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Effects Water Stress on Physiological Traits at Various Growth Stages of Rice

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ABSTRACT

The object of this study was to determine the difference of the time course changes of transpiration, diffusion resistance and photosynthetic rate of rice at several different growth stages subjected to soil moisture stress (SMS) and recovery by irrigation. A japonica rice cultivar 'Dongjinbyeo', was grown under flooded condition in a plastic container filled with silty loam soil. At 5 main growth stages, the container was treated by SMS until initial wilting point (IWP) and then reirrigated. The duration of SMS until IWP were the longest, 13 days for tillering stage, and the shortest, 7 days for panicle initiation and meiosis stage. The transpiration rate rapidly decreased during SMS and the transpiration rate at IWP of the stressed plant showed 10~20% compared with control, and the transpiration rate of stressed plant at most growth stages also recovered rapidly after irrigation and then reached 100% of control within a week. The shoot photosynthetic rate in all growth stages rapidly decreased by SMS, and the rates at IWP of stressed plants were decreased nearly to 0%, beside the treatment at tillering stage. The recovery degree of photosynthetic rate by irrigation ranged from 20 to 90%, showed higher at early growth stages of SMS treatment than that of later stages. At all growth stages the leaf diffusion resistance of stressed plants was over 3 times that of the control resulting from a rapid increase at 3 to 5 days after draining for SMS, and showed quick recovery by irrigation within 3 days after drainage. The above physiological parameters changed in close relation with the decrease of the soil matric potential after SMS. These results indicate that at all main growth stages of rice plants the transpiration and photosynthesis reduction by stomatal closure reponded sensitively to the first stage of SMS closely related with decrease of soil water potential, while those recovery pattern and recovered degree by irrigation are little different by growth stage of rice.

Keywords : rice, soil moisture stress, diffusion resistance, drought, photosynthesis, transpiration.

Rice is a semi-aquatic plant and commonly grown under flooded conditions. In the world, however, about half of the rice cultivation has been done with insufficient water supply 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 as to the degree of soil moisture, growth stage, plant organs and genotypes, etc. (Castillo et al., 1992; Ekanayake et al., 1989; O'Toole and Moya, 1978; RDA, 1995). The SMS and drought affect the rice plant directly, reducing growth rate and tillering, and when it is severe, plant withering the occurs plants. At different growth stages, rice yield damage under water stress was more susceptible at the reproductive growth phase than the vegetative growth phase, especially between the meiosis and heading stages (Ekanayake et al., 1990; Park, et al., 1999; Ram et al., 1996; Wada et al., 1945). The SMS also affects the crop indirectly but immediately, and it causes the plants to decrease the rates of photosynthesis and transpiration, which results in reduced water and nutrient uptake (O'Toole & Baldia, 1982; Lee et al., 1995) as well as assimilation (Bunce, 1982; Marshall et al., 1980). The plant responses and adaptation mechanism to water deficit condition or SMS in plant have been studied for a long time. Particularly, the signal interaction between roots and shoots under SMS have been partially clarified with special reference not only to the physical plant-water relationship (Kramer & Boyer, 1995), but also to the synthesis and translocation of plant hormones (Wilkinson & Davies, 1997) and metabolic products in plant organs (Chen & Kao, 1993).

On the other hand, previous studies related to SMS in rice plants have been mainly concentrated on genotypic variation or mechanism on drought resistance and yield productions (Babu et al., 1999; Choi & Park, 1980; O'Toole & Moya, 1978; Haque et al., 1989), but information on physiological responses is limited, particularly with reference to plant growth stages and the recovery responses according to irrigation

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of stressed plants. The understanding the physiological responses of SMS or irrigated rice plants after SMS can make a strong contribution to rice agronomists and physiologists for establishing a correct rice management system under water deficit conditions and for clarifying the mechanism of drought resistance.

Previous studies examined SMS effects on growth, yield and quality of rice at each growth stage (Park et al., 1999). This study was conducted to clarify differences of time course changes of the physiological responses, such as water content, transpiration, diffusion resistance and photosynthetic ability of rice plants by the treatment of SMS until IWP and then irrigating.

