Growth and Adaptation of Soybean Cultivars under Water Stress Conditions

III. Yield response and dry matter production

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Abstract: Yield and dry matter production were examined under water-stress conditions. Two cultivars (Zhengzhuta 2 and Heinong 33) were grown in a concrete-framed field. From the flowering to the pod-filling stage, four levels of irrigation treatments were carried out (Treatment I, II, III and IV—from the severest, Treatment I to the non water stressed, Treatment IV). The growing periods were shorter with increasing amount of irrigation. Zhengzhuta 2 had larger shoot dry weight than Heinong 33 in every irrigation treatment. Dry weight of each organ tended to increase with increasing amount of irrigation during the treatment. Shoot dry weight ceased to increase in Treatment IV, but increased in the other treatments after the treatment. Percentage dry weight were higher in leaf and root of Zhengzhuta 2, and in pod of Heinong 33. Crop growth rates (CGRs), leaf area indices (LAIs), net assimilation rates (NARs) and pod growth rates (PGRs) were generally higher with increasing irrigation for both cultivars. CGR was closely related to LAI during the treatment. Pod, seed number and seed yield were greater in the plots with greater amount of irrigation. Zhengzhuta 2 had 5400 kg ha⁻¹ in Treatment IV. It's high-yielding potential seemed to be related to it's efficient leaf expansion and radiation interception ability.

Key words: Dry weight, Growth parameters, Irrigation, Pod number, Yield components.

乾燥条件下におけるダイズの生育と適応 第3報 かん水処理に対する乾物生産および収量性について: 王培武・磯田昭弘・魏 国治** (千葉大学園芸学部, **中国石河子農学院)

要 旨: 中国新疆の乾燥地域において、珍珠塔2号と黒農33号を用い、登熟期に4水準のかん水処理を設け、水分ストレス条件下における乾物生産の品種間差異について検討した。生育期間は、珍珠塔2号が黒農33号より長かった。部位別乾物重は、黒農33号に比べ珍珠塔2号が大きく、特に根乾物重が大きかった。かん水処理期間中、両品種とも全乾物重はかん水量が多いほど大きくなった。乾物重割合は、一般的に黒農33号に比べ珍珠塔2号は葉、根乾物重割合が大きく、莢乾物割合が小さかった。個体群生長速度(CGR)、葉面積指数(LAI)、純同化率(NAR)は、両品種とも全般的にかん水量の多い区ほど高い値をとった。莢乾物重増加速度(PGR)は、珍珠塔2号に比べ黒農33号が莢形成期が早いので大きくなり、両品種ともかん水量が多いほど高い値となった。生長パラメータ間の関係は、処理期間中、CGRとLAI、PGRとNARの間に有意な正の相関関係があった。両品種とも莢数、粒数は、かん水量が多いほど大きな値となった。子実収量は両品種ともかん水量が多いほど高く、珍珠塔2号のかん水IV区では5400 kg ha⁻¹と高収量を示した。珍珠塔2号の高収性の要因の1つは、高い葉面積展開能力によるLAIの増大がCGRを高めたことによると考えられた。

キーワード: かん水処理, 乾物重, 莢数, 収量構成要素, 生長パラメータ。

There is greater amount of solar radiation in the Xingjiang area. If there is no problem about water supply, the yield potential of crops will be very high. In fact, the yields of wheat, rice and maize are comparable to the maximum level of the world. In soybean, however, the average yield is still below 2000 kg ha⁻¹. It is necessary to investigate suitable breeding objectives and to establish proper cultivation methods in this arid area. Previously, we reported leaf movement and its relationship to intercepted radiation and leaf tempera-

ture as an adaptive mechanism under water-stress conditions^{24,25}. In this paper, we intend to examine dry matter production and yield ability under water-stress conditions, using two cultivars and four levels of irrigation treatments. Finally, the factors for high yielding under water-stress conditions were discussed, in relation to leaf area index, crop growth rate and radiation interception.

