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Evapotranspiration and Grain Yield in Responses to Different Soil Water Conditions in Soybean

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ABSTRACT : This experiment was conducted to evaluate the effect on evapotranspiration and yield of soybean according to different soil water conditions, and to find the optimum time and amount for irrigation in soybean cultivation. The difference between potential evapotranspiration (PET) and maximum evapotranspiration (MET) during growing season of soybean planted in lysimeter was higher during reproductive stage than during vegetative one. The maximum crop coefficient was obtained at beginning seed stage of soybean. Soil water coefficient of irrigation treatment was higher than that of non-irrigation treatment during soybean growth stage in field experiment. Grain yield was highest in lysimeter due to its high water use efficiency and evapotranspiration rate.

Keywords : soybean, potential evapotranspiration, maximum evapotranspiration, crop coefficient, soil water coefficient.

One of the environmental factors influencing the growth, development, and yield of soybean is the water which is transported to soil-plant-atmosphere system (Federer, 1979; Boyer, 1982; Son *et al.*, 1988). Therefore, optimum irrigation has been an important contributor to increase yields. To obtain maximum yield potential, plant must be grown under the lack of water deficiency during plant growing season, and its water availability should be examined in each growth stage (Williamson *et al.*, 1973; Barros *et al.*, 1993).

Recently, a major concern in cultivating crops has always been water availability in the root zone and water use efficiency of plant during growing season. Plant water use efficiency was a topic for modern scientific study and knowledge about the factors affecting crop water use efficiency and a hope to improve the efficiency has continued to be an objective in a number of modern investigation (Sinclair *et al.*, 1984).

Water movement from soils to crops is an important factor in managing both irrigated and dryland farming operations because it influences the time of seeding, the scheduling of irrigations, and various tillage practices (Idso *et al.*, 1975; Garside *et al.*, 1992). Cumulative water use by a soybean often varies between different growth stages. Greater requirement for water during reproductive than during vegetative growth was reported by many researches (Mason *et al.*, 1982). Also, there was a report that total dry matter yield and evapotranspiration (ET) were linearly related with a high degree of correlation (Hanks *et al.*, 1969).

There was a study reporting that seed yield enhancement in soybean was achieved by irrigation during pod elongation stage (R3 to R4) irrespective of seasonal differences in rainfall amounts and an irrigation during the flowering period (R1 to R2) (Korte *et al.*, 1983).

The objectives of this experiment were to evaluate effect of soil water conditions on changes in evapotranspiration and yield response of soybean and to find the optimum time and amount for irrigation in soybean cultivation.

MATERIALS AND METHODS

Cultural details

The experiment was conducted at the National Crop Experiment Station, RDA, Suwon, Korea from May 27 to October 24, 1998. There were two treatments which were lysimeter system and field condition (irrigation and non-irrigation).

The lysimeter used in this experiment was constructed to measure potential evapotranspiration (PET) and maximum evapotranspiration (MET). The tank for measuring PET was filled with loam soils and grasses were grown in it, but that for mesuring MET was filled with clay loam soils. Each of tank was 4 m^2 in area and 2 m depth. Measurements of volumetric soil moisture content were made at depths of 10 to 70 cm by 10 cm by neutron moisture sub-surface gauge (CPN model 503 DR, 2830 Howe Road Martinez, California, USA). Total soil water in storage was estimated by investigating the volumetric water contents over the entire soil depth. Daewonkong was planted on the lysimeter for measuring MET and also planted in the planting density of 222,000 plants per hectare.

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In the soil tank for measuring MET, the soybean was grown and the water table was set for 70 cm. The water table was maintained to 50 cm below the soil surface for the potential evapotranspiration.

The field was divided into irrigation and non-irrigation plots. The irrigation point for irrigation plot was -0.05 MPa of soil water matric potential.

Measurements of evapotranspiration, crop coefficient, and soil water coefficient

Irrigation reservoirs were checked every day and water was added as needed. Soil water contents in lysimeter and field during growing season of soybean were monitored with a neutron sub-surface moisture gauge in increments of 10 cm to 70 and 50 cm below the soil surface, respectively.

PET, defined by Penman (Penman, 1963) was calculated by measurement for water loss of grasses 10~15 cm of height during soybean growing season with water table depth maintained to 50 cm below soil surface in lysimeter. Crop coefficient (Kc) was calculated by the ratio of MET to potential evapotranspiration. Soil water coefficient (fc) was calculated by the ratio of actual evapotranspiration(AET) in field to MET in lysimeter.

Growth and yield of plant

Developmental growth stages of soybean were investigated as described by Fehr and Caviness (1977). Soybean was harvested for lysimeter and field experiments on October 20, 1998. Plants were sampled from lysimeter, irrigation and non-irrigation plots to estimate growth and yield response by soil water condition. In field experiment, each irrigation treatment plot was divided into 3 sub-plot at harvest and data were analyzed by SAS package and graphed with Sigmaplot program.

