Korean J. Crop Sci. 44(2) : 143~148(1999)

Effects of Soil Moisture Stress at Different Growth Stage on Growth, Yield and Quality in Rice

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ABSTRACT

Soil moisture condition is an important limiting factor in growth and yield in rice culture. The purpose of this study was to compare the influence on the growth, yield and quality of rice subjected to soil moisture stress (SMS) at different growth stages. A Japonica rice cultivar, Dongjinbyeo, was cultured under flooded conditions in a plastic container filled with silty loam soil. The container was subjected to SMS until the initial wilting point (IWP) coincided with about 10% in soil moisture content and about -200 kPa in soil matric potential, and was then irrigated again, at 6 and 5 of main growth stage in 1996 and 1997, respectively. At maturity, the plant height, tiller number, leaf area and top dry weight were decreased more in SMS treatments at the early stage than the late stage. The averaged yield index of SMS to control in both years was lowest at meiosis (62.5%), which primarily resulted from lower percent ripened grain and 1,000 grain weight, and second' reduced the spikelet number per panicle and panicle number per hill, and followed at tillering stage (68.5%) which resulted from the lower production in tiller number and top dry matter during and after SMS treatment. The percent-age of head rice in SMS plants varied with the treatment stage as order of lower at meiosis (44.0%), heading (53.9%), panicle initiation (70.1%), tillering (72.1%), ripening (75.8%) and 5 days after transplanting (DAT) (79.0%). Protein content in brown rice was slightly larger in SMS at late growth stage than the control, while the contents of fat and ash differed very little between SMS and control. Contents of Mg and K and Mg/K in brown rice with SMS were lower at some treatment stages such as at ripening or panicle initiation.

Keywords : drought, growth, quality, rice, soil moisture stress, yield.

In Korea, where irrigation culture predominates, drought frequently causes rice crop failure. Rice fields have been severely affected about 32 times by drought from 1908 to 1994 (RDA, 1995a). Although rice is commonly cultured in paddy fields with irrigation system, drought sometime causes severe damage in growth and yield in rice, because most of precipitation in Korea is usually concentrated in July and August. About half of the rice cultivation area in the world does not have sufficient water to maintain flooded conditions and rice yield is reduced to some extent by drought, a period of no rainfall or no irrigation (Hanson et al., 1990; Setter et al., 1993).

In rice the severity of drought injury and plant response to SMS differ according to the degree of soil moisture, growth stage, plant organs and genotypes, etc. (Boonjung & Fukai, 1996; Castillo et al., 1992; Ekanayake et al., 1989; Ram et al., 1996). Wada et al. (1945) reported that rice yield damage under water stress at different growth stages was most severe at meiosis, followed by heading, milk-ripe, panicle initiation and tillering stage. Castillo et al. (1992), on the other hand, observed that the vegetative phase water deficit was the most sensitive in the reduction of grain and straw yield. Rice yield damage commonly resulted from the decrease of different yield components with growth stage, i.e., the percentage of fertile grain and ripened grain at meiosis and heading stage, spikelet number per panicle at panicle initiation, panicle number at tillering stage, and percentage of ripened grain and rice quality at ripening stage (Kobata et al., 1979; Taira et al., 1973; Wada et al., 1945).

Despite the above mentioned previous studies, there has been limited information on responses of SMS occurring at different growth stages. In order to quantify the degree of SMS at different growth stages of rice, most previous studies were usually done by content of soil moisture as well as by imposing for a fixed duration, without consideration for plant water status varying with growth stage. The present study was, therefore, conducted to examine the effect on the growth, rice yield and quality at different growth stages under SMS in which water supply was limited until IWP on rice plants.

