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Effects of Ridge Height in Dry Paddy Field on Growth and Seed Yield of Soybean Cultivars

Rak Chun Seong*†, Sei Joon Park and Sang In Shim***

**Dept. of Crop Science, College of Natural Resources, Korea University, Seoul 136-701, Korea*
***National Crop Experiment Station, RDA, Suwon 441-100, Korea*

ABSTRACT: Excessive soil water in paddy field induces growth losses during the vegetative stages of soybean plants. Our objectives were to know growth responses of soybean as affected by the level of ridge heights. A field experiment was conducted at the Research Farm of Korea University near Seoul in 1996. Ten cultivars of soybean (*Glycine max* (L.) Merrill) were planted at the ridge heights of 10, 30, and 50 cm in paddy soil on 27 June. Total dry matter accumulation at the 10 cm ridge height was severely decreased until the growth stage of R5 as compared to the ridge heights of 30 and 50 cm, and this decrement was mainly due to both reduced leaf and stem dry weights. However, seed dry weight was not significantly decreased at the lower ridge height with the increment of harvest index. Cultivar differences were found on seed dry weight, crop growth rate from R1 to R5, and leaf/stem ratio of R5. From the above results, soybean growth responses to excessive soil water in paddy field were different between seed filling stage and late vegetative to early reproductive growth stages.

Keywords **:** *Glycine max.*, ridge height, seed dry weight, crop growth rate, leaf/stem ratio, and harvest index.

Soybean is generally susceptible to flooding stress, which is main limiting factors to yield (Oosterhuis *et al.*, 1990; Russel *et al.*, 1990). Therefore, production of soybean in paddy field often fails due to excessive soil water. Studies of excessive water stress in soybean plants were reported with flood duration, flood tolerance, flood injury or waterlogging in the references (Heatherly & Pringle, 1991; Kwon *et al.*, 1982; Kwon & Lee, 1988; Bacanamwo & Purcell, 1999). Two weeks of flood treatments at early vegetative growth stages reduced all root and shoot growth parameters in soybeans (Sallam & Scott, 1987) and in the seedling growth of alfalfa (Teutsch & Sulc, 1997). Scott et al. (1989) reported flood duration effects on soybean growth and yield by continuously flooding with 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 & Saxton, 1988). Canopy height and dry weight decreased linearly with duration of the flood at both vegetative and reproductive growth stages. A linear decrease in seed yield with flood duration was also found. However, ridge effects of paddy soil on soybean growth are limited. Thus, planting of soybean cultivars in paddy field is examined with the level of ridge heights as a method for the stress avoidance to excessive soil water.

Growth responses of soybean plants to excessive water stress differ among the growth stages from emergence (VE) to physiological maturity (R7). Linkemer *et al.* (1998) reported waterlogging effects on growth and yield components in late-planted soybean. Yield loss in both field and greenhouse studies was induced primarily by decreased pod production resulting from fewer pods per reproductive node. They concluded that waterlogging must be avoided during the early reproductive period (R1-R5) and the early vegetative period (V2) to obtain optimal yield. The number of seeds produced by a soybean plant is related to canopy photosynthesis during the early reproductive period (Egli, 1999). Crop growth rate has been usually affected only when the waterlogging stress was applied for more than two days (Griffin & Saxton, 1988; Scott *et al.*, 1989). Greater sensitivity to the excessive water stress was shown during the early reproductive (R1-R5) versus vegetative periods (VE-R1).

VanToai *et al.* (1994) 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 & Ding, 1998). Our objectives of this study were to obtain basic information about growth responses at the level of ridge heights in paddy field and to identify cultivar differences on dry matter accumulation during the early reproductive growth stages of beginning bloom (R1) and beginning seed (R5) and on seed weight at the harvest maturity (R8) of

†Corresponding author: (Phone) +82-2-3290-3004 (E-mail) rcseong@kuccnx.korea.ac.kr <Received February 2, 2000>

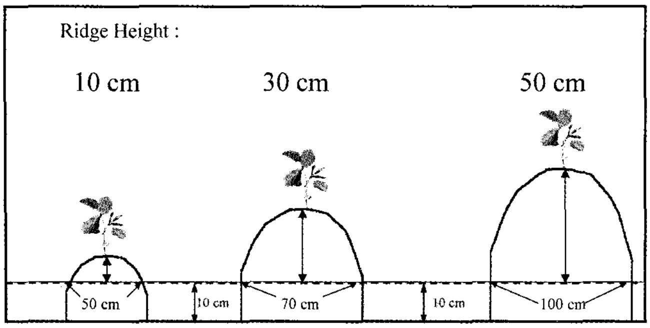

Fig. 1. Diagram of the ridge arrangements in main plot of experiment.

