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Dry Matter Accumulation and Leaf Mineral Contents as Affected by Excessive Soil Water in Soybean†

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ABSTRACT

Excessive soil water at vegetative growth stages during the rainy season induces yield losses in soybeans. Our objectives were to obtain basic information about the cultivar differences and to understand the stress-tolerance process for due to excessive soil water. Previous experiments revealed soybean genotypic differences in tolerance to excessive soil water. A field experiment was conducted at the Research Farm of Korea University near Seoul on 21 May 1998. Soybean[*Glycine max* (L.) Merrill] cultivars, 'Hannamkong'(sensitive) and 'Taekwangkong'(tolerant) were planted in vinyl-lined plots(1.2 × 4.2 × 0.3 m deep) and control plots. Drip irrigation began at V1 growth stage to submerge the soil surface. Three weeks of excessive soil water treatment reduced all growth parameters measured to soybean plants. Excessive soil water stress resulted in decreases of N, P, K, Ca, Mg and Cu, and increases of Fe and Mn contents in soybean leaves. The stress index of tolerant cultivars under excessive soil water showed no large difference in soybean growth characteristics measured at three growth stages. However, K, Ca, Mg, Fe and Mn contents in soybean leaves appeared to differ between sensitive and tolerant cultivars. From the above results, stress and tolerance indices are proposed for a method to test cultivar differences in plant responses within a species under adverse growth environments.

Keywords : *Gycine max.*, growth characteristic, mineral nutrient, stress index, tolerance index.

Stress from excessive soil water occurs in both single and double crop soybean plants in field conditions. Studies of excessive water stress were reported with flood duration, flood tolerance, flood injury or waterlogging in the references(Heatherly and Pringle, 1991; Kwon et al., 1982; Kwon and Lee, 1988). Two weeks of flood treatments at early vegetative growth stages reduced all root and shoot growth parameters in soybeans(Sallam and scott, 1987) and in seedling growth of alfalfa(Teutsch and Sulc, 1997). Scott et al.(1989) reported flood duration effects on soybean growth and yield by continuously flooding 3 cm above the soil surface at either the V4 or R2 growth stage for 2, 4, 7 or 14 days. They found that flood duration effects on the soybean plants were manifested in yellowing and abscission of leaves at the lower nodes, stunting, and reducing dry weight and seed yield(Griffin and Saxton, 1988). Canopy height and dry weight decreased linearly with duration of the flood at both growth stages. A linear decrease in seed yield with flood duration was also found.

Mineral nutrients of soybean leaves were measured by Beeson et al.(1948). Hanway and Weber(1971a,b) reported N, P, and K percentages in soybean plant parts. Distribution of N, P, K, Ca and Mg in soybean leaves were investigated during the period near maturity for four cultivars(Kollman et al., 1974). Accumulations of N, P, K, Ca, Mg, Fe, Mn, Zn and Cu in soybean leaves were found during the vegetative and reproductive phases (Drossopoulos et al., 1994). However, limited references were available for mineral nutrient contents in soybean leaves at early vegetative growth stages under excessive water stress. Nutrient uptake of corn plant tissue decreased with increasing water stress level for the surface submerged treatment(Ahmad et al., 1992). Scott and Sallam(1987) reported the effects of prolonged flooding at the R2 growth stage on N and P uptake of soybean leaves. Leaves of the flooded plants had a greater decrease in N fluxes than did the other plant parts.

VanToai et al.(1994) concluded that flooding tolerance could be defined as high yield under flooding stress and found that differences in flooding tolerance existed among soybean cultivars using a flood tolerance rating(Osborne et al., 1995). Wheat cultivars also differed for grain yield under flooding conditions(Musgrave and Ding, 1998). Our objectives of this study were to obtain basic information for the cultivar differences and to understand the stress-tolerance process for the application to production practices.

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MATERIALS AND METHODS

The field experiment was conducted in 1998 at the Research Farm of Korea University, Korea. Two cultivars of soybean [*Glycine max* (L.) Merrill], 'Hannamkong'(excessive soil water stress sensitive), and 'Taekwangkong'(tolerant), were planted on Baeksan silt clay loam soil in vinyl-lined plots(1.2 × 4.2 × 0.3 m deep) for excessive water treatment and included conventional plots(control) on 21 May. Planting density was 30 × 7.5 cm with two seeds at the time of planting and the final density was 60 × 15 cm with one plant by thinning. Drip irrigation for excessive water treatment began at V1 growth stage(13 June) to submerge the soil surface from 0 to 3 cm. The experimental design was split plot arrangement, in which the main plot was excessive water treatment and sub-plot was cultivar with three replications.