MATERIALS AND METHODS

Plant culture and SMS treatment

This experiment was conducted at National Honam Agricultural Experiment Station with a paddy rice (*Oryza sativar* L.) cultivar, 'Dongjinbyeo', which is widely grown in the Honam area. On 31 May 1997, the seedlings at the 4th leaf stage were transplanted to each container (33×42×22 cm, W×L×H), filled with 16 *l* of silty loam soil, having 6 hills and 3 seedlings per hill. All containers were fertilized at the rate of 220 kg N, 140 kg P_2O_5, and 160 kg K_2O ha^{-1}, which were mixed in soil as basal fertilizer. The containers were placed in an outdoor growing bed which was made by digging to the 50 cm soil depth and a plastic sheet was spread on the surrounding bed to maintain the flooded condition except for the period of SMS treatments.

The treatment of SMS to the rice plants was done at 5 growth stages ; active tillering (T1), panicle formation (T2), meiosis (T3), heading (T4), and dough ripening stage (T5) (Table 1). The treatments of SMS was allowed to reach the IWP of the plant by not irrigating the container after drainage under a plastic green house. After reaching the IWP level of plant, the pots were irrigated.

Measurements

Water potential in soil was measured to -200 KPa by a soil moisture meter (Soil Moisture Equip., Model 5910A, California, IRROmeter Com.) connected to a gypsum block which was laid at the 10 cm depth under the soil surface.

At the IWP state of the plant, 10 segments of 5cm length of leaf blades were collected from the middle portion of the 2nd fully developed leaf blades of the main culm from SMS treated and unstressed (control) plants for the measurement of the relative water content (RWC) of the leaf. Immediately, the fresh weight of leaf segments was measured and then the fully turgid weight of the segments were weighed after immersion in water in a petri dish for 24 hours. The dry weight of the leaf segments was measured after oven drying for 24 hours at 80℃. The RWC of leaves was calculated following the Weatherley's equation (Barrs, 1968).

$$RWC(\%) = (\text{fresh weight-dry weight})/(\text{fully turgid weight-dry weight}) \times 100$$

Transpiration rate and diffusive resistances were measured at 2 day intervals with one day after draining to 11 days after reirrigation using a Steady State Porometer (LI-1600, Li-Cor. INC., USA) on the middle part of the leaf blades which were the 2nd fully developed leaf from the top of the main culm or primary tillers. The photosynthetic rate of the whole hill in the container was determined with an infrared CO_2 analyzer (LCA4, RDC Co., UK) and an acrylic assimilation chamber (50×50×150 cm; L×W×H).

The measurement of the transpiration rate, leaf diffusion resistance and photosynthetic rate and the leaf sampling for the RWC measurement from SMS stressed and unstressed plants were conducted between 11 : 00 ~ 14 : 00 local time, mostly with 2 days interval. Because the leaf transpiration, diffusion resistance and photosynthetic rate are sensitively affected by weather conditions (Ishihara et al., 1981; O'Toole & Baldia, 1982), the time course changes of those physiological parameters of stressed plants after draining and irrigating were shown as relative values to control.

Table 1. The treatments in soil moisture stress (SMS) at each growth stage of rice and duration days after draining stress treatment.

SMS treatment	Growth stage	Drained date (DAT)†	Duration days of SMS
T1	Active tillering stage	June 23 (23)	13
T2	Panicle formation	July 21 (51)	7
T3	Meiosis	Aug. 5 (66)	7
T4	Heading	Aug. 18 (79)	8
T5	Dough ripening	Sept. 8 (100)	8

† DAT: Days after transplanting.

RESULTS AND DISCUSSION

Soil water potential and RWC of leaf

As described in our previous paper (Park et al., 1999), because most leaves were rolled around -200 kPa in container cultured plants, in this study, we also selected -200 kPa for soil matric potential as a standard duration of SMS until IWP at each growth stage of the rice plant. As noted by Ritchie (1973), because we used the shallow containers having a high root density, the IWP in the present study could be measured at a relatively higher soil matric potential than in field conditions.

The duration for dropping the soil matric potential as low as -200 kPa by the SMS varied with rice growth stages, the longest at tillering stage for 13 days and the shortest at panicle initiation and meiosis stage for 7 days (Fig. 1). These differences might be derived mainly from differences in leaf area per hill (Park et al., 1999) and transpiration rate per unit leaf area (Fig. 3-B), besides the difference of evaporation from the surface of container soil among treatment stages. At IWP state of rice plants, the RWC of leaves was 60~75%, depending on treatment stages, and showed relatively lower values at the meiosis stage than other stages (Fig. 2).