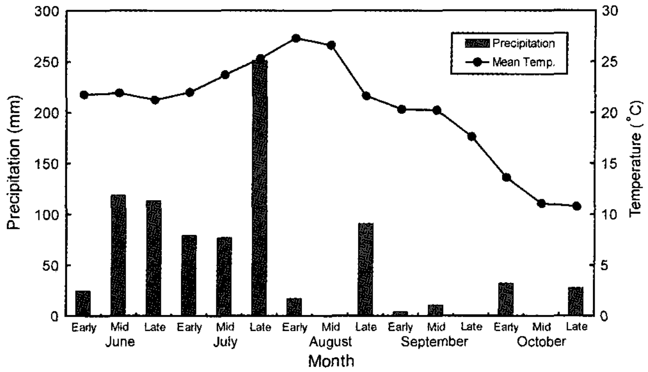

Fig. 2. Precipitation and mean temperature of experimental site during soybean growing season in 1996.

soybean cultivars.

MATERIALS AND METHODS

A field experiment was conducted at the Research Farm of Korea University near Seoul, Korea in 1996. Ten cultivars, 'Danyeobkong', 'Hannamkong', 'Myeongjunamulkong', 'Mallikong', 'Jangsukong', 'Taekwangkong', 'Jinpumkong', 'Sobaegnamulkong', 'Muhankong', and 'Pureunkong' of soybean [*Glycine max* (L) Merrill] were planted on ridge heights of 10, 30, and 50 cm in Baeksan silt clay loam of paddy field on 27 June (Fig. 1). Previous experiments revealed soybean genotypic differences in tolerance to excessive soil water. In this experiment, first three cultivars were classified as sensitive and last seven were tolerant. Ridge width of lower part was 50, 70, and 100 cm, respectively, with the length of 30 m, and water was continuously irrigated with 10 cm deep from planting to harvesting times. Planting space was 15 cm with two seeds at the time of planting in each ridge and the final space was 15 cm with one plant by thinning at the emergence (VE) on 1 July. The experimental design was split plot arrangement, in which the main plot was ridge height and sub-plot was cultivar with three replications.

Three soybean plants were sampled at V6, R1, R5, and R8 growth stages on 1 August, 11 August, 14 September and 24 October, respectively. Plant height, fresh and dry weights were measured after oven drying at 80°C for 48 hours. Leaves including petioles were also measured for number, fresh and dry weights after oven drying. Leaf area index, leaf/stem ratio, and crop growth rate were obtained from the growth stage of R1 to R5. Numbers of nodes and pods including empty pods were counted to the main stem and from the growth stage of R5 to R8, respectively. At the growth stage of R8, branch number, seed number, seed dry weight, and harvest index were obtained from the treatments. All collected data were subjected to analysis of variance and correlation using Statistical Analysis System (SAS, ver. 6.02) with pc-package in the computer terminal.

RESULTS AND DISCUSSION

Precipitation and mean temperature of the experimental site in 1996 are shown in Fig. 2. Mean temperatures during soybean growth from June to October were close to average temperature (data not shown). However, precipitation was above and below averages during vegetative growth and reproductive growth stages of ten soybean cultivars, respectively. The limited precipitation during seed filling period (R5 to R7) which occurred from September to October resulted in reduced seed yields especially at upper level of ridge heights.

Total dry matter accumulation at the growth stage R8 of ten soybean cultivars was significantly different at the level of ridge heights as shown in Table 1. Total dry weight at the ridge height of 50 cm was increased compared to the 10 cm ridge height which stressed with excessive soil water that induced 16% lower dry matter accumulation. However, seed dry weights of ten soybean cultivars were not significantly

Table 1. Influences of ridge height on seed dry weight and several growth characteristics of ten soybean cultivars tested in the experiment.