Five soybean plants were sampled at V3(21 June), V5(28 June) and V7/V8(5 July) growth stages with weekly intervals(Fig. 1). Stem length, fresh, and dry weight were measured after oven drying at 80℃ for 48 hours for stems and leaves including the petioles. Additional leaf samples were prepared by thinning for the analyses of mineral nutrients. N and P contents of dried leaves were determined by Bran + Luebbe TRAACS 800 after digestion by the Kjeldahl method. K, Ca, Mg, Na, Fe, Mn, Zn and Cu contents of the leaves were determined by Inductive coupled plasma Spectrophotometer(Integra XL) after wet digestion using HNO_3. The stress index of each cultivar was calculated by dividing the excessive water response by the control response. The tolerance index for comparing cultivars was calculated by dividing the stress index of tolerant cultivars by the stress index of sensitive cultivars. All collected data were subjected to analysis of variance and correlation

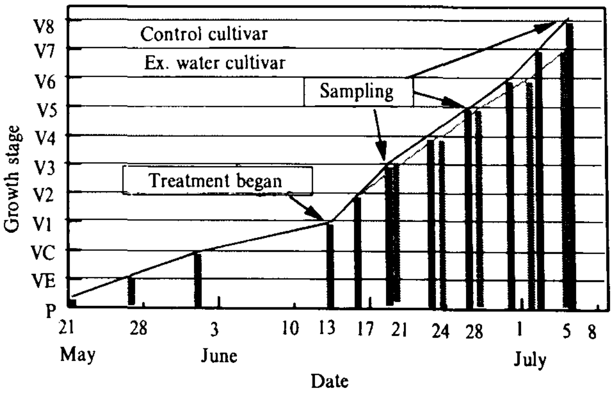

Fig. 1. Growth stage development of soybean cultivars treated with excessive soil water during field experimental periods.

Table 1. Effects of excessive soil water treatment and soybean cultivar on growth characteristics at the three growth stages.

Variable	Treat.	Growth stage			Cultivar	Growth stage		
		V3	V5	V7/V8		V3	V3	V7/V8
Stem LTH (cm/plant)	Cont.	7.8a	11.3a	19.5a	Hannamkong	5.6a	8.4a	14.6a
	Ex.W.	6.7b	9.1b	14.7b	Taekwangkong	8.8b	11.9b	19.6b
Stem DW (g/5plants)	Cont.	0.4a	1.2a	5.8a	Hannamkong	0.4a	1.0a	3.7a
	Ex.W.	0.6a	1.1a	2.8b	Taekwangkong	0.6b	1.4b	5.0b
Leaf DW (g/5plants)	Cont.	2.6a	6.1a	19.0a	Hannamkong	2.3a	4.7a	12.1a
	Ex.W.	2.5a	3.7a	7.4b	Taekwangkong	2.8a	5.0a	14.3b
Top DW (g/5plants)	Cont.	3.0a	7.3a	24.8a	Hannamkong	2.7a	5.7a	15.8a
	Ex.W.	3.1a	4.8a	10.2b	Taekwangkong	3.4a	6.4a	19.3b
Stem WC (%)	Cont.	87a	86a	84a	Hannamkong	83a	83a	83a
	Ex.W.	78b	78b	79b	Taekwangkong	83a	81b	81b
Leaf WC (%)	Cont.	80a	83a	82a	Hannamkong	76a	80a	80a
	Ex.W.	74b	77b	77b	Taekwangkong	78b	80a	80a
L/S ratio	Cont.	6.1a	5.1a	3.3a	Hannamkong	5.8a	4.8a	3.2a
	Ex.W.	4.4b	3.4b	2.6b	Taekwangkong	4.7b	3.7b	2.8b

* Values followed by the same letter were not significantly different within treatment and cultivar means according to LSD at $P<0.05$.

* LTH: Length, DW: Dry weight, WC: Water content, L/S; Leaf stem ,
Cont: Control, Ex. W.: Excessive soil water and Treat.: Treatment.

using Statistical Analysis System with pc-package in the computer terminal.

RESULTS AND DISCUSSION

The development of soybean growth stages was delayed with the excessive soil water treatment compared to the control treatment(Fig. 1). At the time of third sampling(5 July), the growth stages of excessive soil water treated cultivars were V7 as compared to V8 of controled cultivars. Normal growth of field plots continued until final sampling time, except 2 to 3 days of delayed growth from VC to V1 due to lower temperatures at that periods(Data not shown). Generally, soybean plants of excessive soil water treated cultivars exhibited yellowing and abscission of leaves at the lower nodes, stunting, and reduced plant height, branch and leaf size as reported by Scott et al.(1989).

