Soybean Growth and Yield as Affected by Spacing of Drainage Furrows in Paddy Field

Jin-Woong Cho*†, Jung-June Lee, Young-Jin Oh**, Jung D. So***
Jun-Yeon Won*, and Chang-Ho Kim******

**Collage of Agricultural & Life Science, Chungnam National Univ. 305-764, Korea*
***Honam Agricultural Research Institute, National Institute of Crop Science, RDA, 570-080, Korea*
****Dept. of Liberal Arts, Joongbu Univ. 312-702, Korea*
*****Dept. of Plant Resources, College of Industrial Sciences, Kong Ju National Univ. 314-702, Korea*

ABSTRACT : This study was conducted to determine the optimum number of inter-rows according to distance of drainage furrow (DF) for running-off excessive-water stress (EWS) in paddy field. The most soil water potential was shown in high ridge (distance of DF by 70 cm) cultivation and the soil water potential showed increasing tendency in over four inter-rows cultivation by DF. The growth of soybean reduced by extended inter-row and its reducing level was high, especially, over four inter-rows (DF distance by 2.8 m) because of EWS. The photosynthetic rate decreased in the more extensive field by distance of DF at V5 and R2 stages, especially, in over four inter-rows cultivation. Also, root activity decreased at wider DF. The yield was reduced with wider distance of DF more extensively, the highest yield of 270 g per m^2 at the every row, but yield showed decreasing tendency at over the 4^{th} row (2.8 m) cultivation. Soybean cultivation in paddy field could be founded with DF of every other or 4^{th} row.

Keywords: soybean, excessive-water stress, drainage furrow, photosynthetic rate, seed yield, paddy field

In Korea, because of low seed yield per unit area and insufficient commitment of mechanization technology, cultivation area of soybean decreased rapidly from 297,000 ha in 1970 to 87,350 ha in 2000 (Cho *et al.*, 2003). Also, the production of soybean was very low and the self-supply of soybean was not more than 26.8 % in 2000. Therefore, in order to elevate the self-supply of soybean production, it is essential to increase the grain yield per unit area and is necessary to extend the cultivation area of soybean to paddy fields. In case of soybean cultivation on paddy field, seed yield was generally higher in paddy field than in upland (Hwang & Park, 1993) but water-logging is one of the most important damaging factors which is caused by heavy rainfall or poor drainage for rainy season from late June to August (Cho *et al.*, 2004; Seong *et al.*, 2000). Drainage was needed to run off excessive water stress (EWS) during the rainy season for soybean cultivation in the converted upland from paddy field (Son *et al.*, 1997) Also, detrimental effect of prolonged rainfall is usually attributed to an inadequate oxygen supply to sustain root respiration and root availability (Seong *et al.*, 2000). Water requirement of soybean is generally higher than that of other crops, but soybean is very sensitive to excessive water or flood due to less development of vessel in plant's morphological traits (Seong *et al.*, 1999; Cho *et al.*, 2003; Cho *et al.*, 2004).

Specially, despite utilizing the fixed-nitrogen as a major nutrient for soybean by *rhizobium*, the soybean is classified as a yield-secure-difficult crop in paddy field cultivation since insertion problem of *rhizobium* causing the high water-table and bad drainage of paddy field (Puiatti & Sodek, 1999; Shimamura *et al.*, 2003).

Thus, this research carried out to analyze effects of a distance between furrows according to a number of rows on a yield of soybean and growth characteristics in paddy field, and to suggest a proper drainage facility for stable soybean yield against the flooding stress in paddy field cultivation.

MATERIALS AND METHODS

Cultural practices and treatments

Field studies were conducted during 2002 and 2003 in the southeastern Korea (36°N lat) on a commerce silt loam soil on a paddy field using soybean (cv. Doremikong) of determinate growth type. Soybean was planted on May 30 in 2002 and June 4 in 2003 with a plant density of 70 (row width) × 10 (plant spacing) cm. Plants were sowed with a high seeding rate and thinned with two plants per hill prior to V3 stage. Fertilizer was applied prior to planting at a rate of 30 – 30 – 34 kg ($N - P_2O_5 - K_2O$) per hectare. Weeds, diseases, and insects were controlled by recommended pesticides. Chemical characteristics of the experimented soil were shown in Table 1.

