Reduction of Dry Matter Production Related to Electrical Conductivity of Stagnant Water in Rice Subjected to Increasing Salt Stress

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変化する塩ストレス条件下における湛水の電気伝導度とイネの乾物生産低下の関係

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Knowledge about the relationships between the intensity of salinity of rooting medium and dry matter production may contribute to the improvement of rice yield under saline conditions. A rice cultivar Koshihikari was grown in pots with soils under submerged soil conditions. The stagnant water was salinized with NaCl from 31, 45 and 59 days after sowing, and for each of those, the level of salinity was increased every 6 days to maturity at three different rates of increase. Electrical conductivity (EC) of stagnant water was measured. Final dry weight of above ground parts and panicles decreased as initiation of salinization took place earlier and the rate of increase of EC was higher. Reduction in panicle dry weight was correlated with the occurrence of white heads. The values of EC at which plants died increased with the plant development and the rate of increase of EC, while these depended mainly on the rate of increase of EC but not on the time of salinization. In the plants which survived after heading, the final dry weight decreased in proportion to accumulated EC (sum of EC values for each day until harvest). Therefore, except for strong salinity where plants may die before heading, accumulated EC should be abe to predict dry matter production under salinity as an integrated indicator of level and duration of salinity.

Key words : Accumulated EC, Electrical conductivity, White head

Introduction

The cultivation of rice requires a large amount of water for irrigation and the salt level of the water increases because of the salinization and recycling system of irrigation water[4,11]. Flood conditions under which rice is grown are used for desalinization, so rice is planted for reclamation of saline and alkaline lands[2]. Consequently, it is often grown under saline and alkaline conditions[4]. However, rice is relatively sensitive to salinity and its yield is low under such saline conditions[7,10,12]. To improve irrigation practice in rice under saline conditions, it is important to relate rice growth to the level of salinity.

Electrical conductivity can be related to the level of salinity of soil and water[9]. In rice, plant responses could be correlated to the electrical conductivity of the ponded water, mud, soil, and extracts of the mud and soil[11]. So the electrical conductivity of the rooting medium should be a suitable indicator of the level of salinity in rice as well as other crops[10]. The level of salinity in the fields fluctuates because of rainfall, evaporation, etc[4]. Both the intensity and duration of salt stress may affect rice responses to salinity[5,8]. Effect of salt stress on rice growth and development may change with the stages of plant development when plants are subjected to such stress[6]. Younger plants are more sensitive to salinity than older ones[3,5]. Therefore, it would be better to find an integrated indicator of salt stress including both level and duration of salinity. In this study, we examined the relationships between rice plant growth and the electrical conductivity of stagnant water in which the level of salinity gradually increased.

Materials and methods

The experiment was conducted under a rain shelter covered with a clear transparent sheet in the experimental field at Okayama University in 2002. Pregerminated seeds of paddy-field rice cultivar Koshihikari were sown on the soil in a plastic tray on May 15. Sixteen days after sowing (DAS), the seedlings were transplanted singly in to pots with holes in the bottom. The pots contained 2.5 liters of soil, and compound chemical fertilizer (N : P : K = 16 : 16 : 16) was applied at the rate of 3 g/pot. Two pots were placed in a 12-liter container and kept under submerged soil conditions.

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There were three sets of NaCl (salt) treatments started at 31, 45 and 59 DAS (Fig. 1). In the first set of treatment started at 31 DAS, salt was added to the water in the containers so as to increase salinity of the water at the rate of 10, 20 and 30 mM every six days, and the final salt concentrations were 100, 200 and 300 mM at 94 DAS. These three treatments were referred as E1, E2 and E3, respectively. Although salt treatment started later in the second and third sets, the salt concentration was increased to the same final value at the same day. The rate of increase in salt concentration was higher in the second and third sets than in the

