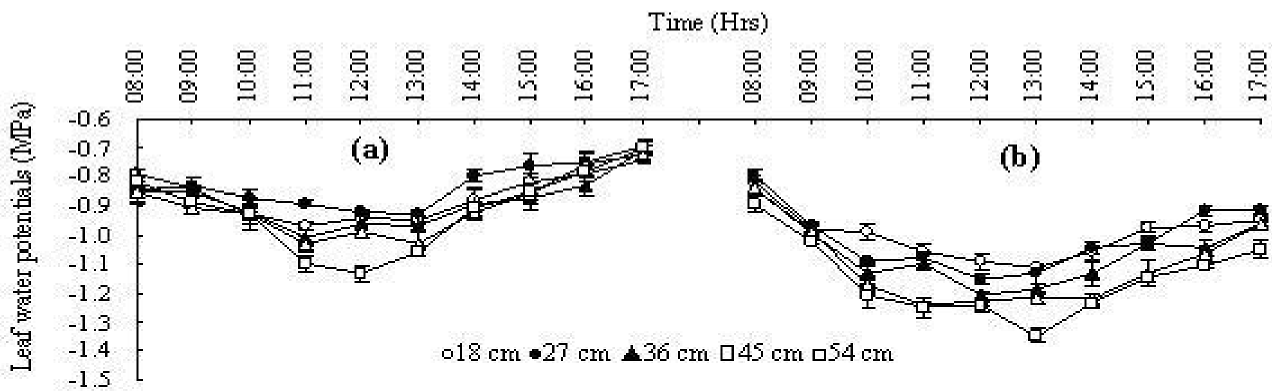

Fig. 2 Daily variation of leaf water potential under different treatments. The data was measured on 19 Aug 2007 (a) and 24 Aug 2008 (b). Error bars are standard error (±SE).

Table 3. Effect of row spacing on the leaf osmotic potential of soybean plant (MPa)

2007	RS (cm)	Jul 4	Jul 14	Jul 24	Aug 3	Aug 13	Aug 23	Sep 2
	18	-0.88a*	-0.85a	-0.77a	-1.19b	-0.98a	-1.00a	-1.13b
	27	-0.87a	-0.86a	-0.78a	-1.17a	-0.99a	-1.02b	-1.06a
	36	-0.87a	-0.90b	-0.80b	-1.24c	-1.12b	-1.10c	-1.14b
	45	-0.93b	-0.97c	-0.87c	-1.33d	-1.15c	-1.13d	-1.14bc
	54	-0.89ab	-0.98c	-0.93d	-1.25c	-1.16c	-1.11c	-1.16c
2008	**RS (cm)**	**Jul 9**	**Jul 19**	**Jul 29**	**Aug 8**	**Aug 18**	**Aug 28**	**Sep 7**
	18	-0.79a	-0.73a	-0.62a	-0.95a	-0.89a	-0.89a	-1.12a
	27	-0.81a	-0.80b	-0.65a	-0.96ab	-0.98b	-0.93ab	-1.19b
	36	-0.82a	-0.82b	-0.70ab	-0.97ab	-1.02bc	-0.98b	-1.20b
	45	-0.83a	-0.86bc	-0.78b	-0.99b	-1.09c	-1.07c	-1.23bc
	54	-0.86b	-0.88bc	-0.77b	-1.08c	-1.08c	-1.09c	-1.23bc

* Means within column groupings with similar letters are not significantly different from each other at the 0.05 probability level.

Plant water relations with yield: During both years, the yield averages of RS 18, 27, 36, 45, and 54 were 2531, 2513, 2272, 2221, and 2151 $kg \cdot ha^{-1}$ (data not shown), respectively, and the yield of RS 18 was significantly higher than that of RS 54 ($P < 0.05$). A significant negative correlation was observed among SWC, RWC, Ψ, π, Y, and RS in both years ($P < 0.05$). SWC, RWC, Ψ, and π correlated positively with Y in soybean, especially π (Table 4). RWC and π correlated positively with Ψ in both years ($P < 0.01$). These results indicated that the high SWC, RWC, Ψ, and π increased yield of crop, whereas wide RS was adverse.

Table 4. Correlation coefficients between row spacing (RS), soil water content (SWC), leaf relative water content (RWC), leaf water potential (Ψ), leaf osmotic potential (π), and yield (Y) of soybean in 2007-2008

	RS	SWC	RWC	Ψ	π	Y
	r					
RS	–	-0.959**	-0.943*	-0.915*	-0.979**	-0.957*
SWC		–	0.874	0.855	0.950*	0.869
RWC			–	0.966**	0.958*	0.930*
Ψ				–	0.970**	0.957*
π					–	0.970**
Y						–

*, ** Correlation is significant at the 0.05 and 0.01 level, respectively.

DISCUSSION

The daily rainfall effected fluctuation of SWC and RS also had obvious effects on SWC. The SWC and soil storage water decreased with evapotranspiration (ETa) and soil evaporation (Es) increments after the reproductive stage; the wide RS increased ETa and Es (Zhou *et al*., 2007). In this study, the SWC decreased with RS increments; these results are similar to those reported in studies that changed the RS of summer soybean under rainfed conditions (Zhou *et al*., 2010).

Crop growth is influenced directly by the water status in crop leaves, and indirectly by soil moisture and other factors (Kriedmann and Barrs, 1983). The water and nutritional status of leaves are usually viewed as important information in living plants (Yu *et al*., 2000; Puri and Swamy, 2001). In this study, RS was found to have obvious effects on leaf water status. RWC gradually decreased with the growth of crop. During the cropping season, the mean RWCs and Ψ for the RS 18 and 27 were significantly higher than in other treatments; in one day, the Ψ average of RS 18 and 27 were significantly higher than those of RS 45 and 54 ($P < 0.05$). Furthermore, changes in π closely paralleled trends in Ψ. The π averages of RS 18 and 27 were significantly higher than that of RS 54 during both growing seasons ($P < 0.05$).

In some cases, osmotic adjustment is associated with the maintenance of growth and stable yield under drought (Gunasekera and Berkowitz, 1992). The vegetative growth continues during the reproductive stage and exacerbates competition for the limited production of photoassimilates. Translocation of assimilates from the source leaf to the pods in soybean plant includes many factors, including impairment of water supply (Ohashi *et al*., 2000; Nobuyasu *et al*., 2003). The results of this study indicated that SWC, RWC, Ψ, and π correlated positively with Y in soybean, and the yield of RS 18 was significantly higher than that of RS 54 ($P < 0.05$). The narrow RS, especially with uniform distribution (RS 18), improved soil and leaf water status, and was able to resist drought stress, leading to increased yield of crop.

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