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Varietal Difference and Temperature Response of Local Soil-Reduction around Germinating Rice Seed*

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Abstract : Local soil-reduction occurs around rice seed when it is sown into flooded soil, and the reduction inhibits seedling emergence. Seedling emergence is more inhibited when the reduced soil area is formed earlier and becomes larger. Varietal difference and temperature response of local soil-reduction were investigated.

Seed was exposed to local soil-reduction around it for a longer period before germination at 17°C than at 20°C. Although the reduction at 17°C proceeded about half as slow as that at 20°C, reduced area size around the time of germination at 17°C was not conspicuously smaller than at 20°C. Thus, the influence of reduction on seedling emergence was supposed to be stronger at lower temperature. This seemed to be closely related to the poor seedling emergence at low temperature. On the other hand, as germination percentage of each variety was much the same between 17°C and 20°C, it seemed to be less susceptible to local soil-reduction compared with seedling emergence percentage. Varietal difference was observed in the course of soil reduction around a seed ; however, neither positive correlation between reduced area size and germination percentage nor negative correlation between reduced area size and seedling emergence percentage were significant. Thus, it was suggested that not only reduced area size but also Eh and tolerance to soil reduction was concerned in the expression of varietal difference of seedling emergence.
Key words : Direct sowing, Germination, Rice, Seedling emergence, Soil reduction, Varietal difference.

発芽中のイネ種子の周りで起こる局所的土壌還元の品種および温度間差異 : 萩原素之・井村光夫**（信州大学農学部・**石川県農業短期大学）

要　旨 : 湛水土壌中にイネ種子を播種すると種子の周りで局所的土壌還元が起こるが，この還元は出芽の阻害要因である．1つの品種についてみた場合，この還元域が早期に，大きくなるほど出芽が阻害される．出芽の品種間差と局所的土壌還元との関係を検討するため，イネ種子の周りで起こる土壌還元の品種および温度による違いを調査した．

17°C では 20°C よりも発芽前に種子が種子の周りで起こる土壌還元にさらされる期間が長かった．還元の進行は 17°C では 20°C の場合の約 1/2 の緩やかさであったが，発芽の頃の還元域は 17°C でも 20°C の場合より著しく小さくはなかった．したがって，局所的土壌還元の出芽に対する影響は温度が低い場合に大きくなると推察した．このことは，一般に低温下で出芽不良となることと関連が深いと思われた．一方，各品種の発芽率は 17°C と 20°C でほぼ等しく，発芽率は出芽率よりも局所的土壌還元の影響を受けにくかった．種子の周りの土壌還元の進行には品種間差がみられたが，還元域の大きさと発芽率との間の正相関および，還元域の大きさと出芽率との間の負相関はいずれも有意ではなかった．したがって，出芽率の品種間差の発現には還元域の大きさだけでなく，Eh や還元土壌条件に対する耐性も関与していると考えられた．
キーワード : イネ，出芽，直播，土壌還元，発芽，品種間差異.

In DIPPS[3], a new direct sowing method of paddy rice, oxygen generator calcium peroxide (CaO_2) is used as a promoter of seedling emergence and establishment[1,7,8], and CaO_2-coated seeds are sown not onto but into flooded soil. By sowing seeds into soil, lodging resistance is improved because the seedlings are firmly anchored in the soil. Tanaka *et al.*[10] and Amano (unpublished) observed varietal difference in seedling establishment percentage of rice seeds sown into flooded soil. In the case of a certain variety, seedling emergence percentage declined when local soil-reduction around a seed began early and became heavy[4]. In the present study, difference due to variety and that in response to temperature of local soil-reduction around rice seed sown into flooded soil were investigated aiming to examine the relation between varietal difference of seedling emergence and local soil-reduction.

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Materials and Methods

When methylene blue is mixed with flooded soil, time course changes in oxidation-reduction state of soil are visually indicated by its color change from blue (oxidized) to colorless (reduced)[3,4]. We name this method methylene blue soil method (MBS method). MBS method is characterized by the detection at plane of oxidation-reduction state of soil in contrast to that at point by an oxidation-reduction electrode. The time course changes in local soil-reduction around germinating seed were observed by using MBS method.