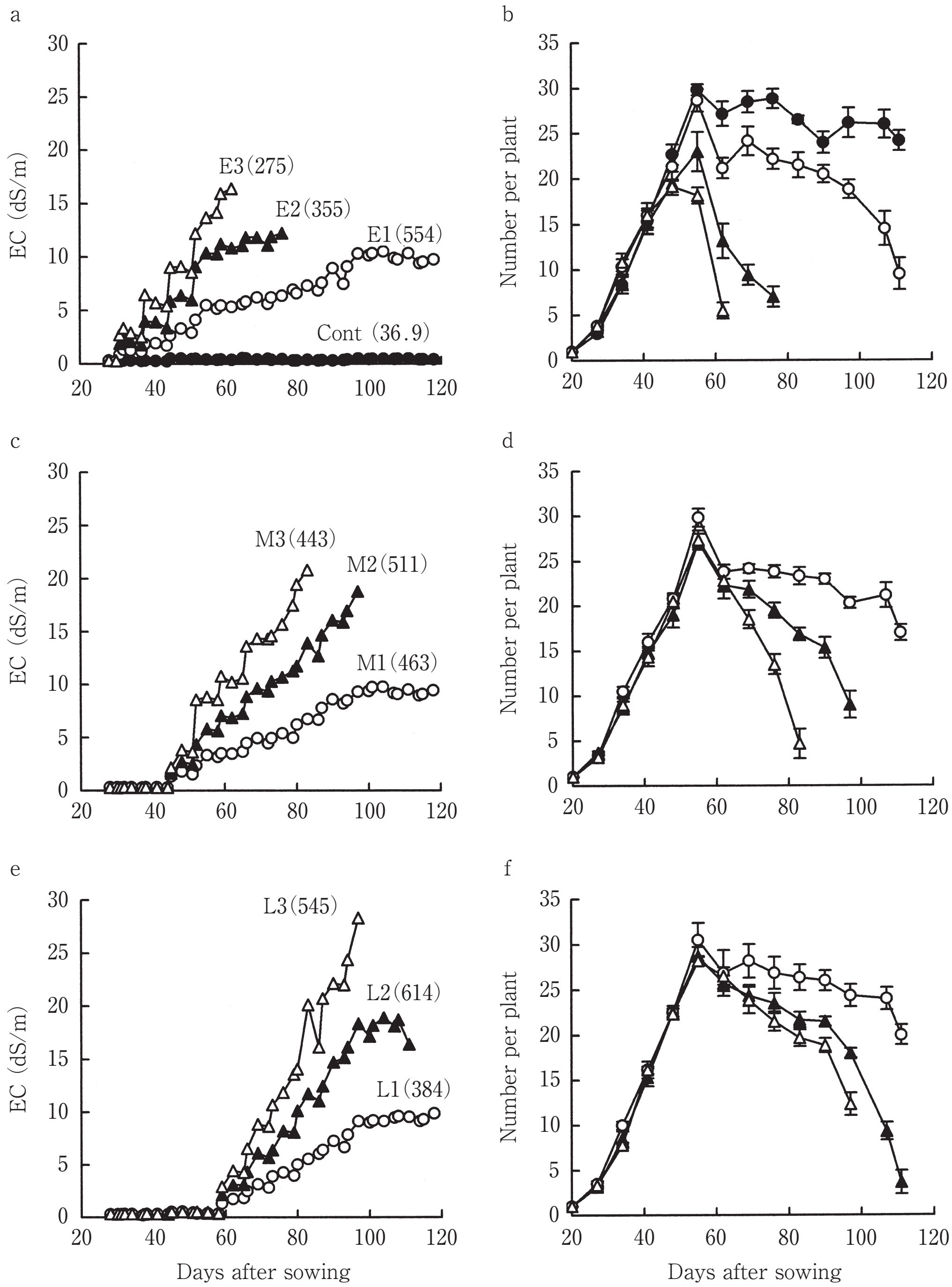

Fig. 1 Changes in electrical conductivity of stagnant water (EC) (a, c and e) and number of tillers per plant (b, d and f) in rice subjected to various salt stresses.
E, M and L, followed by 1, 2, and 3, indicate that level of salt of stagnant water increased gradually from 31, 45 and 59 DAS, respectively. For details of treatments, see text. Numbers in parentheses indicate accumulated EC (dS/m day). Symbols are the same in (a) and (b), in (c) and (d), in (e) and (f), respectively.

first set. The three treatments were referred as M1, M2 and M3 for the second, and L1, L2 and L3 for the third. Salt was not applied to the control plants. Each plot consisted of three containers and was arranged following randomized design with three replicates.

Electrical conductivity (EC) of the water in the containers was measured with a handheld EC meter (Yokogawa, Model SC82) every three days. The EC value was adjusted at 25 °C. The reading of 10.67 dS/m corresponded to 100 mM of NaCl. Accumulated EC (ΣEC) was calculated as the sum of EC from 28 DAS to the day of harvest. The values of EC on the days without measurements were interpolated from the two adjacent measured values.