Parameter	Ridge height (cm)			$LSD_{0.05}$
	10	30	50	
Total dry weight (g/plant)	21.5	24.0	25.5	1.2
Seed dry weight (g/plant)	12.5	12.6	12.9	NS
Branch number (no./plant)	5.7	7.7	8.0	0.7
Pod number (no./plant)	58.0	100.0	118.0	8.1
Seed number (no./plant)	74.3	74.0	74.3	NS
Seed no./pod (no.)	1.3	0.7	0.6	0.1
100 seed weight (g)	16.9	17.1	17.6	0.6
Harvest index (%)	58.2	52.4	50.7	1.4

different among three levels of ridge heights. This results indicated that soybean growth to the levels of ridge heights was differently responded during the growing periods such as vegetative, early reproductive and seed filling stages. The growth responses of soybeans to the excessive water stress differed among the treated growth stages (Sallam & Scott, 1987; Scott *et al.*, 1989). At the 10 cm ridge height, numbers of branches and pods of soybean cultivars were decreased compared with the 50 cm ridge height. Number of seeds per pod was decreased at upper levels of ridge heights which were exposed to dry condition during seed filling period (Fig. 2). One hundred seed weight was decreased at the 10 cm ridge height. However, harvest index of soybean cultivars at the 10 cm ridge height was significantly increased compared to the 50 cm ridge height. This increased harvest index indicated again that the growth responses during seed filling period of soybean cultivars differed among the ridge heights, which means that the 10 cm ridge height induced growth stress during the vegetative and early reproductive stages and growth promotion during the seed filling stages of soybean cultivars. No excessive water stress of soybean plants was found during seed filling period (Linkemer *et al.*, 1998). Increased harvest index which means more transport of assimilates to seeds might require much more water during seed filling period.

Total dry matter accumulation during the growing season from emergence (VE) to full maturity (R8) of ten soybean cultivars is shown in Fig. 3. Total dry weights of ten soybean cultivars were similar among three levels of ridge heights from VE to V6 which measured on 1 July and 1 August. Thus, during the seedling and early vegetative stages of soybean plants, excessive water stress was not affected to the plants with 10 cm ridge height. However, significant differences were found in total dry weights among three levels of ridge heights from beginning bloom (R1) to full maturity (R8), which appeared on 11 August and 24 October. Severe

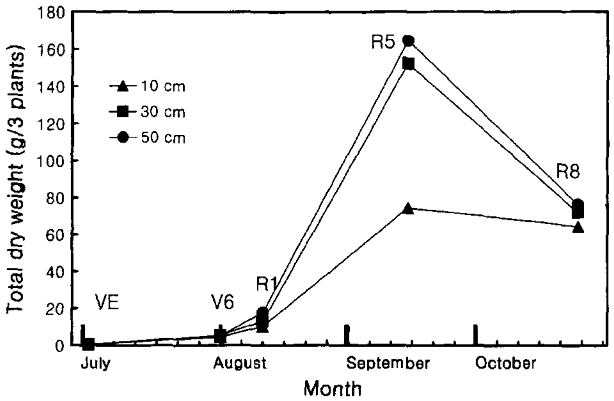

Fig. 3. Dry matter accumulation of ten soybean cultivars at three levels of ridge heights during the growing season.

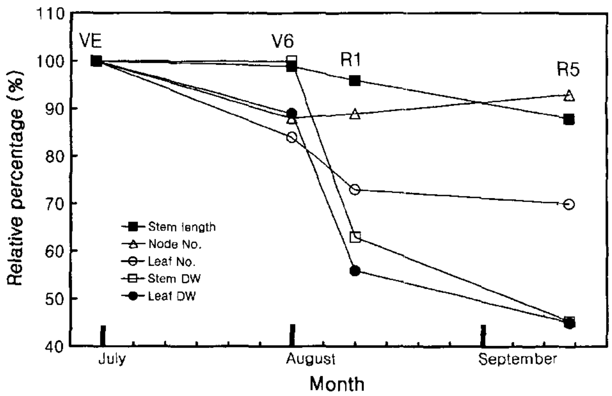

Fig. 4. Relative percentage of the ridge height 10 cm over 50 cm responses in the growth characteristics of ten soybean cultivars during the growing season.

excessive water stress was occurred at the ridge height of 10 cm, especially during the growth stages of R1 to beginning seed (R5) measured on 14 September. Linkemer *et al.* (1998) reported similar results that the early reproductive stages (R1, R3, and R5) of soybean plants were most sensitive to waterlogging. On the other hand, the steep decrements of the total dry weights at R8 stage were found at ridge heights of 30 and 50 cm, primarily due to leaf and pod fallings which induced more by dry condition (Fig. 2).

