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Responses of Soybean Cultivars to Excessive Soil Moisture Imposed at Different Growth Stages

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ABSTRACT: Soybean [*Glycine max* (L.) Merrill] crops, grown in a rice soybean rotation, can suffer when grown in soil with excessive moisture. The objective of this work were to determine the reduction in growth and yield, responses of vegetative and reproductive growth of soybean to excessive soil moisture achieved by prolonged irrigation. Responses of different cultivars were determined at growth stages from V6 to R8 to clarify the sensitive growth stages or characteristics to excessive soil moisture. Cultivar differences in response to excessive soil moisture condition were conspicuous in seed dry weight and harvest index (HI) but not in the response of seed number or pod number per plant. The timing of irrigation causing the condition of excessive soil moisture influenced the vegetative or reproductive traits. Soybean plants were more affected by irrigation commencing at the pre-flowering than at the post-flowering stage. Post-flowering irrigation did not reduce growth of vegetative organs significantly; in fact the growth of stems and leaves was facilitated by the prolonged irrigation commencing at flowering. Differences between cultivar response to prolonged irrigation were assumed to relate to the reduced amount of assimilates translocated to the reproductive organ.

Keywords **:** *Glycine max*, excessive soil moisture, seed dry weight, relative growth rate, total dry weight, harvest index

In Korea, excessive soil moisture is detrimental to soybean growth when the soybean plants are cultivated on the paddy field. The detrimental effects of excessive soil moisture in agricultural land result from the lowered oxygen concentration in the gaseous phase of soil. Although previous studies have reported the harmful effect of waterlogging caused by flooding, there is little basic data for soybean response to excessive irrigation on paddy fields, a response which can be related to heavy rainfall.

The timing of intense irrigation that can cause flooding is an important factor in terms of the detrimental effect to soybean plants. Excess water in the soil can arise from heavy rainfall or from poor drainage of soil or both. The drainage of paddy fields is poor compared with that of upland soil, and this lack of drainage can occur when soybean is cultivated on a paddy field under intense rainfall. Many researchers have reported the effect of waterlogging on soybean plants. In these reported experiments, waterlogging was achieved by flooding after constructing levees (Griffin & Saxton, 1988). However, this method in which soil was flooded can not simulate the excessive soil moisture originating from poor drainage and heavy rainfall. In Korea, heavy rainfall is common during the summer season from June to August. When the soybean plants are grown on a paddy field, this problem is more serious compared with growing on an upland field. Using sprinkler irrigation to achieve excessive soil moisture has not been designed since sprinkling on plants may cause side effect such as decreasing leaf temperature. Nevertheless, sprinkler irrigation is more likely to simulate excessive soil moisture resulting from heavy rainfall. Waterlogging depends on the amount of rainfall as well as the drainage, and prolonged sprinkler irrigation can result in excessive soil moisture in non-sandy soil. Soil oxygen deficit is detrimental to plant growth and yield directly by altering the root metabolism or indirectly by changing the nutrient availability (Trought & Drew, 1980). In wheat, waterlogging detrimentally influenced the grain weight and kernel number and there was a cultivar difference in tolerance to waterlogging (Musgrave & Ding, 1998).

Waterlogging can occur when soybean plants are cultivated on a paddy field in the rice-soybean rotation cropping system. This rotational cropping system takes advantages of the nitrogen fixation ability of legumes. However, the wet soil condition of the paddy fields resulting from the soil physical property related to the poor drainage can cause waterlogging or excessive moisture in the paddy soil in which the soybean plants are growing. To overcome this problem, relatively tolerant cultivars and new cultivation strategies (Seong *et al.*, 2000) have been developed. Excessive water in the soil has been known to creat plant stress due to improper aeration of the soil. Soybean requires relatively large amount of water during the vegetative growing season. The shortage of soil water at this time may affect vegetative and reproductive growth (Scott *et al.*, 1987). Grain yield of soybean was significantly

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affected by flooding duration imposed during vegetative or reproductive stages (Scott *et al.*, 1989). The harmful effects of flooding on plants due to poor aeration caused a reduced oxygen supply to the rhizosphere (Grable, 1966). The physiological basis of the effect of waterlogging varies depending on crop species; in wheat, a species well-known as susceptible to waterlogging or excessive soil moisture, waterlogging restricted stomatal opening and subsequently, reduced photosynthetic assimilation (Sojka, 1992).