Materials and methods

The experiment was conducted in concrete framed fields (3.6 m × 32 m with 1.8 m in

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depth) of the experimental farm of Shihezi Agriculture College, Xingjiang, China in 1990. Two cultivars, Zhengzhuta 2 (active leaf movement) and Heinong 33 (inactive leaf movement), were sown at equidistant spacings of 35 cm on April 26. The seeding rate was 2 or 3 per stand, which was thinned to per stand after emergence. The soil was clay with less nitrogen, organic matter and much potassium. A combination of N, P_2O_5 and barnyard manure was applied in the ratio of 193 kg, 93 kg and 19.6 t per ha, respectively. From the seeding to the flowering stage, adequate irrigation was carried out when necessary. Four levels of the irrigation treatment were conducted as shown in Table 1 which were begun at the flowering stage (from June 20 to July 28). After the treatments, sufficient irrigation was made in every treatment plot from July 28 to the end of the growing season. The experimental plots were arranged in a split plot randomized complete block design with three replications. The main and sub-plots consisted of four irrigation treatments and two cultivars,

respectively.

From July 5, five plants from the center of the plot were harvested from each plot at intervals of two weeks. The roots were dug to a depth of 25 cm. The leaf area of the harvested plants was measured; and dry weight of each organ was recorded after oven drying for 48 hours at 80°C. At harvesting, eight plants were taken from each plot and seed yield and yield components were measured.

Results

1. Changes in dry weight with time

The growing period tended to be shorter as the amount of irrigation increased. Zhengzhuta 2 matured on September 10, 13, 16 and 20 for Treatment IV, III, II and I, respectively. In Heinong 33, the growing period was also longest in Treatment I, followed by Treatment II and III; and shortest in Treatment IV.

Fig. 1 indicates changes in dry weight with time. Zhengzhuta 2 had greater total dry weight during the growing season as compared to Heinong 33. During the irrigation treat-

Table 1. Amount of irrigation during the treatment (mm).

Treatment	June		Date July						Total amount of irrigation	Precipitation
	20	25	2	6	9	14	18	25		
IV	66.6	30.1	15.1	15.1	45.1	45.1	45.1	45.1	307.3	22.8
III	52.4	20.8	7.4	7.4	30.1	30.1	30.1	30.1	208.4	22.8
II	36.5	15.0	4.1	4.1	15.0	15.0	15.0	15.0	119.7	22.8
I	0	20.8	0	0	0	0	0	0	20.8	22.8

Fig. 1. Changes in dry weight with time.

ment, total dry weight in both Zhengzhuta 2 and Heinong 33 were greater with increased amount of irrigation. In particular, leaf and stem growth in Treatment IV was vigorous. The dry weight in Treatment I, except for the root, was smallest. After the treatment, shoot dry weight increased in Treatment III, II and I in both cultivars, although shoot growth in Treatment IV ceased. Root dry weight did not change with increasing amount of irrigation, though it decreased in other organs.

In general, the percentage of dry weight of Zhengzhuta 2 was greater in leaf and root and smaller in stem and pod dry weight as compared to Heinong 33 (Fig. 2). On July 5, the stem percentage in Treatment IV and the root percentage in Treatment I were higher in Zhengzhuta 2. The stem percentages in Treatment IV and the pod percentages in Treatment II and III increased on July 29 and August 17. In Heinong 33, the larger the amount of irrigation, the greater the pod percentage.

2. Growth parameters

Crop growth rates (CGRs) were generally proportional to the amount of irrigation in both cultivars. In particular, Zhengzhuta 2 showed higher CGRs in Treatment III and IV

Fig. 2. Changes in percentage of dry weight with time.

from July 5 to 29. The CGR in Treatment I was greater from July 29 to August 17, resulting in no great differences among the four treatments. Heinong 33 had small differences among the treatments as compared to Zhengzhuta 2, due to larger values in Treatment I and II. Leaf area indices (LAIs) also showed

Fig. 3. Changes in the growth parameters with time.

A : June 20 to July 5, B : July 5 to July 29 and C : July 29 to Aug. 17

CGR : Crop growth rate, LAI : Leaf area index, NAR : Net assimilation rate and PGR : Pod growth rate.

Table 2. Relationship among growth parameters.

Period	n	CGR-LAI	CGR-NAR	CGR-PGR	NAR-LAI	PGR-LAI	PGR-NAR
June 20-July 5	8	0.810*	0.715*	0.224	0.182	-0.287	0.738*
July 5-July 29	8	0.949**	0.094	0.155	-0.216	-0.148	0.971**
July 29-Aug. 17	4	-0.255	0.529	0.859	-0.951*	-0.430	0.703

*, **: 5% and 1% level of significance.

Table 3. Yield and yield components.