†Corresponding author: (Phone) +82-42-821-7824 (E-mail) jwcho@cnu.ac.kr <Received February 21, 2006>

Table 1. Chemical properties of soil of paddy field.

PH (1 : 5)	OM (g kg $^{-1}$)	T-N (%)	P_2O_5 (mg kg $^{-1}$)	Ex. Cat. (c mol $^+$ kg^{-1})			CEC (c mol $^+$ kg^{-1})
				K	Ca	Mg	
5.8	26.3	0.124	111	0.44	3.7	0.4	8.3

Table 2. Temperature and precipitation data during growth stages of soybeans in 2002 and 2003. Number in parenthesis indicates the difference with respect to normal temperature and precipitation.

Growth stages (Time)	Temperature (°C)		Precipitation (mm)	
	2002	2003	2002	2003
VE ~ V1 (early-Jun.)	22.3 (+1.3)	22.8 (+1.2)	15.3 (-12.5)	0.0 (-38.2)
V2 ~ V7 (Mid-June ~ Early-July)	23.6 (-0.3)	16.9 (-7.3)	38.1 (-42.9)	500.8 (+247.2)
R1 ~ R3 (Mid-July ~ Mid-Aug.)	25.5 (-0.9)	20.9 (-5.9)	109.7 (+28.7)	491.3 (-25.6)
R4 ~ R5 (Late-Aug. ~ Mid-Sep.)	26.2 (-0.3)	23.8 (-0.4)	129.6 (+35.7)	248.2 (+64.3)
R6 ~ R8 (Mid-Sep. ~ early-Oct.)	21.5 (+0.8)	19.1 (-1.1)	23.4 (-9.0)	95.7 (+20.0)

The drainage furrow (DF) was installed with every row (0.7 m), every other row (1.4 m), every 4th row (2.8 m), and 6th row (4.2 m), and every 12th row (8.4 m). The DF at the field was created by cultivator with depth of 30 cm.

The treatment size of field was 2.8 × 40 m for the every row drainage, 5.6 × 40 m for the every other row drainage, 5.6 × 40 m for the every 4th row drainage, 8.4 × 40 m for the every 6th row drainage, and 16.8 × 40 m for the every 12th row drainage. The experiment field was designed as a randomized complete block design and replicated three times.

Growth and yield factors

The characteristics of growth was measured at mature stage of Oct. 10, 2002 and Oct. 14, 2003, and the plant height, stem width, and number of branches were measured with randomly chosen 10 plants in each treatment field and replicated three times.

The yield of soybean as 100-seed weight, collected by hand, was measured within a field size of 2 m^2 after dried soybeans to 16% of moisture content. Also, the number of leaves and branches per plant were measured in each treatment from randomly selected 10 plants and replicated three times.

Photosynthetic rate

The photosynthesis was measured using portable photosynthesis measuring device (LCA-4, UK). Measurements were taken from 9: 30 in the morning to 2: 30 in the afternoon by six replications per treatment at the full blooming stage (R2) and the early seed filling stage (R5). The light intensity used to measure the photosynthesis was in the range of 1700 ~ 2000 ìmol m^{-2} s^{-1} photosynthetically active radiation (PAR). The CO_2 concentration was 330 ~ 370 ppm and the flow rate of the air was 400 ml min^{-1}.