In legumes, it has been shown that waterlogging affects the activity of symbiotic bacteria. Several studies suggest that the detrimental effect of excessive irrigation on soybean growth is related to the activity of nitrogen-fixing bacteria on the roots or the transport of fixed nitrogen (Sallam & Scott, 1987; Puiatti & Sodek, 1999). One of the anatomical differences between cultivars tolerant or susceptible to waterlogging is the development of aerenchyma roots to facilitate aeration from aerial parts to the roots (Bacanamwo & Purcell, 1999). The anatomically modified roots under flooding ameliorate the damage to symbiotic bacteria.

To verify the growth character and yield component traits that are liable to be affected by excessive irrigation it is important to manage the soybean correctly under heavy rainfall or extremely poor drainage in the field. Linkermer *et al.* (1998) reported that yield reduction in waterlogged soybean was induced primarily by decreased pod production resulting from fewer pods per reproductive node.

The objective of this study was to determine the detrimental effect of excessive soil moisture on soybean growth characteristics related to yield, and to compare the response of soybean cultivars that already have shown difference in susceptibility to excessive soil moisture stress. To identify soybean growth stages sensitive to waterlogging, we examined yield components and physiological parameters explaining yield losses induced by waterlogging; and determined the extent of yield losses induced by waterlogging under natural conditions.

MATERIALS AND METHODS

A field experiment was carried out on the Research Farm of Korea University at Dukso, Kyunggi province in 1997. The soil of the experimental field was silt clay loam. This field had previously been planted to soybean and already had plentiful nitrogen-fixing bacteria, so that no artificial inoculation was needed. Five soybean cultivars, Hannamkong, Myeongjuna-mulkong, Taekwangkong, Sobaegnamulkong, and Muhankong, the first two known as susceptible and the last three as tolerant to excessive soil moisture stress were planted on 7 June. The planting arrangement was 60 × 15 cm, and to adjust to the correct planting density, plants were thinned after emergence. The appropriate pesticides were used to control weeds, diseases, and insects. Fertilizers were applied at the recommended rate prior to ploughing. Each plot consisted of three rows of soybean and the plot length was 3.75 m and the plot width was 1.80 m. The experimental design was a split plot arrangement with three replications. The three main plots were irrigation treatments and split for 5 cultivar sub-plot. Main treatments consisted of a control and excessive irrigation treatments commencing at 2 different growth stages (V2 and R2). Excessive soil moisture treatments were achieved by sprinkler irrigation of water at the pre-flowering (V2-R2) and the post-flowering (R2-R8) stages. Daily irrigation by sprinkler was accomplished three times for 1 hr a day with a precipitation of 46.15 mm. This amount of precipitation was enough to saturate the soil gaseous phase with water. Five soybean plants were sampled from each plot at V6, R2, R6, and R8 growth stages and separated into parts to determine the growth characteristics or yield components. Growth characters including plant height, leaf number, node number, stem weight, and leaf weight were determined at V6 after samples were separated into leaves, petioles, branches, and stems. In addition, yield-related components such as branch number, pod and seed number and weight were determined.

RESULTS AND DISCUSSION

Analysis of variance of growth characteristics was not significantly different between treatments until the prolonged irrigation was treated. In addition, varietal differences were not observed in growth characters except for plant height, stem weight, and leaf weight until prolonged irrigation began. At the R2 growth stage, stem and leaf growth were significantly affected by prolonged irrigation treatments and cultivars (Table 1). The effects of the irrigation treatments and the cultivars represent environmental and genetic effect on growth traits, respectively, during the vegetative growth stage. In the course of reproductive growth (R2-R8), the effect of prolonged excessive soil moisture was highly significant for all traits except for node number at the R8 growth stage. During the reproductive stages (R6-R8), yield-related characters such as pod number, seed number, and seed weight were also highly affected by cultivar as well as by the irrigation treatments. It is suggested that the excessive soil moisture affected the vegetative organs that produce assimilates to be remobilized or to be translocated into the growing reproductive organs.