RESULTS AND DISCUSSION

Meteorological data

Changes in daily mean temperature and rainfall distribution from May 10 to October 20 in Suwon, Korea was illustrated in Fig. 1. The amount of rainfall from July 21 to August 20 was occupied about 57 % of total amount of rainfall during soybean growing season in 1998. Therefore, it was difficult to clarify the effect of irrigation treatment compared to non-irrigation treatment (natural field condition) because of unevenly distributed rainfall.

During soybean growing season, soil water potential at 30 cm of soil depth in non-irrigation plot was maintained to above -0.05 MPa due to severe rainfall (Fig. 1). Irrigation date and amount of irrigation to the irrigation plot were shown in Table 1.

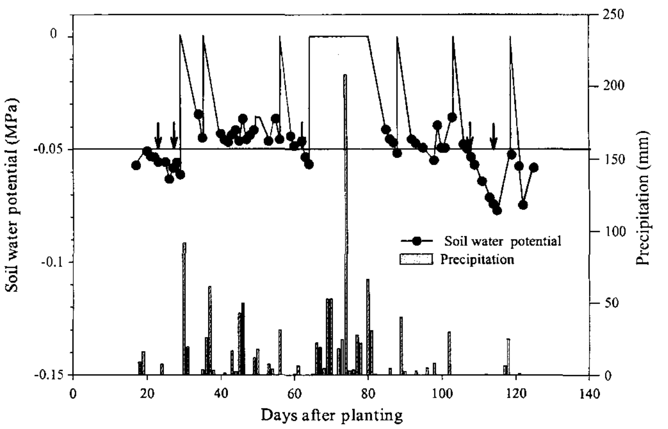

Fig. 1. Changes in soil water potential at 30 cm of soil depth from soil surface and precipitation for soybean growing season (arrows indicate the irrigation point).

Table 1. Date and amount of irrigation for irrigation treatment in field experiment.

Irrigation date	Irrigation amount(mm)
June 18	25.4
June 22	17.6
July 27	0.4
September 11	10.0
September 18	10.0

Change in water storage and evapotranspiration

Differences in daily PET and daily MET during vegetative growth were not significantly different. MET increased remarkably at flowering stage (R2) when compared to PET, and, after then, MET was maintained to much higher than PET (Fig. 2). This result indicated that water requirement of soybean was markedly increased in reproductive stage, especially R2 and beginning seed (R5) to full seed (R6) stages, and that irrigation for R5 to R6 as well as R2 was very important in soybean cultivation.

In early vegetative growth, AET in field irrigation treatment was higher than lysimeter due to much rainfall and worse drainage of field condition. But in lysimeter, AET (= MET) was sharply increased after V9 to V12 stage, and, after then, maintained high evapotranspiration rate (Fig. 3). It was assumed that growth response of plant in lysimeter was more vigorous than that of field condition during respective period. During growing season, actual evapotranspiration in irrigation plot was maintained to higher than

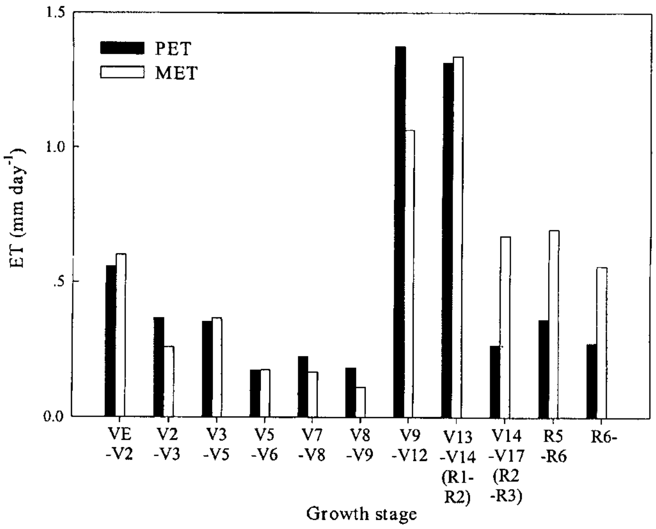

Fig. 2. Changes in potential evapotranspiration (PET) and maximum evapotranspiration (MET) during growing season of soybean in lysimeter experiment.