Excessive soil water treatment reduced significantly stem length from V3 to V7/V8 stages as shown in Table 1. Similar results were reported by Griffin and Saxton(1988) and Osborne et al.(1995). After one week of excessive soil water treatment, stem length decreased 14% compared to control, and 25% in three weeks, which is shown as stress index in Table 2. Stem length of 'Taekwangkong' was longer than 'Hannamkong', which indicated a genetic trait, but the tolerance index for comparing cultivars was not so high at V7/V8 stage. VanToai et al.(1994) calculated the flood tolerance rating to find differences among soybean cultivars.

Stem and leaf dry weights of soybean plants differed at the V7/V8 stage between excessive soil water treatment and control. Sallam and Scott(1987) and Scott et al.(1989) found that the dry weight of soybean plants decreased with prolonged flood duration. Stress indices of stem and leaf dry weights averaged 0.49 and 0.39, respectively. Thus, over half of the dry matter accumulation of soybean plants decreased by three weeks of excessive soil water treatments. Stem dry weight of 'Taekwangkong' was greater than 'Hannamkong' at all three sampling stages. Stem and leaf water contents of both cultivars were lower in excessive soil water treatment during three sampling stages. Stress indices of them ranged from 0.90 to 0.94 which indicated a 6 to 10% reduction due to excessive soil water stress. Cultivar differences occurred at V5 and V7/V8 stages in stem water content and V3 stage in leaf water content, impling that leaf water status responded more rapidly than did stem water status. Leaf stem ratio appeared to be significantly different in both treatments and cultivars. Tolerance indices of 'Taekwangkong' were 0.92, 0.91 and 0.93 at three sampling stages, which again had relatively larger stem dry weight.

Nitrogen(N), P and K contents of soybean leaves were generally in the range as reported by Hanway and Weber(1971a). Ca, Mg, Na, Fe, Mn, Zn and Cu contents were also similar to the results (Drossopoulos et al., 1994; Kollman et al., 1974). N and P contents of soybean leaves at three sampling stages decreased significantly with excessive soil water treatment(Table 3). Similar results were reported by

Table 2. Stress and tolerance indices in growth characteristics of soybean cultivars at the three growth stages.

Variable	Cultivar	Stress index			Tolerance index		
		V3	V5	V7/V8	V3	V5	V7/V8
Stem LTH	Hannamkong	0.88	0.83	0.76			
	Taekwangkong	0.83	0.79	0.75	0.94	0.95	0.99
Stem DW	Hannamkong	ns	ns	0.48			
	Taekwangkong	ns	ns	0.49	ns	ns	1.02
Leaf DW	Hannamkong	ns	ns	0.40			
	Taekwangkong	ns	ns	0.38	ns	ns	0.95
Top DW	Hannamkong	ns	ns	0.43			
	Taekwangkong	ns	ns	0.40	ns	ns	0.93
Stem WC	Hannamkong	0.90	0.91	0.94			
	Taekwangkong	0.90	0.91	0.93	ns	1.00	0.99
Leaf WC	Hannamkong	0.91	0.93	0.94			
	Taekwangkong	0.93	0.94	0.94	1.02	ns	ns
L/S ratio	Hannamkong	0.75	0.70	0.83			
	Taekwangkong	0.69	0.64	0.77	0.92	0.91	0.93

* LTH: Length, DW: Dry weight, WC: Water content, and L/S; Leaf stem.

Table 3. Effects of excessive soil water treatment and soybean cultivar on mineral nutrient contents of leaves at the three growth stages.