MATERIALS AND METHODS

Plant culture

This experiment was conducted at National Honam Agricultural Experiment Station in 1996 and 1997 using the paddy rice (*Oryza sativar* L.) cultivar,

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Dongjinbyeo, which is widely grown in the Honam area. On May 31 in both years, seedlings at the 4th leaf stage were transplanted to each container (33×42×22 ㎝, W×L×H), filled with 16 l of silty loam soil, having 6 hills per container and 3 seedlings per hill. All containers were fertilized at the rate of 220 ㎏ N, 140 ㎏ P_2O_5 and 160 ㎏ K_2O ha^{-1}, which were mixed in soil as the basal fertilizer. The containers were placed in an outdoor growing bed at which was made by digging to the 50 ㎝ soil depth and a plastic sheet was spread on the surrounding bed to maintain the flooded condition except for the period of SMS treatments.

SMS treatments and measurement of soil water potential

The treatment of SMS to the rice plants was applied at various stages coinciding with five rice growth stages, i.e., active tillering (T1), panicle initiation (T2), meiosis (T3), heading (T4) and ripening (T5) stages for both 1996 and 1997, and 5 DAT (T0) was added in 1996. The treatment dates at each growth stage in both years are shown in Table 1. The treatment of SMS was allowed to reach the IWP of the plant, which was imposed by not irrigating the container after drainage under a plastic green house.

Water potential in the container soil was measured by a tensiometer up to -2 bar, and lower than -2 bar by a soil moisture meter (Soil Moisture Equip. Model 5910A) connected to a gypsum block which was laid at 10㎝ depth under the soil surface. And the content of soil moisture at 5-10㎝ depth was determined by gravimetric method and expressed as a percentage of oven dry weight.

Growth and yield measurement

Plant height and tiller number were checked before and after SMS at each treatment stage. The plant height, tiller number per hill, leaf area and top dry weight were measured at 20 days after heading. All plants were harvested on October 10 at maturity. The average length of culm and the panicle were determined by the lengths from the ground to the base of the panicle and from the base to the top of panicle excluding awn length respectively, of randomly selected 15 main culms and primary tillers. The plants of 10 hills were sun-dried and yield and yield components were measured by following the standard method of RDA (1995b) in both years.

Grain texture and rice quality

From the brown rice in 1996 experiment, the apparent grain texture was classified into perfect rice and 4 kinds of imperfect rice grains, such as rusty, green kerneled, immature opaque and cracked rice, following the standard proposed by Hoshikawa (1989).

Upon the milling the brown rice, the chemical properties in powdered milled rice were analysed by using the following as the Juliano method (Juliano, 1979) for Amylose, Micro Kjedal method for crude protein, AOAC method (AOAC, 1980) for fat and ash, and atom absorbtion measuring with an analyzer (Perkin Elmer 2380) for K and Mg.

RESULTS AND DISCUSSION

Changes in soil water potential

The relationship between the water content and matric potential in the 5~10㎝ soil layer of silty loam soil after the SMS treatment is shown in Fig. 1 as an example at active tillering stage in 1996 and 1997. In both years, the soil water content before SMS treatment was around 30~33%, the same as the field moisture capacity, and it gradually decreased with days after SMS. The soil water content in both years at 11~13 days after SMS reached 8~13% which is similar with the case of most crops in loam soil (Cho et al., 1977), when the soil matric potential was around -200 kPa. The water content and matric potential in soil are greatly dependent on soil texture when the crop is showing IWP. Generally, most crops show the IWP around -1,000 kPa of soil matric potential (around 4pF), when the soil water content varies around 33% for clay, 10% for loam and 2~3% for sandy soil (Cho et al., 1977). On the other hand,

Table 1. The treatments in soil moisture stress (SMS) at growth stage in 1996 and 1997.

Treatment	Growth stage	Date (DAT)†		Duration days of SMS	
		1996	1997	1996	1997
T0	5 DAT	June 5 (5)	-	22	-
T1	Active tillering	June 26 (26)	June 23 (23)	13	13
T2	Panicle initiation	July 24 (54)	July 21 (51)	6	7
T3	Meiosis	Aug. 9 (70)	Aug. 5 (66)	7	7
T4	Heading	Aug. 20 (81)	Aug. 18 (79)	7	8
T5	Ripening	Sept. 9 (101)	Sept. 8 (100)	8	8

† Days after transplanting.