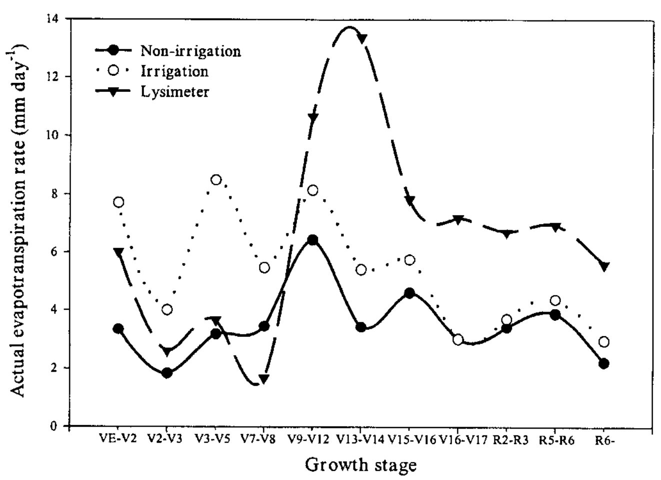

Fig. 3. Changes in actual evapotranspiration (AET) for non-irrigation, irrigation treatment, and lysimeter during soybean growing season.

that of non-irrigation plot.

Crop coefficient (Kc), defined as the degree of water requirement of crop at a given stage, was varied to soybean growth stages. Kc was considerably increased after R2 stage as described in Table 2 and maintained high level until R5 and even after R6. It indicated that irrigation for R2, R5, or R6 stage can increase the reproductive growth of soybean, such as number of seed and seed weight. The relationship between Kc and days after planting during soybean growth season was shown in Fig. 4. Kc was highly correlated with days after planting (r^2=0.268**). Using this regression equation, maximum Kc was recorded at 104 days after planting. Son et al. (1988) reported similar result that crop coefficient was highly correlated with growth degree (r^2=0.97**).

Table 2. Crop coefficients in lysimeter, irrigation, and non-irrigation treatments.

Treatment	Vegetative stage	R2	R5	R6
Irrigation	0.57	1.38	1.22	1.08
Non-irrigation	0.34	1.28	1.08	0.81
Lysimeter	0.78	2.51	1.93	2.04

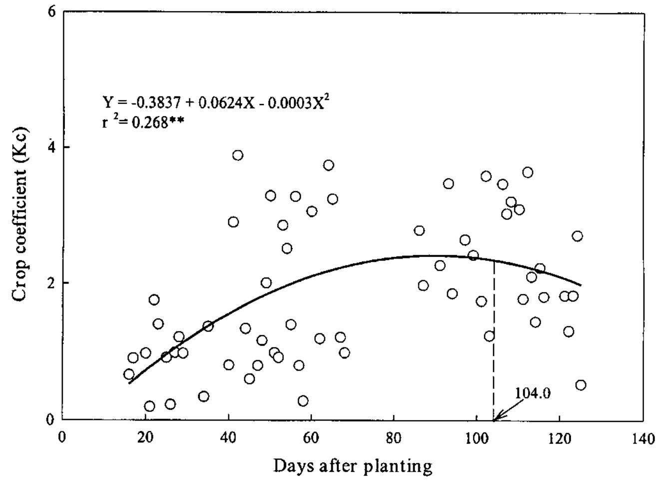

Fig. 4. Changes of crop coefficient (Kc) in lysimeter during soybean growing season.

Table 3. Soil water coefficient for irrigation and non-irrigation treatments at different growth stages of soybean.

Treatment	Before R1	R2	R5	R6
Irrigation	1.48	0.55	0.63	0.53
Non-irrigation	0.68	0.51	0.56	0.40

Kc in lysimeter and field experiment were increased remarkably after R2 stage, but the increasing rate in field trial was not so high as in lysimeter (Table 2). It was thought that irrigation at reproductive stage, especially at R5 and R6 stages was very important, and would considerably increase yield potential of soybean.

Soil water coefficient was used as index of water use by plant from soil, and it was higher in irrigation plot than in non-irrigation plot during vegetative growth period. At reproductive stage, it also tended to be slightly higher. This result indicated that soil water absorption by plant was easier in irrigation plot for early growth stage (Table 3).

Yield, water use efficiency (WUE), and evapotranspiration (ET)

Yield in lysimeter and irrigation plot were 4.0 and 3.3 ton/

Table 4. Comparisons of yield, water use efficiency (WUE), and daily evapotranspiration rate (ET) between lysimeter and field experiment.

Treatment	Yield	WUE‡	ET
	ton ha^{-1}	ton ha^{-1} mm^{-1}	mm day^{-1}
Non-irrigation	2.8c†	0.63b	3.3b
Irrigation	3.3b	0.51c	4.7ab
Lysimeter	4.0a	0.83a	6.0a

†Means in a column followed by the same letter are not significantly different at the 0.05 level of probability.
‡WUE=Yield per ha/amount of ET during soybean growing season.

ha, and were increased 41% and 16% compared to that in non-irrigation, respectively. Daily evapotranspiration rate was 6.0 mm day^{-1} for lysimeter and differences between irrigation and non-irrigation was not significant. Water use efficiency (WUE) in lysimeter was the highest among three treatments and WUE in non-irrigation plot was higher than that of irrigation plot. It was considered that increasing rate of yield in lysimeter was higher than that of water use by plant. But in field experiment, increasing rate of yield was lowered than that of water use by plant because many environmental factors influenced on yield as a negative effect.

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