Many results indicate that the rhizosphere activity can be influenced by flooding treatment resulting in reduced growth of aerial part in legumes (Sallam & Scott, 1987; Barta, 1988). Although we did not determine root growth and nodule

Table 1. Analysis of variance for growth characteristics and yield components at different growth stages, V6, R2, R6, and R8 for soybean as affected by excessive moisture treatment.

Growth stage	Source of variation	df	Plant height	Leaf number	Node number	Branch number	Pod number	Seed number	Stem dry weight	Leaf dry weight	Petiol dry weight	Pod dry weight	Seed dry weight
V6	Treatment (T)	2	NS	NS	NS	-	-	-	NS	NS	NS	-	-
	Cultivar (C)	4	***	NS	NS	-	-	-	***	***	***	-	-
	T × C	8	NS	NS	NS	-	-	-	NS	NS	NS	-	-
	CV		10.7	10.1	8.0	-	-	-	17.1	19.5	30.2	-	-
R2	Treatment (T)	2	***	***	***	***	-	-	***	***	***	-	-
	Cultivar (C)	4	***	**	***	**	-	-	*	NS	NS	-	-
	T × C	8	**	*	***	***	-	-	NS	NS	NS	-	-
	CV		8.8	15.1	5.3	12.5	-	-	25.0	21.6	28.8	-	-
R6	Treatment (T)	2	*	***	**	***	***	-	***	***	***	***	-
	Cultivar (C)	4	***	NS	***	NS	***	-	***	**	**	***	-
	T × C	8	NS	NS	***	*	*	-	NS	NS	NS	**	-
	CV		12.8	18.1	4.3	10.6	20.2	-	23.7	22.8	23.3	25.3	-
R8	Treatment (T)	2	*	-	NS	***	***	***	***	-	-	***	***
	Cultivar (C)	4	***	-	***	**	***	***	***	-	-	NS	*
	T × C	8	NS	-	**	NS	NS	NS	NS	-	-	NS	NS
	CV		11.0	-	4.8	13.1	21.0	24.0	19.2	-	-	20.7	22.6

*, **, ***: Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.
NS : Not significant at the 0.05 probability level.

activity, the reduction in growth characters over the reproductive stages may have resulted from the decrease in root activity. As shown by other results (Seong *et al.*, 2000; Bacanamwo & Purcell, 1999), a cultivar effect on the response to flooding was observed and the treatment × cultivar interaction was also significant in many characters at the R2 and R6 growth stages (Table 1). Node number is known to be a strongly genetic-controlled trait, and was not significantly affected at harvest (R8) by prolonged irrigation, even though it was significantly affected at the earlier R2 and R6 growth stages. Coefficient of variance of node number also showed the lowest value among examined traits, confirming this trait is less affected by excessive irrigation treatment.

The comparison of effect of treatment on growth characteristics at the R6 growth stage is shown in Table 2. Prolonged irrigation commencing at pre-flowering strongly influenced all growth characteristics examined at the R6 growth stage. Plant height, leaf, node, branch and pod number, and stem, leaf, petiole and pod weights were all significantly reduced. As reported by many researchers (Griffin & Saxton, 1988; Scott

Table 2. Effect of excessive moisture treatment at pre-flowering and post-flowering stages on vegetative and reproductive traits of soybean at R6 growth stage.

		Plant height	Leaf number	Node number	Branch number	Pod number	Stem dry weight	Leaf dry weight	Petiole dry weight	Pod dry weight
		(cm)	---------- No./plant ----------				---------- g/plant ----------			
Treatment	Control	61.0	27.0	16.8	4.82	60.4	7.8	7.50	4.00	11.4
	Pre-flowering	53.8	18.0	15.9	2.58	32.1	4.5	4.20	1.82	5.7
	Post-flowering	61.8	32.8	16.8	5.34	48.4	11.1	7.64	6.08	7.6
	$LSD_{0.05}$	5.6	3.5	0.5	0.34	7.1	1.4	1.10	0.70	1.6
Cultivar	Hannamkong	61.9	23.3	17.4	4.32	45.8	6.1	5.20	3.02	9.3
	Myeongjunamulkong	49.9	27.6	16.7	4.38	58.2	7.3	5.86	3.26	10.6
	Taekwangkong	64.2	27.4	17.0	4.12	35.4	10.6	7.76	5.10	6.1
	Sobaegnamulkong	41.5	23.6	13.7	4.06	56.2	6.5	6.20	4.72	5.9
	Muhankong	76.7	27.8	17.9	4.36	39.3	8.5	7.22	3.72	9.3
	$LSD_{0.05}$	7.3	4.5	0.7	0.44	9.1	1.8	1.42	0.89	2.0