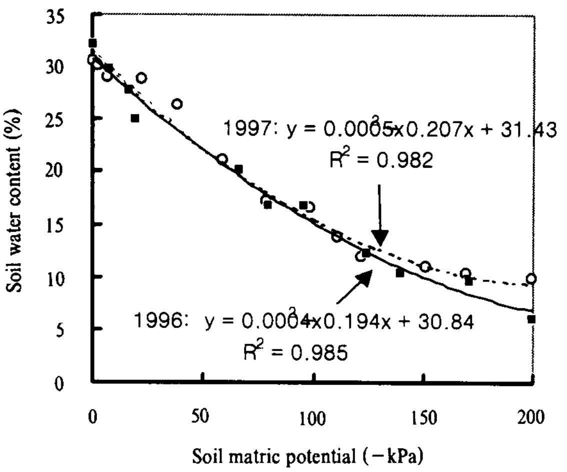

Fig. 1. Relationship between soil moisture content and soil matric potential by soil moisture stress (SMS) treatment at tillering stage in 1996 and 1997.

the symptoms of SMS on rice plants in this study was not observed until the soil matric potential dropped below -50 kPa and leaf rolling was generally appeared when the soil water potential was around -100 kPa, and then most leaves were rolled around -200 kPa (data not shown). The duration period for SMS treatment, therefore, was selected at -200 kPa in soil matric potential as a standard for IWP at all growth stages of rice plant in this study. Because we used shallow containers for this study, the -200 kPa in soil matric potential for the standard of IWP might be relatively higher than the soil matric potential in field conditions or other crops. And the duration for dropping the soil matric potential as high as -200 kPa by the SMS varied with the rice growth stage of treatment, which was longest at 5 DAT with 21 days in 1996 followed by at tillering stage with 13 days and shortest at panicle initiation and meiosis stage for 6 or 7 days (Table 1).

Shoot growth

The plant height on the last date of SMS treatment was slightly decreased in treated plants before heading stage. The reduced tiller number by SMS was greater at 5 DAT and tillering stage, and little differences were found from T1 to T5 stage (Table 2). At 20 days after heading, the leaf area and top dry weight decreased more in treatments at the early stage than the late stage. And the culm length at harvesting stage also decreased more at T0, T1, T2 and T3 stages than that at T4 or T5 stages, particularly at meiosis stage in both years and on 5 DAT in 1996 (Table 3).

Yield and yield components

The delayed heading dates were observed as one to three days in SMS treated plants before the heading stage (Table 4). According to SMS treatment at each stage, the milled rice yield per hill was lowest at 5 DAT in 1996 and at meiosis stage in 1997, and in each of the following two years at the meiosis stage and tillering stage, respectively. Therefore, the averaged yield index in SMS to control in both years was lower, in order, at meiosis (62.5%), at tillering (68.8%), at panicle initiation and heading (78.0%), at ripening stage (92.0%), except for 57.0% at 5 DAT in 1996.

In SMS plants, the reduction rate in panicle number per hill was highest at 5 DAT in 1996 and at tillering the stage in 1997, and lowest at 20 days after the heading stage in both years. While the reducing rate in the spikelet number per panicle, percent ripened grain and 1,000 grain weight in SMS showed the highest at the meiosis stage, and decreasing tendency at ripening or tillering stage (Table 5).

The above mentioned results indicate that the lower rice yield in SMS at the meiosis treatment might result primarily from lower percent ripened grain and

Table 2. Differences of plant height and tiller number per hill at the last date of soil moisture stress (SMS) treatments at each growth stage in 1996 and 1997.