Transpiration Rate

Average transpiration rate in control plants throughout the SMS treatments was highest at heading stage and was followed by the panicle initiation, tillering, meiosis and dough ripening stage (Fig. 3-A). The percentage of transpiration rate of stressed plants versus the control plants was slightly declined at the tillering stage and dropped below 20% at 11 days after SMS, while in the other growth stages it rapidly declined and then reached approximately 5~15% at 7 days after draining (Fig. 3-B). Those values are lower than the results by O'Toole & Baldia (1982) who reported that while the water stress continued below -150 kPa of soil matric potential the daily transpiration rate of rice stabilized at about 37% of control.

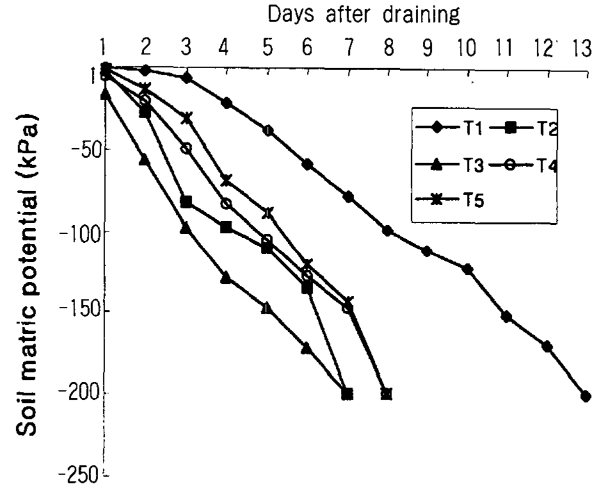

Fig. 1. Time course changes in soil matric potential according to soil moisture stress at each growth stage of rice. T1: tillering, T2: panicle formation, T3: meiosis, T4: heading, and T5: dough ripening stage.

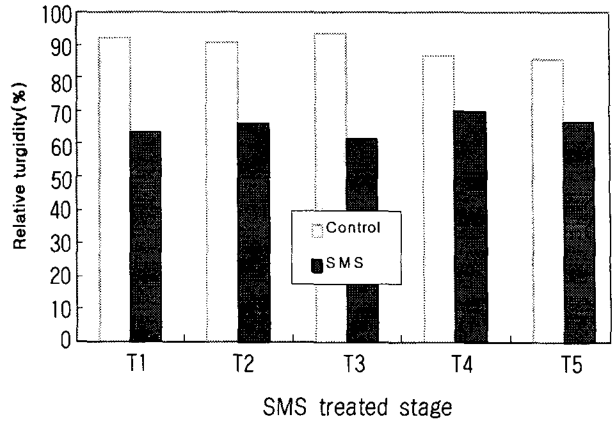

Fig. 2. The relative water content of SMS treated and control plant at each growth stages of rice.

After irrigating, the recovery of transpiration rate of the stressed plant versus the control plant was most rapidly increased at the panicle initiation stage, followed by the meiosis stage. Those stages showed nearly 100% recovery rate at 7 days after irrigation. The recovery on transpiration of irrigation slowly increased at the dough ripening stage and reached about 65% at the final observation.

Leaf·diffusion resistance

The averaged diffusion resistance of control plant leaves was highest at the dough ripening stage and lowest at the tillering stage (Fig. 4-A). The SMS resulted in a rapid increase of leaf diffusion resistance, therefore the increase of leaf diffusion resistance by SMS at all growth stages was 3 times more than the control within 5 days after draining (Fig. 4-B). By irrigating the stressed plants, a remarkable recovery was showed within 1 to 3 days, varying with treatment stages (Fig. 4-C). Especially, the stressed plant at the heading stage recovered 1.5 times versus control plant at only one day after irrigation, although the reason is not known yet.