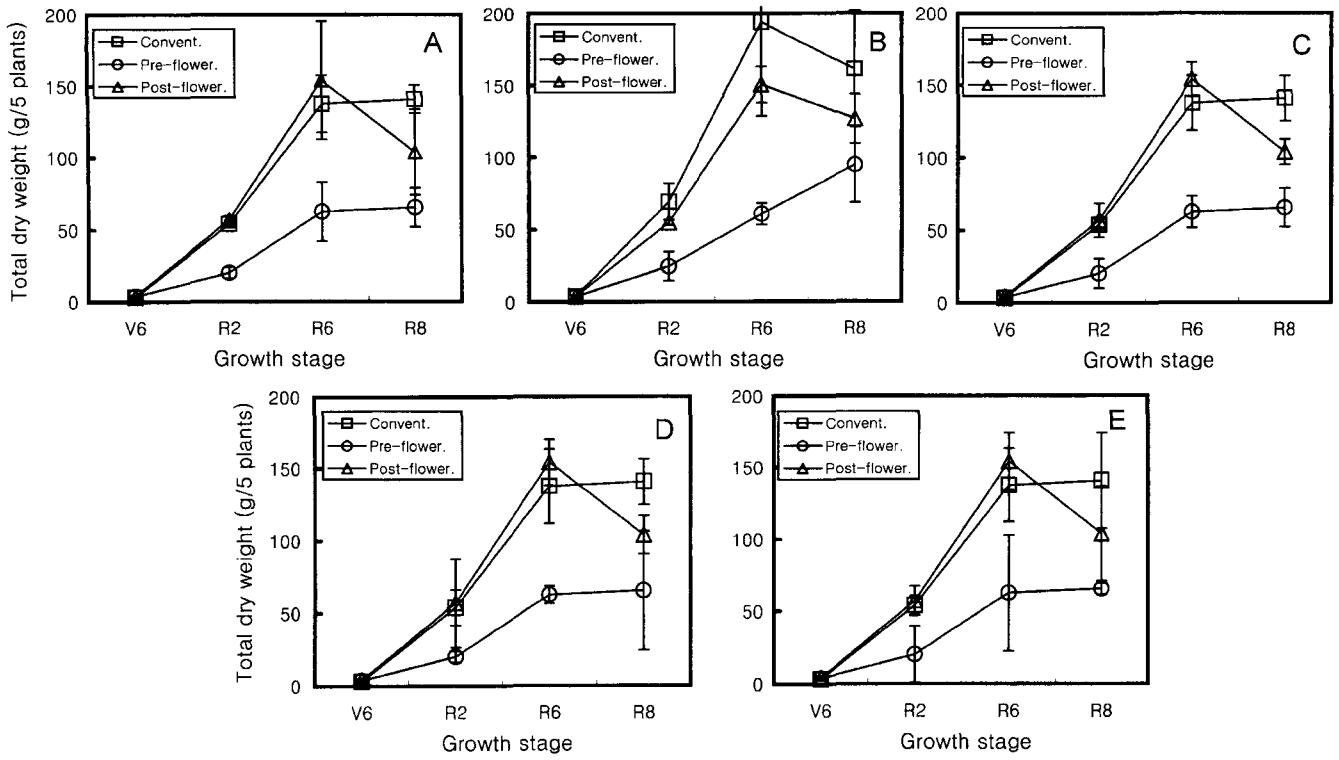

Fig. 1. Changes of total dry weight from V6 to R8 growth stage by excessive soil moisture treatment commenced at pre-flowering or post-flowering stage. A: Hannamkong, B: Myeongjunamulkong, C: Taekwangkong, D: Sobaegnamulkong, E: Muhankong.