Treatment†	Plant height				No. of tiller(panicle)/hill			
	1996		1997		1996		1997	
	SMS	Control	SMS	Control	SMS	Control	SMS	Control
	cm				no.			
T0	42	47	-	-	9.1	20.4	-	-
T1	50	54	51	54	20.5	28.0	22.9	26.2
T2	83	86	69	83	19.4	20.1	17.1	19.3
T3	90	92	90	96	14.8	17.9	16.8	16.9
T4	95	96	100	103	15.1	16.5	14.0	14.4
T5	96	96	104	105	(15.7)‡	(16.0)	(14.4)	(14.4)

† T0; 5 DAT, T1; Active tillering, T2; Panicle initiation, T3; Meosis, T4; Heading, T5; Ripening stage.
‡ Panicle number.

Table 3. Shoot characteristics on 20 days after heading as affected by soil moisture stress treatment at each growth stage.

Year \ Treatment	Leaf area (cm²/hill)	Top dry weight (g/hill)	Culm length (cm)	Panicle length (cm)
1996				
T0	1,520 d†	29.1 c	62 cd	15.1 ab
T1	2,256 bc	37.8 ab	71 a	15.3 ab
T2	2,129 bc	36.8 bc	64 bcd	15.3 ab
T3	1,970 cd	34.5 bc	61 d	14.7 b
T4	2,390 abc	39.2 ab	68 abc	15.3 ab
T5	2,632 ab	41.2 ab	70 ab	15.6 a
Control	2,818 a	45.2 a	73 a	15.4 ab
1997				
T1	1,912 d	32.1 c	72 b	16.0 b
T2	2,432 bc	40.8 b	72 b	16.8 ab
T3	2,456 bc	41.2 b	69 b	15.8 b
T4	2,608 ab	43.8 ab	78 a	16.9 ab
T5	2,718 a	45.8 ab	80 a	17.5 a
Control	2,840 a	47.7 a	80 a	17.6 a

† Means followed by the same letters within a column of each year are not significantly different at 5% probability level by DMRT.

1,000 grain weight, and secondly form decreasing the spikelet number per panicle and panicle number per hill. While lower rice yield at 5 DAT and tillering, result from the lower production in tiller number and top dry matter during and after SMS treatment. These different factors caused the yield reduction at different stages is also similar to most of the previous studies (Boonjung & Fukai, 1996; Rhaman & Yoshida, 1985; Kobata et al., 1979; Wada et al., 1945).

Quality

From the classification by appearance of brown rice, the percentage of perfect rice kernels decreased in SMS plants, which varied with the treatment stage as lowest at meiosis (44.0%), heading (53.9%), panicle initiation (70.1%), tillering (72.1%), ripening (75.8%), and 5 DAT (79.0%) compared with control (87.7%). Among the imperfect rice kernels, the rusty rice kernels substantially increased by SMS at heading

Table 5. Difference on reducing rate of yield components by soil moisture stress to control at each growth stage in rice.

Year \ Treatment	No. of panicle / hill	No. of spikelet /panicle	Percent ripened grain	1,000 grain weight
1996	--------	--------%	--------	--------
T0	23.7	6.2	9.6	0.9
T1	6.9	3.1	11.8	3.5
T2	8.7	6.2	8.2	4.3
T3	13.1	7.8	18.8	15.2
T4	8.7	4.7	16.5	4.3
T5	1.9	1.6	4.7	3.9
1997				
T1	12.5	14.9	8.4	5.3
T2	5.6	16.3	9.5	7.8
T3	4.2	16.3	23.2	11.9
T4	2.8	9.0	8.4	4.9
T5	1.4	0	9.5	3.7

Table 4. Yield and yield components as affected by soil moisture stress treatment at each growth stage.