Plant height, the number of leaves expanded on the main stem (leaf age) and the number of tillers per plant were determined weekly. Heading date was recorded as the day of the first appearance of a spikelet on a plant. The number of panicles and white heads per plant were determined 10 days after heading. Plants were harvested at the maturing stage or when about 95% of leaves had died. Plant materials including dead parts were separated into leaf blades (leaf), stem and leaf sheath (stem) and panicles. The materials were dried in an oven and dry weight was determined.

Results

The changes in EC and plant growth are shown in Fig. 1. Effect of salinity was more prominent in the number of stems per plant than leaf age and plant length, so only the number of stems per plant is presented as plant growth data.

Adding salt to the water, EC increased linearly while the EC value was stable about at 0.4 dS/m in the control plots (Fig. 1). In the E1 plot where the salt treatment started at 31 DAS, the value of EC increased at the rate of about 0.164 dS/m per day, and reached about 10 dS/m corresponding to about 100 mM at 94 DAS as planned. The plants of E1 plot matured and were harvested at 118 DAS on the same day of harvest as the control plants. Since the plants in E2 and E3 died at 76 and 62 DAS when panicles had not appeared, EC did not reach 20 or 30 dS/m as planned for E2 or E3; the final values were 12.3 and 16.4 dS/m in E2 and E3, respectively. The values of ΣEC were 554, 355 and 277 dS/m day in E1, E2 and E3, respectively, but only 36 dS/m day in the controls. Plants subjected to salt treatment from 45 and 59 DAS produced panicles, except for the plants in M3 which produced no panicles. Plants subjected to salinity at a larger rate of salinity increase tended to die earlier. The values of EC and ΣEC at

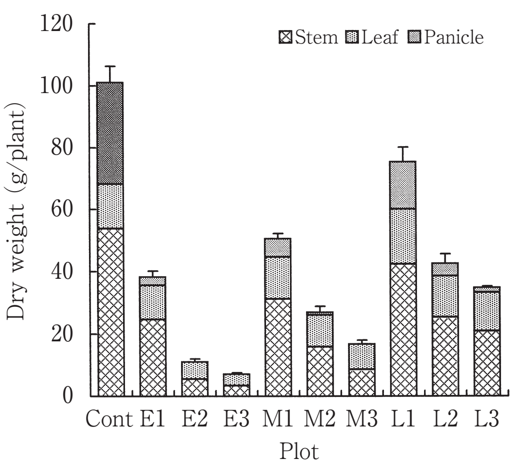

Fig. 2 Effect of various salt stresses on dry weight of panicle, leaf blade and stem including leaf sheath in rice.
Values are mean of three replications. Bars indicate one standard error of mean for the sum of dry weight only. For details of treatments, see text and Fig. 1.

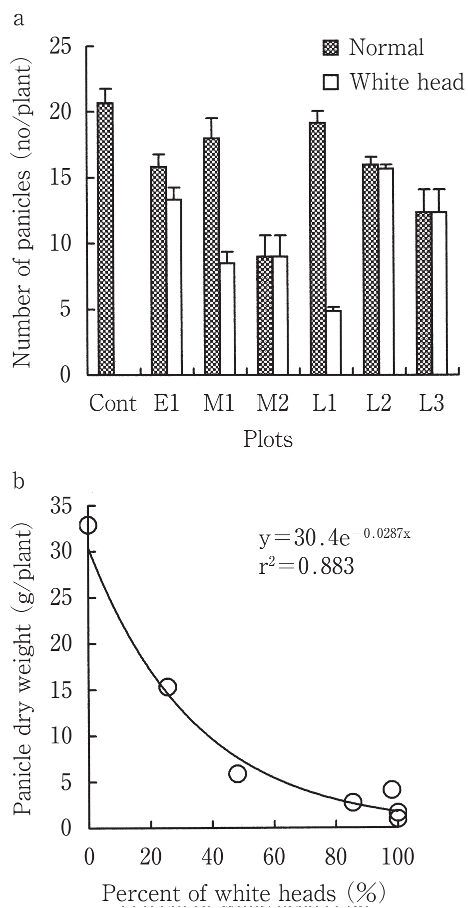

Fig. 3 Number of panicles of normal and white heads (a) and relationship between percent of white heads and dry weight of panicles (b) in rice subjected to various salt stresses.
Data is shown only for plots where heading was observed. Values means for three replications, and bars in (a) one standard error of the mean.

which plants died were larger as the initiation of salt treatment was delayed.