Nutrient	Treat.	Growth stage			Cultiva	Growth stage		
		V3	V5	V7/V8		V3	V5	V7/V8
				……g/kg……				
N	Cont.	40.1a	42.9a	32.8a	Hannamkong	30.3a	33.3a	28.4a
	Ex.W.	21.6b	24.8b	24.6b	Taekwangkong	31.4a	34.3a	29.0a
P	Cont.	2.9a	3.4a	2.6a	Hannamkong	2.5a	2.9a	2.3a
	Ex.W.	2.1b	2.2b	1.9b	Taekwangkong	2.5a	2.8a	2.2a
K	Cont.	16.2a	16.7a	15.6a	Hannamkong	11.4a	13.4a	13.6a
	Ex.W.	9.1b	10.3b	10.8b	Taekwangkong	13.9b	13.6b	12.8b
Ca	Cont.	17.2a	18.3a	14.5a	Hannamkong	16.0a	17.8a	14.4a
	Ex.W.	14.1b	16.2b	13.8a	Taekwangkong	15.2b	16.7b	13.9b
Mg	Cont.	6.0a	6.2a	5.2a	Hannamkong	4.4a	4.9a	4.2a
	Ex.W.	3.6b	3.7b	3.4b	Taekwangkong	5.3b	5.0b	4.4b
				……mg/kg……				
Na	Cont.	381a	371a	268a	Hannamkong	368a	348a	279a
	Ex.W.	376a	357a	305a	Taekwangkong	389a	380a	295a
Fe	Cont.	332a	292a	285a	Hannamkong	336a	326a	516a
	Ex.W.	290a	403a	701b	Taekwangkong	286a	369a	470b
Mn	Cont.	55a	59a	48a	Hannamkong	86a	117a	99a
	Ex.W.	117b	181b	156b	Taekwangkong	86a	122a	105b
Zn	Cont.	39a	50a	45a	Hannamkong	30a	35a	34a
	Ex.W.	28a	27a	28a	Taekwangkong	37a	42a	39a
Cu	Cont.	11a	11a	10a	Hannamkong	8a	8a	7a
	Ex.W.	3b	4b	4b	Taekwangkong	7a	7a	7a

* Values followed by the same letter were not significantly different within treatment and cultivar means according to LSD at $P<0.05$.

* Cont.: Control, Ex. W.: Excessive soil water and Treat.: Treatment.

Table 4. Stress and tolerance indices in mineral nutrients of soybean cultivars at the three growth stages.

Variable.	Cultivar	Stress index			Tolerance index		
		V3	V5	V7/V8	V3	V5	V7/V8
N	Hannamkong	0.53	0.59	0.72			
	Taekwangkong	0.55	0.57	0.79	ns	ns	ns
P	Hannamkong	0.80	0.66	0.72			
	Taekwangkong	0.70	0.64	0.70	ns	ns	ns
K	Hannamkong	0.68	0.67	0.70			
	Taekwangkong	0.48	0.56	0.68	0.71	0.84	0.97
Ca	Hannamkong	0.79	0.84	ns			
	Taekwangkong	0.86	0.94	ns	1.09	1.12	ns
Mg	Hannamkong	0.66	0.57	0.60			
	Taekwangkong	0.56	0.64	0.70	0.85	1.12	1.17
Fe	Hannamkong	ns	ns	2.54			
	Taekwangkong	ns	ns	2.37	ns	ns	0.93
Mn	Hannamkong	2.37	3.42	2.94			
	Taekwangkong	1.87	2.81	3.67	ns	ns	1.25
Cu	Hannamkong	0.19	0.36	0.33			
	Taekwangkong	0.38	0.35	0.47	ns	ns.	ns

Scott and Sallam(1987). Stress indices of both nutrients ranged from 0.53 to 0.80 indicating 20 to 47% decrements with excessive soil water stress(Table 4). However, both nutrients showed no differences between cultivars at all three growth stages, which meant no tolerance indices. K, Ca and Mg contents of soybean leaves were significantly different between excessive soil water treatments and cultivars. K contents decreased with excessive soil water treatment and the decrements ranged 30 to 52% as shown in the stress index. K contents of 'Taekwangkong' decreased more at V3 and V5 stages compared with 'Hannamkong', as shown in the tolerance index. Ca contents decreased from 6 to 21% at V3 and V5 stages and 'Taekwangkong' showed a relatively higher stress index than 'Hannamkong' as in the tolerance index. Mg contents also decreased from 30 to 44% with excessive soil water treatment and 'Taekwangkong' showed 17% higher Mg content than did 'Hannamkong' at V7/V8 stage.

With excessive soil water treatment, Fe content in soybean leaves greatly increased up to 254% at the V7/V8 stage. 'Taekwangkong' had significantly less Fe content than 'Hannamkong'. Mn content also increased largely from V3 to V7/V8 stages with the treatment. In contrast to Fe, 'Taekwangkong' showed much more Mn content with a tolerance index of 1.25 than did 'Hannamkong'. But, Cu content of soybean leaves decreased rapidly from V3 to V7/V8 stages with excessive soil water treatment and no cultivar effect was found. Based on the experimental data, the results concluded that some mineral nutrient contents in soybean leaves clearly differed between two cultivars under excessive soil water stress.

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