Cultivar	Treatment	Pod number (plant ⁻¹)	Seed number (pod ⁻¹)	Seed number (plant ⁻¹)	100 seed weight (g)	Total dry weight (gm ⁻²)	Harvest index (%)	Seed yield (kg ha ⁻¹)
Zhengzhuta 2	IV	158.3	1.58	248.8	26.51	141.7	46.77	5400.6
	III	147.8	1.55	228.9	26.88	127.3	48.44	5012.6
	II	138.6	1.53	213.4	26.59	117.2	48.16	4632.9
	I	116.1	1.56	195.9	26.13	93.8	48.71	3700.4
Significance		**	ns	**	ns	**	ns	**
Correlation coefficient with seed yield		0.874**	0.195	0.679*	0.374	0.956**	0.233	
Heinong 33	IV	112.6	2.78	312.2	17.98	104.4	53.8	4572.8
	III	98.1	2.66	265.0	20.20	96.1	55.7	4363.4
	II	88.3	2.61	230.6	21.58	94.4	53.1	4075.5
	I	69.1	2.54	175.3	20.12	66.5	52.5	2848.9
Significance		**	ns	**	*	*	ns	*
Correlation coefficient with seed yield		0.927**	0.717**	0.936**	-0.295	0.981**	0.535	

ns, *, **: No significance, 5% and 1% level of significance, respectively.

higher values in the plot with greater amount of irrigation. Zhengzhuta 2 had increased LAIs after July 29 as compared to Heinong 33. Particularly, LAI attained in Treatment IV was more than 6. Heinong 33 showed a little increase in LAIs even in Treatment IV and III. Net assimilation rates (NARs) also varied with the amount of irrigation during the treatment. During the period from July 29 to August 17 (after the treatment), However, Zhengzhuta 2 had smaller value in the plot with larger amount of irrigation. Heinong 33 showed rather high values as compared to Zhengzhuta 2. The differences among the treatments were smaller from July 5 to 29 due to the higher values of Treatment I and II. Pod growth rates (PGRs) in Zhengzhuta 2 were lower than those in Heinong 33 because of late pod formation. Every treatment in Zhengzhuta 2 had low values from June 20 to July 5. Treatment IV and III had greater PGRs in the next period, however, the differ-

ences among the treatments became small due to relatively large values in Treatment I and II. In Heinong 33, the differences among the treatments were small from July 5. In the next period, the plot with a larger amount of irrigation showed the higher PGRs.

Relationships among the growth parameters are shown in Table 2. CGR was significantly related to LAI from June 20 to July 29 and to NAR from June 20 to July 5. Between July 29 to August 17 (after the treatment), there was a negative relationship between NAR and LAI, indicating mutual shading in Treatment IV of Zhengzhuta 2. There were also significant correlations between PGR and NAR, revealing early pod formation in Heinong 33 and higher PGRs in Treatment III and IV of both cultivars increased NARs.

3. Yield and Yield components

Pod and seed number were greater in the plot with larger amount of irrigation (Table 3) in both cultivars. There was no significant

difference in the 100 seed weight in Zhengzhuta 2. In Heinong 33, however, Treatment IV was significantly lower. Harvest index was not significantly different among the treatments for both cultivars and was higher in Heinong 33 as compared to Zhengzhuta 2. The greater the amount of irrigation, the higher the seed yield in both cultivars. In particular, Treatment IV of Zhengzhuta 2 showed 5400 kg ha⁻¹. The yields of Treatment I were significantly lower for both cultivars, while there were no large differences among Treatment II, III and IV. The seed yield was significantly related to pod and seed number, indicating that the yield was decreased by the treatment, as pod number decreased.

Discussion

In this experiment, 5400 kg ha⁻¹ was obtained in less water stressed conditions. Even in the severest water stressed conditions, 3700 kg ha⁻¹ and 2849 kg ha⁻¹ were recorded for Zhengzhuta 2 and Heinong 33, respectively. Gotoh⁶⁾ reported that the highest yield recorded in soybean was 7860 kg ha⁻¹ for the agricultural institutes' level and 5720 kg ha⁻¹ for the farmers' level and that the necessary conditions for high-yield were greater number of pods and a long pod filling period. Gay et al.⁷⁾ also reported that high-yielding cultivars had long pod-filling periods and greater number of seeds per unit area. In general, it was reported that the growing period was shortened by water stress^{5,13,16,21)}. In this experiment, however, the more severely water-stressed plot showed the longest growing period. This difference might be caused by the period of the irrigation treatment. The irrigation treatments in the previous reports were made till the end of the growing season. In this experiment, however, the irrigation treatment was ceased in the middle and the end of the pod filling period (Zhengzhuta 2 and Heinong 33, respectively) and re-irrigation was carried out. Bunce³⁾ and Wenkert et al.²⁶⁾ reported that cell division continued but cell elongation was suppressed under water stressed conditions and that the suppression of cell elongation was rapidly supplemented after water stress was relieved. The water stressed plots in this experiment could re-start growth by re-irrigation. This would have extended the growing period, resulting in the high yields of the