The final dry weight was much reduced under salinity (Fig. 2). The reduction of dry weight became larger as the salt treatments started earlier and as the final salt concentration was higher. The panicle dry weight decreased more than stem and leaf dry weight. The number of panicles per plant decreased under salinity, whereas the percent of white heads increased (Fig. 3). Panicle dry weight age correlated well to the percent age of white heads.

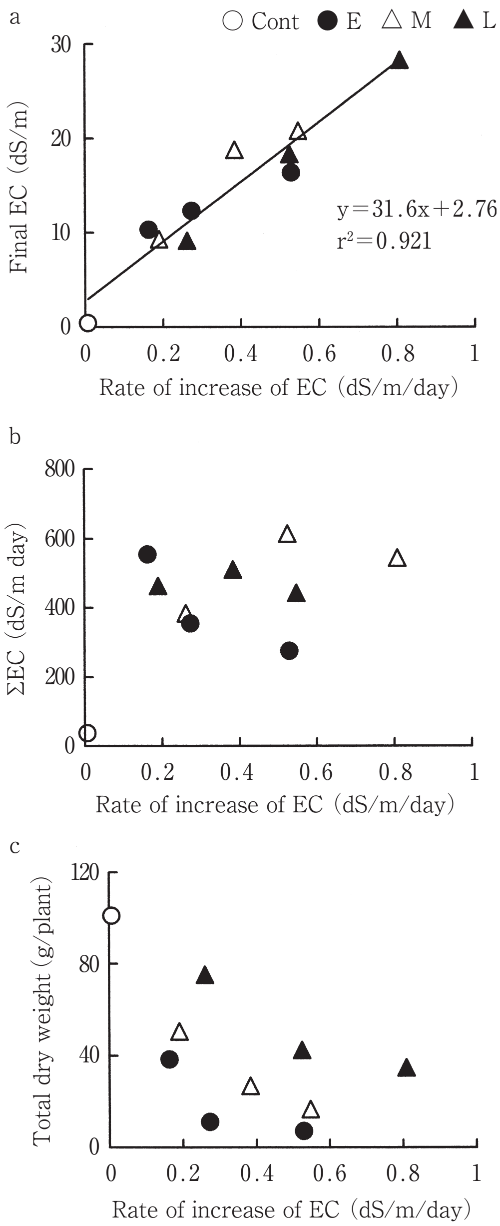

Fig. 4 Relationships of final EC (a), accumulated EC (ΣEC) (b) and total dry weight at harvest (c) to the rate of increase of EC in rice subjected to various salt stresses.
Regression in (a) was drawn using all data.

The level of salt in the water increased faster as the initiation of salt treatment was delayed, so the rate of increase might influence the salt concentration where plants died. The relationship between the rate of increase of EC and the final value of EC is shown in Fig. 4. The final EC increased in proportion to the rate of increase of EC and there were no clear separations due to the time of salt treatment. The coefficient of correlation was strongly significant; 0.960 including control and the three sets of salt treatment ($n=10$). On the other hand, there was no distinct relationship between the rates of increase of EC and ΣEC or plant dry weight.

Relationship between ΣEC and dry weight is shown in Fig. 5. Values for plants that died without heading are indicated by open symbols and those for plants which survived after heading by closed symbols. Both total and panicle dry weight decreased as ΣEC increased in plants which survived after heading, whereas they increased in plants which died before heading. Dry weight was larger in plants which survived after heading when ΣEC was similar.

Discussion

The final dry weight of plant decreased as the salt treatment was started earlier and as the salinity level

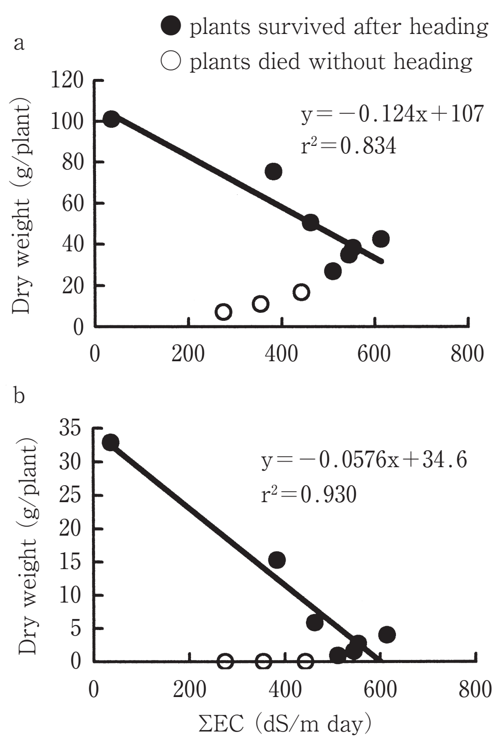

Fig. 5 Relationship between ΣEC and dry weight of total (a) and panicles (b) in rice plants subjected to various salt stresses.
Regression was applied for values of closed symbols.