From the varieties Tanaka *et al.*[10] and Amano (unpublished) used, 5 varieties were chosen : 3 as excellent seedling establishment ones (Arroz da Terra, Italica Livorno, Kaeu-N17) and 2 as poor seedling establishment ones (Annan V_1 and Hatanishiki). Two more varieties were used as standard ones (Table 1). Dry paddy field soil mixed with 1 mg g^{-1} of methylene blue was puddled in parallelepiped glass vessels (staining jars), and kept flooded at 20°C for 2 days until sowing. Dry seeds without CaO_2-coating were sown at 2 cm depth in the soil, which was still blue (i.e., oxidized), with their basal-end downward and embryo-side contacted with the lateral glass surface, so that germination could be observed. After sowing, the soil was kept flooded to 1 cm depth. Fifty-nine seeds of each variety were germinated at 17°C or 20°C, respectively, under a 12h photoperiod. Lateral surfaces of the vessels were covered with aluminium foil after sowing except when the following measurement was made : the vertical and the horizontal lengths of reduced soil area formed around a seed were measured every day. Germination and seedling emergence percentage and plumule length were recorded 18 days (17°C) or 14 days (20°C) after sowing. Germinated seed was defined as that with plumule longer than 1 mm at the time of sampling, because not a few decayed seeds were observed and in most of such seeds whether they germinated but plumule was decayed or failed to germinate was not clear.

Table 1. Varieties used.

Variety	Provenance	Abbreviation
Annan V_1	China	ANN
Arroz da Terra	Portugal	ARR
Italica Livorno	Italy	ITA
Kaeu-N17	C.I.S.	KAE
Kagahikari	Japan	KAG
Koshihikari	Japan	KOS
Hatanishiki*	Japan	HAT

* Upland rice.

Results

1. Local soil-reduction around a seed

Local soil-reduction around a seed generally began 3 days (17°C) or 2 days (20°C) after sowing, and varietal difference was not clear. Germination was generally observed 8-10 days (17°C) or 4-6 days (20°C) after sowing and varietal difference was not clear. These observations show that the reduced area around a seed appeared 5-7 days (17°C) and a few days (20°C) before gemination. Thus, seeds were exposed to local soil-reduction for a longer period before gemination at 17°C than at 20°C.

In all varieties, the shape of the reduced soil area around a seed was oval at first, and it seemed to be a reflection of the seed shape (Fig. 1). At the beginning, the boundary between the oxidized and reduced soil was indistinct. But within a few days, the reduced soil area was clearly formed and it became almost circle in all varieties. On the other hand, the size of the reduced soil area (reduced area size) was different between the varieties as shown in Figs. 1 and 2. In poor seedling establishment varieties, the enlarge-

Table 2. Reduced area size at the time around germination.

Variety	17°C(A)	20°C(B)	A/B(%)
ARR	260	289	90.0
ITA	325	409	79.5
KAE	317	358	88.5
KAG	263	344	76.5
KOS	208	337	61.7
HAT	387	492	78.7
Mean	269	345	78.0

Mean of 8 and 9 days after sowing (17°C) and 4 and 5 days after sowing (20°C). As germination percentage was very low, ANN was excluded.