et al., 1989; Linkemer *et al.*, 1998), the waterlogging condition is more deleterious during the vegetative stage than the reproductive stage. All characters were reduced by pre-flowering excessive irrigation. However, excessive irrigation at the post-flowering stage was not harmful to the characters examined. All characters except pod number and pod weight showed equal or higher values; leaf and branch number and stem and petiole weights were significantly higher than the controls suggesting that the effect of excessive irrigation treatment at the post-flowering is organ-specific depending on the growth stage. Since the dry weight of vegetative organs at the R6 growth stage was not reduced by excessive soil moisture, the reduction in pod weight may be the result of decreased remobilization or translocation of assimilates stored in vegetative organs such as leaves, petioles, or branches. The slight increase of vegetative organs in the plots treated from the post-flowering stage might be the result of sufficient watering during early reproductive stages at which natural heavy precipitation and too high air temperature limit vegetative growth of soybean plant in Korea. If the conventional irrigation by natural rainfall was not sufficient for soybean growth, the soil moisture resulting from prolonged irrigation might be more adequate for soybean growth. In addition, the leaf temperature might be decreased into a more optimal range in which maintain respiration was lowered by evaporation on leaf surface under sprinkler irrigation.

Dry matter accumulation of aerial parts from V6 to R8 was shown Fig. 1. Total dry weight changes differed between treatments. Differences between conventional irrigation on the controls and prolonged irrigation become apparent from the R2 growth stage at which flowering occurs. The reduction in total dry weight by excessive soil moisture from the pre-flowering stage resulted in differences in seed yield at harvest (Table 3). Total dry weight (Fig. 1) was highest in the plots treated by irrigation at post-flowering stage except for cultivar Myeongjunamulkong. This result indicated that excessive irrigation after flowering is not detrimental to vegetative growth. However, prolonged irrigation from the pre-flowering growth stage reduced total dry weight in all the cultivars examined. Total dry weight of all cultivars did not show a significant difference between conventional irrigation and prolonged irrigation from the post-flowering stage.

Relative growth rates were calculated in terms of vegetative capacity of soybean plants (Fig. 2). The duration of excessive irrigation affected the relative growth rate (RGR). The tolerant cultivars, Taekwangkong, Sobaegnamulkong, and Muhankong showed less difference among treatments compared with susceptible cultivars, Hannamkong and Myeongjunamulkong when treated with pre-flowering irrigation. There were no significant differences in RGR among

Table 3. Effect of excessive moisture treatment at pre-flowering and post-flowering stages on yield-related characteristics in soybean cultivars at harvest (R8).

Character	Treatment	Cultivar					LSD (5%)
		Hannam-kong	Myeongju namulkong	Taekwang-kong	Sobaegna-mulkong	Muhan-kong	
Seed dry weight (g/plant)	Conventional	15.5	18.0	16.9	17.6	20.6	
	Pre-flowering	7.1	10.5	10.0	11.3	10.9	
	Post-flowering	9.7	11.8	10.9	13.6	15.5	
	Mean	10.8	13.4	12.6	14.1	15.7	2.9
Seed number (No./plant)	Conventional	123.6	160.3	76.3	165.3	126.3	
	Pre-flowering	67.3	96.3	49.4	108.0	57.9	
	Post-flowering	117.4	116.3	57.0	151.0	103.7	
	Mean	102.8	124.3	60.9	141.4	96.0	24.2
Pod number (No./plant)	Conventional	57.7	75.8	40.5	68.8	59.7	
	Pre-flowering	33.7	44.1	25.9	47.3	32.9	
	Post-flowering	49.9	55.6	29.7	63.3	44.7	
	Mean	47.1	58.5	32.0	59.8	45.8	9.8
Seed No./pod	Conventional	2.1	2.1	1.9	2.4	2.1	
	Pre-flowering	2.0	2.2	1.9	2.3	1.8	
	Post-flowering	2.4	2.1	1.9	2.4	2.3	
	Mean	2.2	2.1	1.9	2.4	2.1	1.3
100-seed weight (g)	Conventional	12.6	11.3	22.2	10.7	16.3	
	Pre-flowering	10.6	11.0	20.3	10.5	18.9	
	Post-flowering	8.1	10.1	19.1	9.1	15.0	
	Mean	10.4	10.8	20.5	10.1	16.7	0.7
Harvest Index (%)	Conventional	55.2	55.0	52.7	60.0	55.3	
	Pre-flowering	54.5	56.3	49.1	60.8	46.9	
	Post-flowering	46.1	46.6	42.0	50.4	48.7	
	Mean	51.9	52.6	47.9	57.1	50.3	2.6