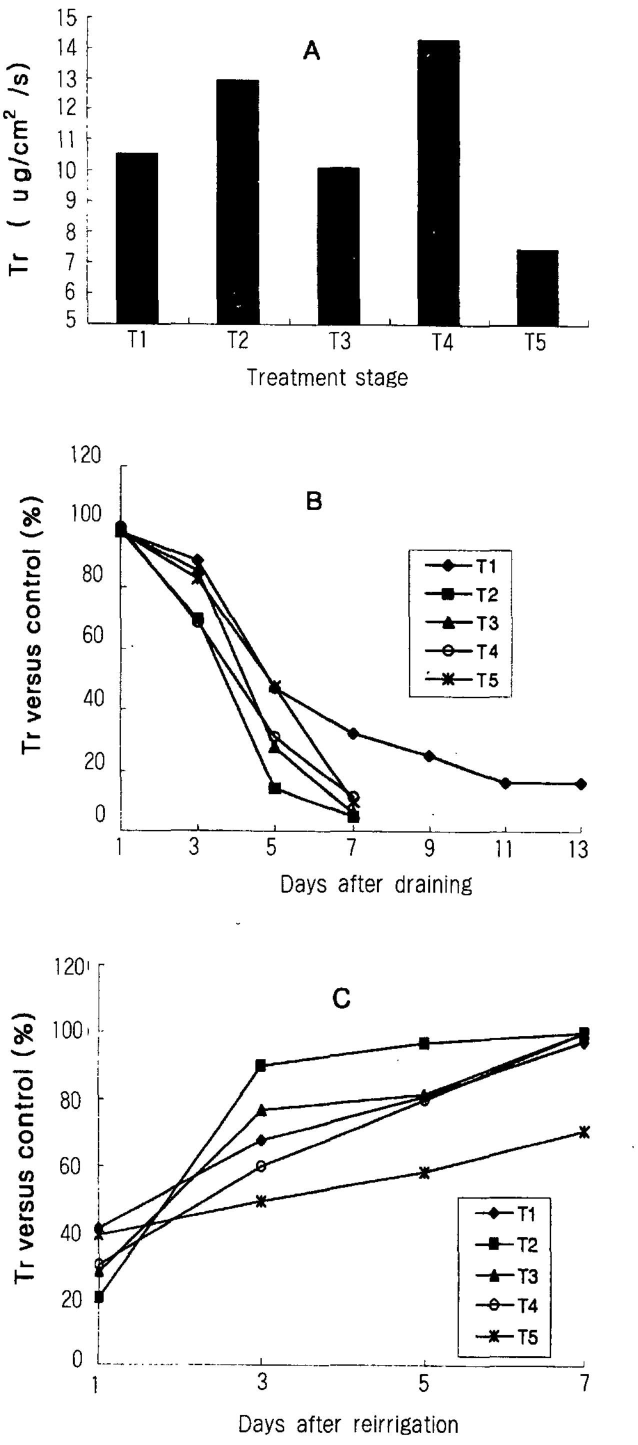

Fig. 3. Averaged transpiration rate (Tr) of unstressed (control) plants during the SMS treated period of each growth stage (A), and the time course changes of Tr on SMS treated plants versus control plants (B), and stressed plants after irrigation at IWP versus control plants (C).