irrigation treatments except the severest plot. Many reports have cited that there was less effect of water stress on seed yield before the reproductive stages as compared to, after the reproductive stages^{2,4,9,14,18,22)}. It has been also reported that the pod filling period was most critical for water stress and that seed yield was seriously reduced^{5,10,13)}. Water stress in this experiment was relieved during the greater part of the most critical period (i.e., the pod filling period), particularly in Zhengzhuta 2. There was no difference in 100 seed weight, indicating that the seed growth would not be affected by water stress after seed growth had been initiated, as was similarly reported by Ramseur et al.¹⁸⁾. Irrigation at the pod filling stage is of prime importance for seed yield in order to sustain pod number.

Kokubun¹²⁾ cited the present objective in the soybean breeding procedure would be the improvement of plant type for increasing yield, as a next step to the enlargement of leaf area. In drought conditions, however, the enlargement of leaf area may be the primary problem. There were significant correlations between CGR and LAI, indicating that the limiting factor for dry matter production would be leaf expansion ability. Varietal differences in leaf capacity for expansion existed, as was similarly reported by Frederick⁶⁾, i.e. Zhengzhuta 2 showed rather large LAI even in the more severely water-stressed plots. Leaf expansion ability is assumed to be closely related to the water absorption capacity of the root system. However, there are very few reports about this relationship¹⁹⁾. It has been reported that there is no close relationship between water absorption capacity and root distribution^{20,23)}, root dry weight¹⁾ and root length²⁰⁾. It was shown that the amount of water absorption increased with increasing root depth^{1,11)}. Zhengzhuta 2 with greater root system exhibited high drought tolerance. Therefore, this result suggests that the larger size of the root system may be one of the reasons for high leaf expansion ability under water-stress conditions. An adequate evaluation of water absorption and leaf expanding capacities will require further investigation.

In addition, leaf movement might play an important role for high yield observed in Zhengzhuta 2. In the previous papers^{24,25)}, it was found that the period of diaheliotropic

leaf movement increased, and intercepted radiation was greater as the amount of irrigation increased, resulting in increasing dry matter production in Zhengzhuta 2. It was reported that the optimum LAI in soybean ranged from 4.5 to 6¹⁷⁾. The longer maintenance of diaheliotropic movement may therefore be significant for increasing dry matter in soybean up to an LAI of 4 or 5. On the other hand, paraheliotropic movement may improve radiation penetration after the canopy is closed. After the treatment (recommencing irrigation), the LAI of Zhengzhuta 2 attained was 7, indicating that severe mutual shading caused a decrease in NAR. The irrigation control may be possible in reducing mutual shading and increasing radiation penetration, by promoting paraheliotropic movement in such a case. In this experiment, the possibility of high-yield was exhibited under drought conditions if sufficient water is available. Proper irrigation management will maintain pod numbers and manipulate leaf movement, resulting in high yield.