Year \ Treatment	Heading date	No. of panicle /hill	No. of spikelet /panicle	Percent ripened grain	1000 grain weight (g)	Rough rice yield (g/hill)	Yield index
1996							
T0	Aug. 21	12.2 c†	60 a	77 bc	22.9 a	14.9 e	57
T1	Aug. 22	14.9 ab	62 a	75 cd	22.3 a	18.6 cd	70
T2	Aug. 22	14.6 ab	60 a	78 bc	22.1 a	19.9 bc	77
T3	Aug. 21	13.9 b	59 a	69 e	19.6 b	15.6 de	60
T4	Aug. 20	14.6 ab	61 a	71 de	22.1 a	19.2 bc	75
T5	Aug. 20	15.7 a	63 a	81 ab	22.2 a	22.1 b	87
Control	Aug. 20	16.0 ab	64 a	85 b	23.1 a	25.5 a	100
1997							
T1	Aug. 20	12.6 a	57 b	87 b	23.1 a	16.4 c	67
T2	Aug. 21	13.6 a	56 b	86 b	22.5 b	19.5 bc	79
T3	Aug. 20	13.8 a	56 b	73 c	21.5 b	15.9 c	65
T4	Aug. 18	14.0 a	61 ab	87 b	23.2 a	20.0 abc	81
T5	Aug. 18	14.2 a	67 a	86 b	23.5 a	23.9 ab	97
Control	Aug. 18	14.4 a	67 a	95 a	24.4 a	24.6 a	100

† Means followed by the same letters within a column of each year are not significantly different at 5% probability level by DMRT.

Table 6. Apparent characteristics of brown rice as affected by soil moisture stress treatment at each growth stage in 1996.

Treatment	Perfect rice kernel	Imperfect rice kernel			
		Rusty	Green	Immature opaque	Cracked
	----------	----------	%----------	----------	----------
T0	79.0	14.7	0.9	4.5	0.9
T1	72.1	15.1	0.1	10.9	1.8
T2	70.1	16.8	0.5	10.4	2.2
T3	44.0	30.7	5.5	18.7	1.2
T4	53.9	17.7	0.5	13.3	14.6
T5	75.8	9.5	0.7	9.9	4.1
Control	87.7	8.6	0.2	1.7	1.8

Table 7. Difference in chemical composition in brown rice as affected by soil moisture stress at growth stage in 1996.

Treatment	Amylose	Protein	Fat	Ash	Mg	K	Mg/K
	--------	------%------	--------	--------	------ppm	------	---mEq---
T0	20.4	7.43	1.71	1.40	836	1765	1.52
T1	19.5	7.41	1.69	1.38	789	1781	1.43
T2	19.8	7.48	1.69	1.37	773	1768	1.41
T3	20.9	7.47	1.84	1.42	824	1803	1.47
T4	19.4	7.57	1.77	1.40	810	1797	1.45
T5	20.2	7.48	1.69	1.36	761	1749	1.40
Control	20.0	7.37	1.81	1.46	829	1819	1.47

stage (30.3%). The percentage of green rice kernels was highest at meiosis stage (5.5%), but lower than 1% at other treatment stages and the control. The percentage of immature opaque rice kernel was significantly increased in SMS compared to the control, particularly at meiosis and heading stage showing 18.7% and 13.3%, respectively. The percentage of cracked rice was highest in SMS at heading stage (14.6%) and slightly higher at ripening stage than control rice (1.8%). These results indicate that the imperfect rice kernels with SMS were relatively increased at reproductive stage, such as meiosis, heading and panicle initiation stage.

Amylose content in brown rice ranged from 19.4 to 20.9% and no difference among SMS treatments and control was found. Protein content was a little higher in SMS rice than control, while the fat and ash content had very little difference between SMS and control. The content of Mg and K and Mg/K rate in brown rice with SMS were decreased at some treatment stages such as at ripening or panicle initiation stage. Taira et al. (1973, 1974) reported that brown rice subjected continuously to low soil moisture (pF 2.2 or 2.7) after the panicle initiation stage had significantly increased content of protein, and relatively larger decreased contents of ash and K, but slightly increased contents of fat and Mg than those of control with soil moisture pF 0. Compared with the above mentioned results from Taira et al. (1973, 1974), in the present study the change by SMS in protein and mineral compositions were relatively low, which were possibly derived from the difference in the experiment conditions or genotype between the two experiments.

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