Soybean growth characteristics were analyzed by dividing the growth of 10 cm ridge height by the growth of 50 cm ridge height as shown in Fig. 4. The most sensitive growth responses were found on stem and leaf dry weights at the growth stages of R1 and R5. Stem dry weight of the 10 cm ridge was decreased 37% at R1 and 55% at R5 growth stages compared to the 50 cm ridge, and leaf dry weight was also decreased 44% and 55%, respectively. This results implies that the late vegetative and early reproductive growth stages are most sensitive to excessive water stress (Linkemer *et al.*, 1998). These dry weight decrements were related to the growth responses of leaf number, node number, and stem length. Leaf number of the 10 cm ridge was decreased 27% at R1 and 30% at R5 growth stages compared with the 50 cm ridge. Node number was also decreased from 4 to 12% during the growth stages of R1 and R5.

Soybean cultivars to excessive soil water in field conditions responded to sensitive or tolerant with their genotypic differences during the life cycle of growth periods (VanToai *et al.*, 1994; Osborne *et al.*, 1995). Seed dry weights and related components of ten soybean cultivars at the three ridge heights were shown in Table 2. First three cultivars were classified sensitive and later seven were tolerant to excessive water stress in the previous experiments. Seed dry weights at the 10 cm ridge height were relatively higher in

Table 2. Responses of yield-related characteristics of ten soybean cultivars at three ridge heights.

Parameter	Ridge height	Cultivar										$LSD_{0.05}$
		1	2	3	4	5	6	7	8	9	10	
Seed dry weight	10 cm	9.2	9.2	8.6	18.9	16.3	14.0	15.1	8.8	14.0	11.2	
(g/plant)	30 cm	9.0	9.8	8.8	16.0	17.8	15.0	14.4	8.1	16.0	11.0	
	50 cm	10.2	10.0	9.6	16.8	15.5	16.3	15.1	9.3	15.2	10.9	
	mean	9.4	9.7	9.0	17.2	16.6	15.1	14.9	8.7	15.1	11.0	1.3
Seed number	10 cm	70.0	83.3	70.7	86.0	71.0	64.3	70.3	73.0	70.7	83.3	
(no./plant)	30 cm	69.0	79.0	75.3	84.3	74.0	64.7	66.0	66.0	79.7	82.0	
	50 cm	69.7	80.7	77.0	82.7	68.3	66.7	67.3	67.7	80.7	81.7	
	mean	69.7	81.0	74.3	84.3	71.0	65.3	68.0	69.0	77.0	82.3	5.7
Pod number	10 cm	102.3	52.3	62.7	50.0	45.0	70.3	51.3	53.0	28.7	65.3	
(no./plant)	30 cm	147.3	99.7	114.7	83.7	88.3	101.7	85.0	125.0	74.3	81.3	
	50 cm	181.0	145.3	114.0	76.0	87.7	124.7	101.1	154.3	95.3	101.0	
	mean	143.7	99.0	97.0	70.0	73.7	99.0	79.0	110.7	66.0	82.7	14.8
Seed no./pod	10 cm	0.7	1.6	1.1	1.7	1.6	0.9	1.4	1.4	2.5	1.3	
(no.)	30 cm	0.5	0.8	0.7	1.0	0.8	0.6	0.8	0.5	1.1	1.0	
	50 cm	0.4	0.6	0.7	1.1	0.8	0.5	0.7	0.4	0.9	0.8	
	mean	0.5	0.8	0.8	1.2	1.0	0.7	0.9	0.6	1.2	1.0	0.4
100 seed weight	10 cm	13.2	11.0	12.2	21.9	23.0	21.8	21.4	12.0	19.6	13.4	
(g)	30 cm	13.0	12.4	11.7	19.0	24.0	23.1	21.7	12.3	20.2	13.4	
	50 cm	14.6	12.4	12.6	20.3	22.9	24.4	22.5	13.7	19.0	13.4	
	mean	13.6	11.9	12.2	20.4	23.3	23.1	21.9	12.7	19.6	13.4	1.1
Harvest indexI	10 cm	50.0	58.5	57.8	63.0	58.1	55.6	56.0	65.0	64.1	54.3	
(%)	30 cm	41.5	53.7	52.1	58.0	52.2	50.3	53.7	54.5	56.6	51.6	
	50 cm	40.7	49.5	51.6	60.9	49.7	48.5	50.5	52.4	54.3	48.7	
	mean	44.1	53.9	53.8	60.6	53.3	51.4	53.4	57.3	58.3	51.6	2.5

Cultivar; 1: Danyeobkong, 2: Hannamkong, 3: Myeongjunamulkong, 4: Mallikong, 5: Jangsukong, 6: Taekwangkong, 7: Jinpumkong, 8: Sobaegnamulkong, 9: Muhankong, 10: Pureunkong.