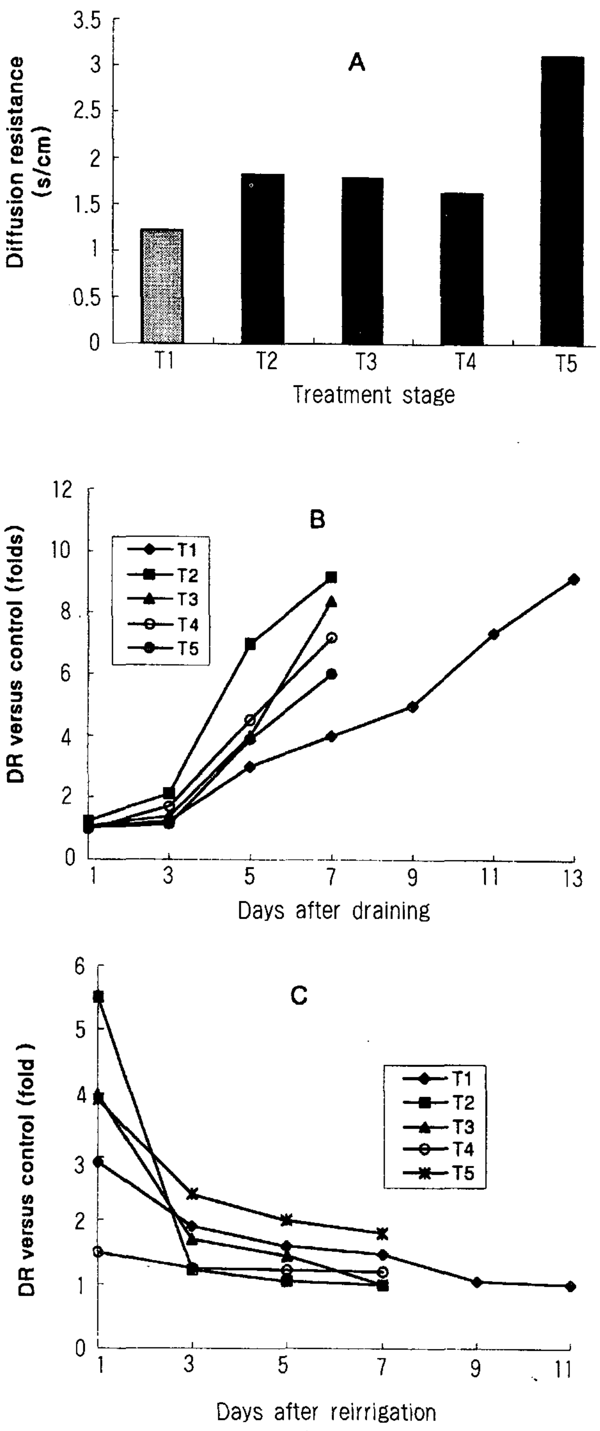

Fig. 4. Averaged diffusion resistance (DR) of control plants during the SMS treated period of each growth stages (A), and the time course changes of DR on SMS plant versus the control plant (B) and its recovery degree on stressed plants after irrigation at IWP versus control plants (C).

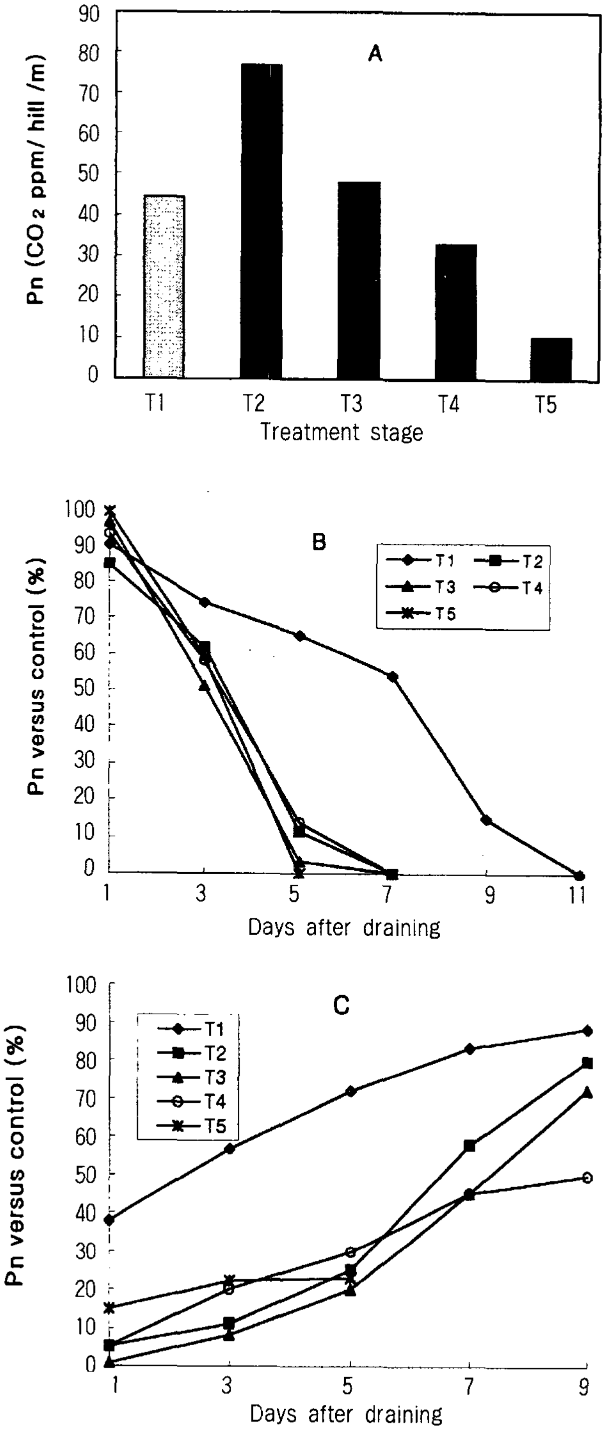

Fig. 5. Averaged photosynthetic rate (Pn) of control plants during SMS treated period of each growth stage (A), and the time course changes of photosynthetic rate on stressed plant versus the control plant (B) and the recovery degree of stressed plant after irrigation at IWP versus control plant (C).