Root activity

The root activity was determined by modified TTC (triphenyl-tetrazolium chloride) method (Lee *et al.*, 1996). The root activity was measured with fresh sample of 5 g with TTC solution (1% TTC: 0.1M sodium phosphate: distilled water = 1: 4: 5) for 2 hours on water bath of exhausted air at 30 °C. Then, the formazan was extracted with a homogenizer using 3-5 mL of ethyl acetate while the reaction of samples was stopped by 2N H_2SO_4 and it was determined with a spectrophotometer (Spectronic genesys 2PC, USA) at 470 nm. The standard curve of root activity was obtained using $Na_2S_2O_4$ and ethyl acetate.

RESULTS AND DISCUSSION

Temperature and precipitation

Table 2 shows the average temperature and precipitation during experiment period. The average temperature and precipitation in 2002 and 2003 showed a different aspect according to average. The average temperature in 2002 showed no difference with respect to normal temperature, but the average temperature in 2003 was 5.9~7.3 °C lower

Table 3. Growth characteristics of soybean at the ripening period in various distance of drainage furrow at paddy field in 2002 and 2003.

Years	Distance of drainage ditch (m)	Plant height (cm)	Stem diameter (mm)	Node no. on main stem ($plant^{-1}$)	Branch No. ($plant^{-1}$)	Nodule No. ($plant^{-1}$)	Waterlogging index (1-9)
2002	0.7	65.5	7.8	14.4	4.7	46.5	1
	1.4	68.2	8.0	13.4	4.5	39.2	1
	2.8	64.3	7.2	13.0	4.5	23.4	2
	4.2	59.9	7.7	13.2	4.3	21.1	3
	8.4	60.6	6.5	13.3	4.5	24.1	5
	LSD (0.05)	5.3	ns	ns	ns	6.7	-
2003	0.7	68.4	7.7	12.5	4.9	40.1	2
	1.4	69.3	7.8	13.7	4.9	35.1	2
	2.8	63.8	6.4	13.1	4.3	20.8	4
	4.2	58.9	6.6	12.9	4.0	16.2	6
	8.4	50.9	5.4	12.1	4.4	16.7	7
	LSD (0.05)	8.8	1.0	ns	ns	7.1	-

than normal temperature at from early vegetative growth stage and seed filling stage. The precipitation in 2002 was less than normal until early vegetative growth stage, but was more than normal from after flowering to ripening stage. The precipitation in 2003 was more than normal throughout whole growth stage except from sowing to emergency.

Growth

The growth of soybean decreased as the distance of the DF increased, and it was greater in 2003 than in 2002 (Table 3). The waterlogging index increased with wide DF compared to narrow DF, and it was greater in 2003 than in 2002. The waterlogging appeared at the DF of 4.2 m in 2002 but in 2003, and it appeared at distance of the DF of 2.8 m. This could attribute to a lower growth environment of soybeans characterized by lower solar radiation and lower temperature. Also, more irregular heavy rainfall caused more waterlogging in 2003 than in 2002.

The plant height significantly decreased in the wider DF compared to the narrower DF. The highest plant height of 68.2 cm in 2002 and of 69.3 m in 2003 appeared at the 1.4 m of the DF. The plant height greatly decreased at the 4.2 m and 8.4 m of DF.

The stem diameter showed no significant difference in 2002, but significant difference ($p<0.05$) in 2003. The number of nodes on main stem and number of branches was not affected with different distances of DF in both years. The significant reduction of nodule number appeared at DF of 2.8 m wider than it in both years. For the number of nodules according to different distances of DF in paddy field, the DF of 0.7 m was the greatest by 46.5 in 2002 and 40.1 in 2003, and