treatments from the R2 to R6 growth stages. It is suggested that differences in RGR between conventional and pre-flowering irrigation relate to varietal differences in tolerance to excessive irrigation. Prolonged excessive irrigation did not decrease RGR from R2 to R6 growth stage (Fig. 2). The effects of prolonged irrigation on yield-related characters are presented in Table 3. Both pre-flowering and post-flowering treatments resulted in decreased seed production and harvest index (HI). In chickpea, waterlogging at different times gave significant differences in effects on yield, and waterlogging at flowering reduced seed yield (Cowie *et al.*, 1996). In this experiment, the excessive soil moisture treatment from the flowering stage showed a similar tendency in seed yield. It is suggested that reduced translocation of assimilates to the seed resulted in the lowered HI under the excessive soil moisture. Seed number was less affected by excessive soil moisture because seed numbers per pod were relatively unaffected. Hundred seed weight was also less sensitive to excessive soil moisture than total seed weight, seed number, pod number, and harvest index.

Growth characters averaged over cultivars at the R6 growth stage showed that there was no feature among the vegetative characteristics by which the cultivars could be classified for sensitivity to excessive moisture. Cultivar differences in response to excessive soil moisture, however, were conspicuous in seed dry weight and harvest index but not in the response of seed number or pod number (Table 3). This result indirectly reflects that the translocation of assimilates into reproductive organs may be different between susceptible and tolerant cultivars. In addition, even though the excessive irrigation at flowering did not affect on the growth of vegetative organs, continuous excessive irrigation reduced pod-setting and pod growth. The highly significant treatment × cultivar interaction at R6 was found in node number and pod dry weight.

In conclusion, the timing of prolonged irrigation causing the excessive soil moisture differently influenced vegetative or reproductive traits. Soybean plants were more highly affected by irrigation beginning at pre-flowering stage than post-flowering. The treatment commencing at post-flowering did not reduce growth of vegetative organs significantly. On the other hand, the growth of some organs such as stems and