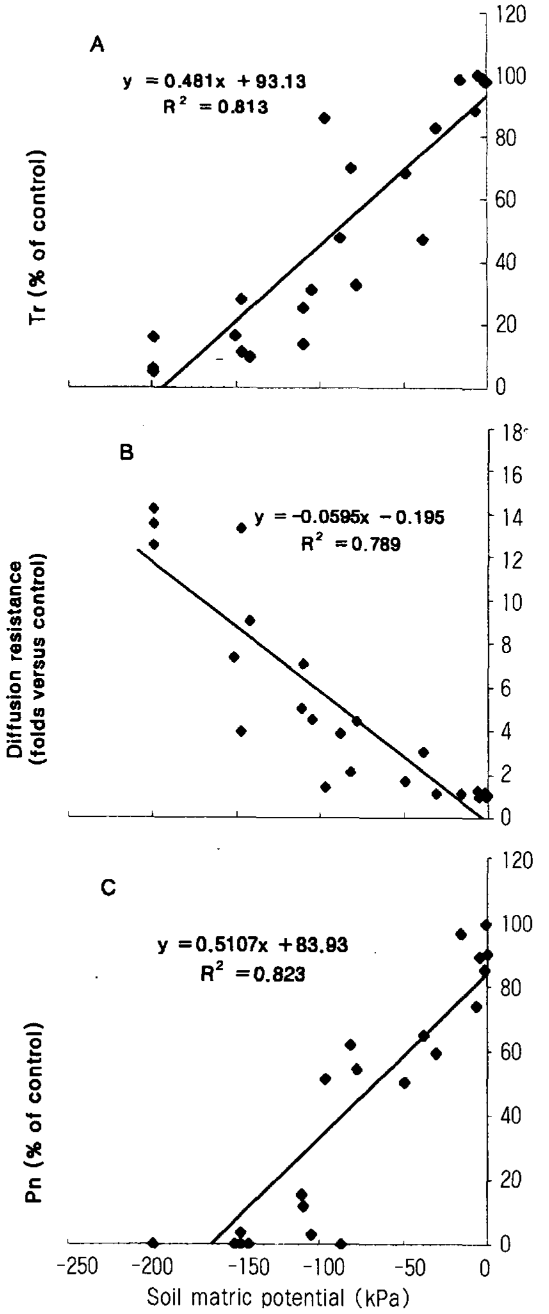

Fig. 6. The relationships between soil matric potential and relative values of physiological parameters of the water stressed plant to the control plant; leaf transpiration rate (A), leaf diffusion resistance (B) and shoot photosynthetic rate (C).

These results indicate that the diffusion resistance is a very sensitive parameter which may cause earlier stomatal closure than leaf rolling at the early stress stage (Hasio et al., 1984; Ishihara et al., 1981), and it strongly influences the decrease of transpiration and photosynthetic rate of stressed leaves.

Photosynthesis

The averaged shoot phtotosynthetic rate was highest at the panicle initiation stage, then gradually decreased with progressing growths stages of rice (Fig. 5-A). The percentage of photosynthetic rate of stressed plants to control plants started to decrease at 1 to 2 days after SMS treatment, and then rapidly dropped to ≈0% within a week, except for the SMS treatment at the tillering stage when it slowly declined and required 11 days to reach ≈0% (Fig. 5-B). This result means that photosynthesis of the SMS rice plant was almost injured at one or two days prior to IWP of plant. The decrease of photosynthetic rate of stressed plant might be increased by diffusion resistance (Fig. 4-B) or stomatal resistance (Sinha et al., 1996; Marshall et al., 1980).

After irrigation, the photosynthetic rate of sressed plants to control plants gradually recovered at most growth stages (Fig. 5-C).

The recovery degree of photosynthesis versus control at 9 days after irrigating was higher at the early stage of SMS, with the range of 20 to 90%, showing highest at the tillering stage and lowest at the dough ripening stage.

Relationships between physiological parameters and soil water potential

Finally, the relationships between the soil matric potential and the relative values of physiological parameters on stressed plants versus control plants were analysed using the data from the period of SMS treatments of all growth stages. As the soil matric potential decreased to -200 kPa, transpiration and photosynthetic rates of stressed plants decreased with significant relationships. The diffusion resistance of stressed plants was increased by an increase of soil matric potential with significant relation. These results indicate that the changes of transpiration, diffusion resistance and photosynthesis of water stressed rice are affected mainly by the decrease of soil matric potential through a decrease of water potential in plants.

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