increased (Fig. 2). Similar results were found by Kaddah and Fakhry[5] who supported the general agreement that "rice is sensitive to salinity at the early stage of growth and that the tolerance increases with growth development". This view is well accepted[3,14]. However, one should be careful to accept this conclusion based only on their study and this because the level and duration of salinity could be related to the time of treatments: for example, plants subjected to treatments from the early stage of plant development experienced salinity stress for longer. As an integrated index of level and duration of salinity, ΣEC was calculated and correlated with the final dry weight (Fig. 5). The relationship between ΣEC and final dry weight was fairly good for plants which survived after heading, so ΣEC could be a suitable indicator of salinity stress. For plants which died before heading, the salinity level at which plants would die may be more important.

The final EC increased as the initiation of salt treatment was delayed (Fig. 1). This result seemed to indicate that plants became tolerant to salinity. However, the final EC increased in proportion to the rate of increase of EC regardless of the time of salt treatment (Fig. 4). Therefore, the increase of salt tolerance with plant development may depend on the rate of increase of EC. This was not consistent with Flowers and Yeo[3] who found increase of an salinity resistance with the age of seedlings. They compared seedlings 7–35 days after germination, whereas plants were subjected to salinity from 31–59 DAS in this study. Changes of salinity resistance with plant development may depend upon cultivars[6,7,14]. In the cultivar Koshihikari, salt tolerance may be stable after 31 DAS. Linear increase of final EC with the rate of increase of EC provides useful information. When sudden salinization such as intrusion of sea water occurs, farmers might avoid crop failure by washing out fields with fresh water as soon as possible.

Besides the relationships between salinity and dry matter production, it was found that dry weight of panicle was correlated with occurrence of white head (Fig. 3). Generally, white head causes high sterility[13], so further research may be directed to reduce occurrence of white heads.

The relationship between ΣEC and dry weight would be useful to plan an irrigation schedule with the use of salinized water for the whole growth period; for example, farmers should use irrigation water of low level of salinity to avoid risk of low yield in late maturing varieties because ΣEC would increase proportionally to growth duration. However, salinity damages may differ with meteorological conditions, etc.[1], and it is well documented that plants respond differently to various patterns of salt stress[6,7,13,14]. It does not seem that the relationship between ΣEC and dry matter production observed in this study is always valid. The relationships should be verified under various conditions and modified for more precise applications of ΣEC. Despite such incompleteness, ΣEC would be a better indicator of salinity than EC itself since ΣEC includes both level and duration of salinity stress.

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変化する塩ストレス条件下における湛水の電気伝導度とイネの乾物生産低下の関係

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塩性環境における稲作改善のために，イネの乾物生産と根域の塩性程度との関係を知ることは重要である．水稲品種コシヒカリを用い，土壌を詰めたポットで湛水栽培し，湛水に塩化ナトリウム（塩）を添加することによって塩ストレスを与えた．塩添加は播種後31，45および59日目から開始され，それぞれ6日ごとに3段階の異なる速度で塩を添加するとともに，湛水の電気伝導度（EC）を測定した．地上部および穂の最終的な乾物重は，塩添加開始が早いほど，EC の増加速度が大であるほど低下した．そして，穂の乾物重は白穂の発生率が高いほど低下した．植物体が枯死したときの EC 値もまた，塩添加の開始時期が早いほど速度が大であるほど大きかったが，この EC 値は主に EC 増加速度に依存しており，塩添加開始時期の影響は小さかった．一方，出穂した植物で乾物重は積算 EC 値（毎日の EC の値を植物体採取日まで足した値）に対して直線的に低下した．以上より，出穂する前に枯死するような強い塩性環境を除けば，積算 EC 値は塩ストレスの強さと期間を総合した指標で，イネの最終的な乾物生産をよく予測すると考えられた．