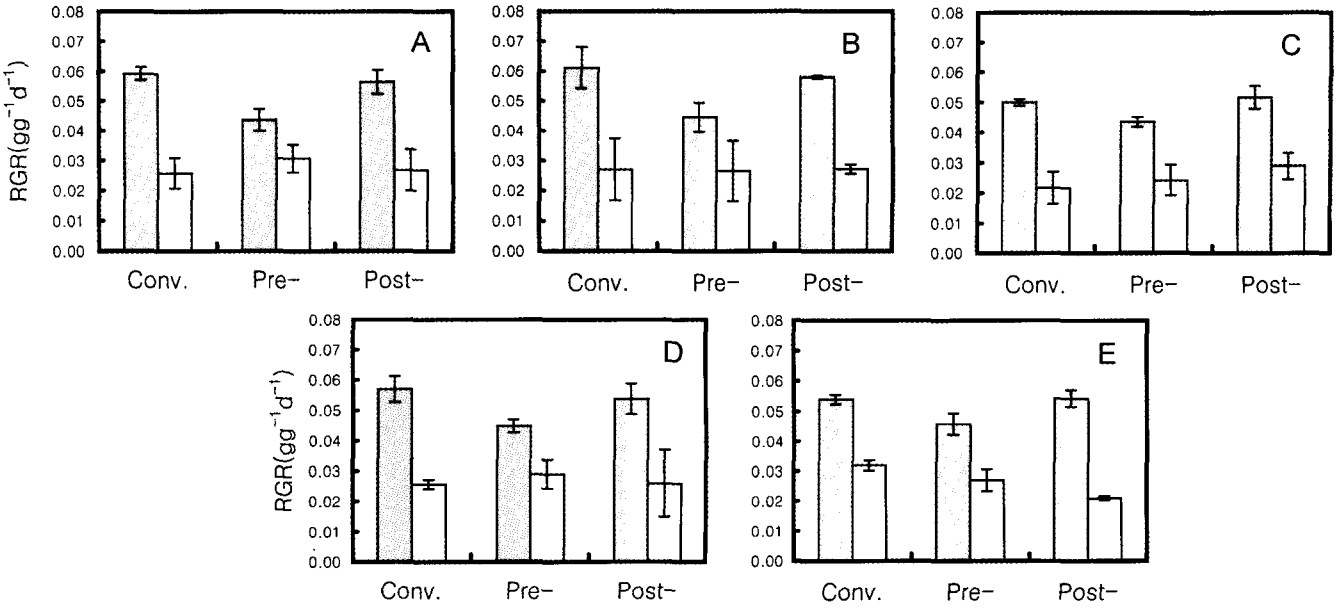

Fig. 2. Effect of excessive soil moisture treatment on relative growth rate of five different soybean cultivars during V6 to R6 (filled bars) and R2 to R6 (empty bars). Cultivar names were presented in Fig. 1.

leaves was facilitated by the prolonged irrigation commencing at flowering. It is assumed that differences between cultivars in the response to prolonged irrigation were due to the reduced amount of assimilates translocated to the reproductive organs.

REFERENCES

Bacanamwo, M. and L. C. Purcell. 1999. Soybean root morphological and anatomical traits associated with acclimation to flooding. *Crop Sci.* 39 : 143-149.

Barta, A. L. 1988. Response of field grown alfalfa to root waterlogging and shoot removal. I. Plant injury and carbohydrate and mineral content of roots. *Agron. J.* 80 : 889-892.

Cowie, A. L., R. S. Jessop, and D. A. MacLeod. 1996. Effects of waterlogging on chickpeas. *Plant and Soil* 183 : 97-103.

Grable, A. R. 1966. Soil aeration and plant growth. *Adv. Agron.* 18 : 57-106.

Griffin, J. L. and A. M. Saxton. 1988. Response of solid-seeded soybean to flood irrigation. II. Flood duration. *Agron. J.* 80 : 885-888.

Linkemer, G., J. E. Board, and M. E. Musgrave. 1998. Waterlogging effects on growth and yield components in late-planted soybean. *Crop Sci.* 38 : 1576-1584.

Musgrave, M. E. and N. Ding. 1998. Evaluation wheat cultivars for waterlogging tolerance. *Crop Sci.* 38 : 90-97.

Puiatti, M. and L. Sodek. 1999. Waterlogging affects nitrogen transport in xylem of soybean. *Plant Physiol. Biochem.* 37 : 767-773.

Sallam, A. and H. D. Scott. 1987. Effects of prolonged flooding on soybeans during early vegetative growth. *Soil Sci.* 144 : 61-66.

Scott, H. D., J. A. Ferguson, and L. S. Wood. 1987. Water use, yield, and dry matter accumulation by determinate soybean grown in a humid region. *Agron. J.* 79 : 870-875.

Scott, H. D., J. DeAngulo, M. B. Daniels, and L. S. Wood. 1989. Flood duration effects on soybean growth and yield. *Agron. J.* 81 : 631-636.

Seong, R. C., S. J. Park, and S. I. Shim. 2000. Effects of ridge height in dry paddy field on growth and seed yield of soybean cultivars. *Kor. J. Crop Sci.* 45 : 88-92.

Sojka, R. E. 1992. Stomatal closure in oxygen-stressed plants. *Soil Sci.* 157 : 591-596

Trought, M. C. T. and M. C. Drew. 1980. The development of waterlogging damage in wheat seedlings (*Triticum aestivum* L.). I. Shoot and root growth in relation to changes in concentration of dissolved gases and solutes in the soil solutions. *Plant and Soil* 54 : 77-94.