Table 3. Ridge height effects and cultivar differences on major vegetative growth characteristics at the stage of beginning seed (R5).

Treatment		Stem weight (g/plant)	Leaf weight (g/plant)	Leaf number (no./plant)	Leaf area index (leaf areas/land area)	Leaf/stem ratio (leaf weight/stem weight)	Crop growth rate (g/day/plant)
Ridge height	10 cm	4.6	9.6	36.9	4.0	2.1	0.32
	30 cm	8.4	19.3	51.4	7.9	2.4	0.69
	50 cm	8.6	21.3	52.8	8.9	2.5	0.70
	$LSD_{0.05}$	0.7	1.7	4.6	1.1	0.1	0.02
Cultivar	1. Danyeobkong	8.6	19.1	58.8	7.6	2.2	0.66
	2. Hannamkong	6.1	12.6	45.3	5.8	2.1	0.40
	3. Myeongjunamulkong	5.4	11.6	41.7	4.8	2.1	0.42
	4. Mallikong	5.8	15.7	44.4	7.1	2.7	0.47
	5. Jangsukong	10.1	19.5	41.1	8.4	1.9	0.76
	6. Taekwangkong	9.0	23.2	58.6	10.1	2.5	0.74
	7. Jinpumkong	8.8	20.2	43.0	7.8	2.2	0.66
	8. Sobaegnamulkong	4.5	15.6	45.0	4.4	3.3	0.52
	9. Muhankong	6.7	16.1	51.4	7.2	2.3	0.54
	10. Pureunkong	7.0	13.9	40.9	6.1	2.0	0.53
	$LSD_{0.05}$	1.3	3.1	8.5	2.1	0.2	0.11

the tolerant cultivars such as 'Mallikong', 'Jangsukong', 'Taekwangkong', 'Jinpumkong', and 'Muhankong'. No responses in seed number were found among the three ridge heights even though there were cultivar differences. Significant difference was found in pod number among the ridge heights at the stress sensitive cultivar, 'Danyeobkong', which showed much empty pods at the 10 cm ridge height appeared on seed number per pod. Stress tolerant cultivars, 'Mallikong', 'Jangsukong', 'Taekwangkong', and 'Jinpumkong' showed higher one hundred seed weights especially at the 10 cm ridge height, which means more transport of assimilates to the seed at the conditions of excessive soil water. Bradford (1994) reported that water relations are important in sink activity and other aspects of seed development. Higher harvest index at the 10 cm ridge height was found at the cultivars, 'Mallikong', 'Sobaegnamulkong', and 'Muhankong', which classified as stress tolerant to excessive soil water. Thus, cultivar, 'Mallikong' showed the higher transport capability of assimilate at the 10 cm ridge height.

Growth characteristics of ten soybean cultivars at the stage of R5 were summarized in Table 3. Stem and leaf dry weights were high in 'Jangsukong', 'Taekwangkong', and 'Jinpumkong' among ten soybean cultivars at the growth stage of R5. Leaf number and leaf area index were largest in 'Taekwangkong'. Leaf/stem ratio was higher in 'Mallikong', 'Taekwangkong', 'Jinpumkong', 'Sobaegnamulkong', and 'Muhankong'. Crop growth rate was highest in 'Jangsukong', and 'Taekwangkong'. Crop growth rates of soybean cultivars at excessive water stress were also reported by Griffin & Saxton (1988), Linkemer *et al.* (1998), and Scott *et al.* (1989). Thus, cultivar 'Taekwangkong' showed relatively more leaves compared to stem, and transpired more water at the excessive soil water in 10 cm ridge height, which stimulated higher crop growth rate. Based on the experimental results, the ridge height of 10 cm in paddy field was the growth stress level from the late vegetative to R5 stages and the growth promotion level during the seed filling period (R5 to R7) of ten soybean cultivars. Soybean cultivars, 'Mallikong', 'Jangsukong', 'Taekwangkong', 'Jinpumkong', and 'Muhankong' showed tolerant to excessive soil water in relation to their growth characteristics and final seed weights.

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