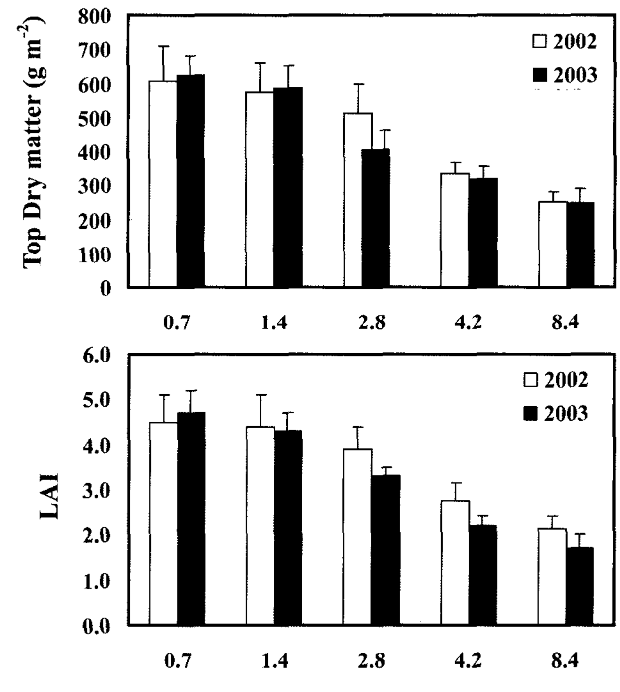

Fig. 1. LAI and top dry matter of soybean at the full pod (R4) stage with various distance of the drainage furrow in paddy field.

there was no significant difference at the DF among 2.8 m, 4.2 m, and 8.4 m in both years. Soybean flooded at vegetative stage reduced leaf area, dry weight, and plant weight (Cho, *et al.*, 2004; Heatherly & Pringle, 1991) Specially, Griffin & Saxton (1988) stated that soybean flooded at V6 had severe chlorosis and stunting after 4 days standing water. Also, these researchers reported that crop growth rate (CGR) had been usually affected when the EWS was applied for more than 2 days. Meanwhile, in the hydroponic study, Boru *et al.* (2003) reported that soybean plants were chloroyic, stunted, and produced fewer shoots and roots than soybean in the no oxygen or low oxygen treatments. However, when anaerobic root-zone CO_2 was increased to 50%, a quarter of the plants died and survived soybeans showed severe symptoms of chlorosis, necrosis, and root death.

As stated above, the different number of nodules with regard to distance of the DF, the number of nodules decreased as distance of the DF increased, was considered to be due to poor growth and multiplication of *rhizobium* caused by poor drainage with high underground water level at the paddy field.

Fig. 1 shows the leaf area index (LAI) and dry matter of soybeans according to distance of the DF. As shown fig. 1, the dry matter of aerial part of soybeans at the full pod stage (R4) was the greatest of 607 g and 622 g in 2002 and in 2003, respectively, at the DF of 0.7 m, and was the lowest of 254 g and 246 g in 2002 and in 2003, respectively, at the DF of 8.4 m. The dry matter decreased significantly from the DF of 4.2 m in 2002, and from the DF of 2.8 m in 2003 compare to the DF of 0.7 m.

The LAI also showed similar trend with the dry matter at the R4 stage. The LAI decreased significantly from the DF of 4.2 m in 2002, and from the DF of 2.8 m in 2003 compare to the DF of 0.7 m.

Photosynthetic rate and root activity

Photosynthetic rate (P_N) and root activity (R_A) of soybean with different distance of the DF were shown in Table 4. P_N and R_A were measured at the V5 and the R2 stages. P_N of soybean had a significant difference ($P < 0.05$) among different distance of the DF at both stages, and slightly decreased as distances of the DF increased in 2002 and 2003.

The highest P_N of 17.3 μmol CO_2 m^{-2} s^{-1} observed at the distance of the DF of 1.4 m in 2002 and 17.4 μmol CO_2 m^{-2} s^{-1} observed at the distance of the DF of 0.7 m in 2003 at the V5 stage. Meanwhile, the highest P_N of 30.9 and 31.6 μmol CO_2 m^{-2} s^{-1} was observed at the distance of DF of 0.7 m in 2002 and 2003, respectively, at R2 stage.