References

1. Allmaras, R.R., W.W. Nelson and W.B. Voorhees 1975. Soybean and corn rooting in southwestern Minnesota. I. Water-uptake sink. *Soil Sci. Am. Proc.* 39 : 764—771.
2. Ashley, D.A. and W.J. Ethridge 1978. Irrigation effects on vegetative and reproductive development of three soybean cultivars. *Agron. J.* 70 : 467—471.
3. Bunce, J.A. 1977. Leaf elongation in relation to leaf water potential in soybean. *J. Exp. Bot.* 28 : 156—161.
4. Doss, B.D. and D.L. Thurlow 1974. Irrigation, row width, and plant population in relation to growth characteristics of two soybean varieties. *Agron. J.* 66 : 620—623.
5. Foroud, N., H.H. Mündel, G. Saindon and T. Entz 1993. Effect of level and timing of moisture stress on soybean plant development and yield components. *Irrig. Sci.* 13 : 149—155.
6. Frederick, J.R., J.T. Woolley, J.D. Hesketh and D. B. Peters 1991. Seed yield and agronomic traits of old and modern soybean cultivars under irrigation and soil water-deficit. *Field Crop Res.* 27 : 71—82.
7. Gay, S., D.B. Egli and D.A. Reicosky 1980. Physiological aspects of yield improvement in soybeans. *Agron. J.* 72 : 387—391.
8. Gotoh, K. 1982. Limitations of yields in agricultural crops (2). *Agric. Hort.* 57 : 737—744***.
9. Heatherly, L.G. 1983. Response of soybean cultivars to irrigation of a clay soil. *Agron. J.* 75 : 859—864.
10. Huck, M.G., K. Ishihara, C.M. Peterson and T. Ushijima 1983. Soybean adaptation to water stress at selected stages of growth. *Plant Physiol.* 73 : 422—427.
11. Jung, Y.S. and H.M. Taylor 1984. Differences in water uptake rates of soybean roots associated with time and depth. *Soil Sci.* 137 : 341—350.
12. Kokubun, M. 1988. Design and evaluation of soybean ideotypes. *Bull. Tohoku Natl. Agric. Exp. Stn.* 77 : 77—142*.
13. Korte, L.L., J.H. Williams, J.E. Specht and R.C. Sorensen 1983. Irrigation of soybean genotypes during reproductive ontogeny. I. Agronomic responses. *Crop Sci.* 23 : 521—527.
14. Martin, C.K., D.K. Cassel and E.J. Kamprath 1979. Irrigation and tillage effects on soybean yield in a Coastal Plain soil. *Agron. J.* 71 : 592—594.
15. Mayaki, W.C., I.D. Teare and L.R. Stone 1976. Top and root growth of irrigated and nonirrigated soybeans. *Crop Sci.* 16 : 92—94.
16. Meckel, L., D.B. Egli, R.E. Phillips, D. Radcliffe and J.E. Leggett 1984. Effect of moisture stress on seed growth in soybeans. *Agron. J.* 76 : 647—650.
17. Nakaseko, K. and K. Gotoh 1981. Comparative studies on dry matter production, plant type and productivity in soybean, azuki bean and kidney bean. III. Dry matter production of soybean plant at various population densities. *Jpn. J. Crop Sci.* 50 : 38—46**.
18. Ramseur, E.L., V.L. Quisenberry, S.U. Wallace and J.H. Palmer 1984. Yield and yield components of 'Braxton' soybeans as influenced by irrigation and intrarow spacing. *Agron. J.* 76 : 442—446.
19. Reicosky, D.C. and L.G. Heatherly 1990. Soybean. In Stewart, B.A. and D.R. Nielsen eds, *Irrigation of agricultural crops*. ASA-CSSA-SSSA, Madison. 639-674.
20. Reicosky, D.C., R.J. Millington, A. Klute and D. B. Peters 1972. Patterns of water uptake and root distribution of soybeans (*Glycine max*) in the presence of a water table. *Agron. J.* 64 : 292—297.
21. Sionit, N. and P.J. Kramer 1977. Effect of water stress during different stages of growth of soybean. *Agron. J.* 69 : 274—278.
22. Sojka, R.E., H.D. Scott, J.A. Ferguson and E.M. Rutledge 1977. Relationship of plant water status to soybean growth. *Soil Sci.* 123 : 182—187.
23. Stone, L. R., I.D. Teare, C.D. Nickell and W.C. Mayaki 1976. Soybean root development and soil water depletion. *Agron. J.* 68 : 677—680.

24. Wang, P., A. Isoda and G. Wei 1993. Growth and adaptation of soybean cultivars under water stress conditions. I. Leaf movement and leaf temperature. *Jpn. J. Crop Sci.* 62 : 401—407*.
25. Wang, P., A. Isoda, G. Wei, T. Yoshimura and T. Ishikawa 1994. Growth and adaptation of soybean cultivars under water stress conditions II. Effects of leaf movement on radiation interception. *Jpn. J. Crop Sci.* 63 : 699—705.
26. Wenkert, W., E.R. Lemon and T.R. Sinclair 1978. Leaf elongation and turgor pressure in field-grown soybean. *Agron. J.* 70 : 761—764.
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