The lowest P_N of 13.7 and 11.5 μmol CO_2 m^{-2} s^{-1} was observed at the DF of 8.4 m in 2002 and 2003, respectively, at V5 stage. The significant reduction of P_N occurred from the DF of 2.8 m at both of stages. Therefore, we think that the reduction of P_N of soybeans on wider DF was caused by excessive water content in soil by poor drainage. According to Yordanova & Popova (2001), the decreased change in P_N after flooding might be mediated by stomata closure causing a reduction in CO_2 supply and capacity of plants for fixation. Ahamed *et al.* (2002) stated that photosynthetic rate of mungbean with waterlogging declined rapidly progressive waterlogging at vegetative stage, and waterlogging caused a fast decline in the photosynthetic rate indicated that reduction of photosynthetic rate might be due to a mechanism independent from stomatal closure. Also, when waterlogging was removed, photosynthetic rate increased to a control level on 8 days at vegetative stage.

On the other hand, R_A of soybeans grown in paddy field decreased at wider distance of the DF. Specially, R_A sharply reduced at the distance of the DF of 2.8 m at V5 stage and of

Table 4. The photosynthetic rate and the root activity of soybean with various distance of the drainage furrow.

Years	Distance of DF (m)	Photosynthetic rate (μ mol CO_2 m^{-2} s^{-1})		Root activity (mg Fermazan g^{-1} D.W. hr)	
		V5	R2	V5	R2
2002	0.7	16.9	30.9	2.08	1.99
	1.4	17.3	30.7	2.15	2.01
	2.8	15.9	28.3	1.99	1.88
	4.2	13.7	25.1	1.87	1.79
	8.4	13.9	24.7	1.80	1.81
	LSD (5%)	2.7	2.9	0.11	0.15
2003	0.7	17.4	31.6	1.78	1.58
	1.4	17.1	29.8	1.83	1.55
	2.8	13.5	23.8	1.44	1.42
	4.2	12.4	23.3	1.40	1.05
	8.4	11.5	21.4	1.44	1.03
	LSD (5%)	3.3	2.8	0.14	0.17

Table 5. Seed yield and yield components of soybean grown in paddy field with various distances of the drainage furrow.

Year	Distance of drainage ditch	No. of pods ($plant^{-1}$)	No. of seed ($plant^{-1}$)	Seed per pods (no.)	100-seed weight (g)	Yield ($g\ m^{-2}$)
2002	0.7m	72	207	3.7	11.9	271
	1.4m	65	194	3.1	11.7	269
	2.8m	59	153	2.6	11.4	238
	4.2m	55	133	2.4	11.4	206
	8.4m	55	130	2.4	11.2	208
	LSD (0.05)	16.6	59.6	0.3	ns	33.2
2003	0.7m	84	217	2.6	11.3	268
	1.4m	86	203	2.4	10.9	261
	2.8m	72	149	2.1	11.0	199
	4.2m	65	127	2.0	10.5	188
	8.4m	49	105	2.1	10.2	194
	LSD (0.05)	15.6	48.3	0.2	ns	55.4

4.2 m at R2 stage. R_A, however, was higher in V5 than in R2 stage. This result indicated that soybeans grown at wider distance of the DF in paddy field might be greater reduction of R_A at reproductive growth stage than vegetative growth stage.

Also, the root activity according to growth stages showed no significant difference with the DF of 0.7 m, but it decreased greatly as growth developed from the two row DF.

The root activity reduction according to the wider distance of the DF with the growth development was considered to be due to reduction of the respiratory capability, higher production of lactic acid and alcohol, and reduction of creation of ATP by the flooding stress.

Yield and yield components

The yield and yield components showed decreasing trend as the distance of the DF increased. The pod number of 99 was the highest at the distance of the DF of 0.7 m and of 52 was the lowest at the distance of the DF of 8.4 m per plant. The number of pod was higher in 2003 than in 2002 except the distance of the DF of 8.4 m.

The number of seeds per plant showed similar trend with the number of pod. The highest number of seeds observed at the high ridge cultivation and the lowest number of seeds of 14.1 g observed at the distance of the DF of 8.4 m.

The annual difference of the number of seeds per plant showed similar trend with the number of pod. The number of seeds in 2003 was higher than in 2002 at the distance of the DF of 4.2 m. According to Seong *et al.* (2000), the excessive water stressed soybean was more highly affected by irrigation beginning at pre-flowering stage than post-flowering because flooded soybean at post-flowering stage did not reduce growth of vegetative organs significantly. In the southern Korea, soybean has been cultivated with late planting (after mid-June) because of double cropping after a winter crops, even if it is a common problem for soybean production. However, because the rainy season is common during the summer from mid-June to mid-July when soybean is grown on a paddy field, the growth of vegetative growth stage from emergence to prior flowering stage could be declined by excessive water stress in this season (Cho *et al.*, 2004; Seong *et al.*, 1999; Seong *et al.*, 2000). Therefore, the yield also greatly decreased as the distance of the DF increased. Even though the soybean cultivation at the paddy field has been known as unfavorable by the flood stress under nation's weather condition of heavy rain during July and August and high underground water level, the stable soybean yield could be expected at the DF distance of 2.8 m with the interrow spacing of 70 cm under the condition of low light intensity with long rainy days such like in 2003 as well as based on good weather forecast system development. Also, the stable soybean yield could be expected with the DF of 4.2 m with the same weather condition as normal.

REFFERENCES

Ahmed, S., E. Nawata, M. Hosokawa, Y. Domae, and T. Sakuratani. 2002. Alterations in photosynthesis and some antioxidant enzymatic activities of mungbean subjected to waterlogging. plant Sci. 163 : 117-123.

Boru, G., T. Vantonai, J. Alves, D. Hua, and M. Knee. 2003. Responses of soybean to oxygen deficiency and elevated rootzone carbon dioxide concentration. Annals of Botany. 91 : 447-453.

Cho, J. W., M. S. Park, J. J. Lee, M. J. Lee, J. D. So, T. S. Kim, and

S. B. Lee. 2003. Topping effect on growth and yield of soybean growth in paddy field. Korean J. Crop Sci. 48 : 96-102.

Cho, J. W., J. J. Lee, and C. S. Kim. 2004. Effects of planting dates on growth and yield of soybean cultivated in drained-paddy field. Korean J. Crop Sci. 49 : 325-330.

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

Heatherly, L. G. and H. C. Pringle. 1991. Soybean cultivars' response to flood irrigation of clay soil. Agron. J. 83 : 231-236.

Hwang, Y. H. and S. G. Park. 1993. Growth characteristics and yield potentials of soybeans in upland and paddy field. Korean J. Crop Sci. 38 : 336-342.

Lee, S. Y., C. S. Kim, J. W. Cho, and Y. G. Kang. 1996. Physiological response of barley seedlings to salt stress. Korean J. Crop Sci. 41 : 665-671.

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

Seong, R. C., J. Y. Sohn, and S. I. Shim 2000. Response of soybean cultivars to excessive soil moisture imposed at different growth stages. Korean J. Crop Sci. 45 : 282-287.

Seong, R. C., J. G. Kim, and C. J. Nelson. 1999. Dry matter acculumation and lesf mineral contents as affected by excessive soil water in soybean. Korean J. Crop Sci. 44 : 129-133.

Shimamura, S., T. Moghizuki, Y. Nada, and M. Fukuyama. 2003. Secondary aerenchyma formation, growth and yield of soybean plants grown under continuously flooded conditions. Jpn. J. Crop Sci. 72 : 25-31.

Son, B. Y., D. H. Kim, E. S. Kim, S. K. Kim, D. J. Kang, W. K. Shin, and H. S. Lee. 1997. Effect of planting dates and drainage methods on growth and yield of sprout soybeans in converted upland from paddy field. Korean J. Crop Sci. 42 : 323-332.

Yordanova, R. Y. and L. P. Popova. 2001. Photosynthetic response of barley plants to soil flooding. Photosynthtica. 39 : 515-520.