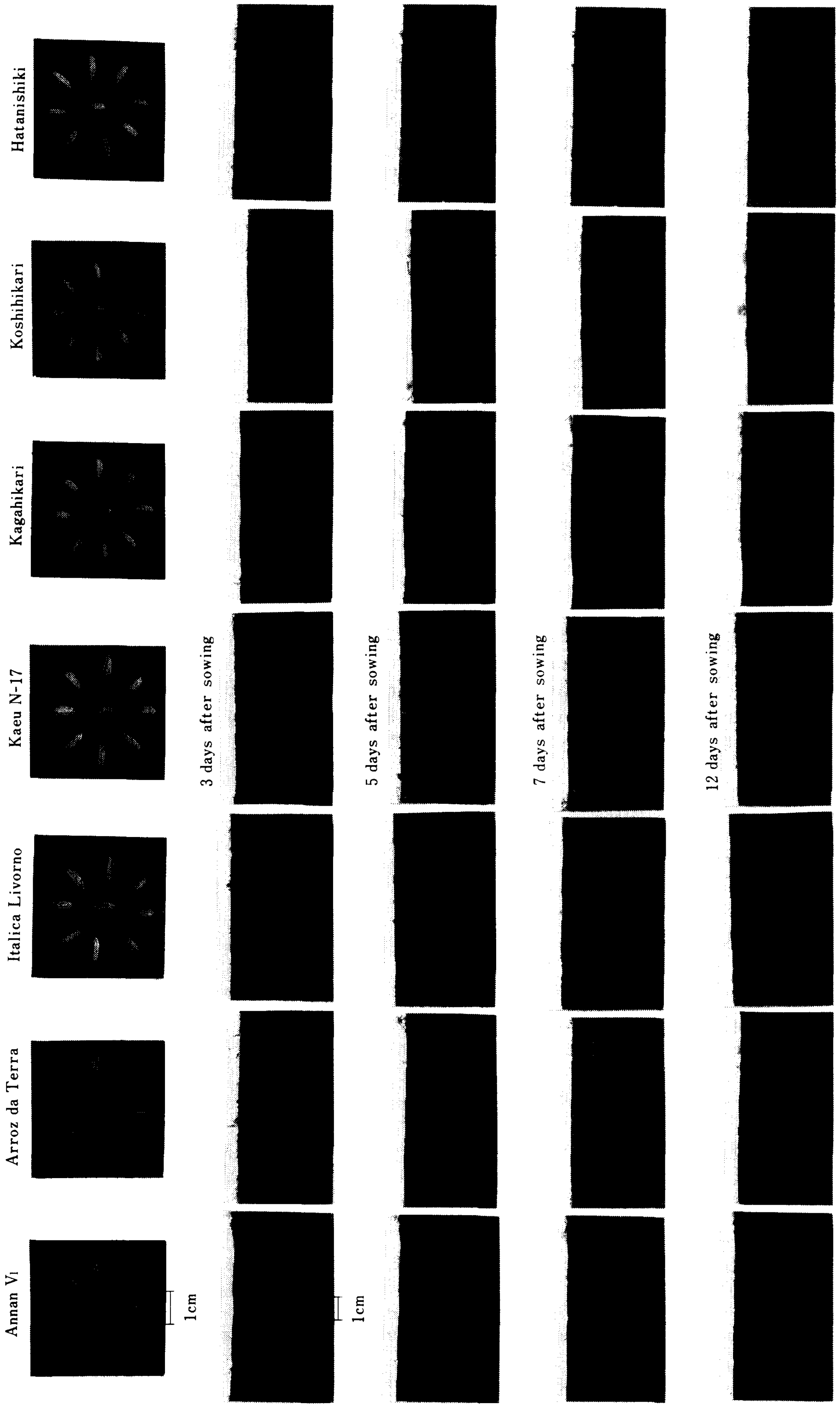

Fig. 1. Seed shape and time course of the enlargement of reduced soil area around a seed at 17°C. In Arroz da Terra, Kaeu-N17 and Hatanishiki, awn-removed seeds are shown. Light parts are reduced soil areas and dark parts oxidized soil areas.

ment of reduced area size was most rapid (Hatanishiki) or slowest (Annan V_1) among all varieties, whereas that of excellent seedling establishment ones (Arroz da Terra, Italica Livorno and Kaeu-N17) was relatively rapid and that of standard ones intermediate (Fig. 2). In general, the enlargement of reduced area size at 17°C was about half as slow as that at 20°C (Fig. 2). However, when compared at the time around germination, reduced area size at 17°C was not conspicuously smaller than that at 20°C (Table 2).

2. Germination and seedling emergence

As shown in Table 3, germination percentage was generally high in Arroz da Terra, Italica Livorno and Kaeu-N17. Very low germination percentage in Annan V_1 was due not to low germination vigor but to very poor plumule elongation or decay of seed. In gen-

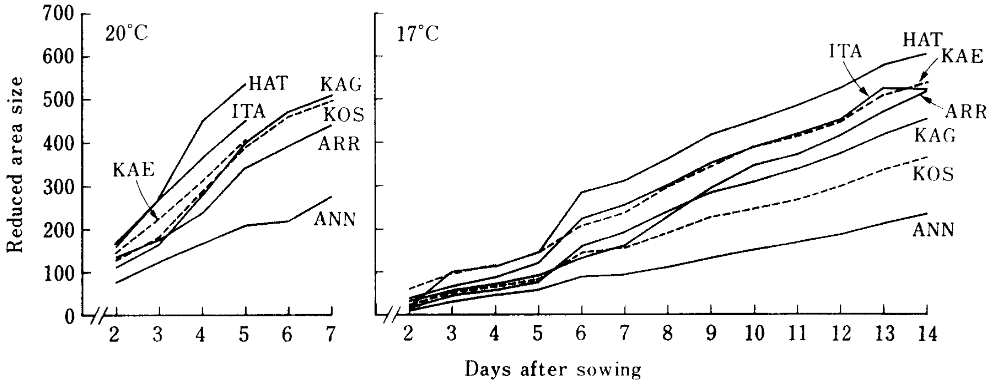

Fig. 2. Time course changes in reduced area size.
Reduced area is vertical length (mm) × horizontal length (mm) of the reduced soil area around a seed.
See table 1 for abbreviations. Standard error, not shown in the figure, was around 2 at the beginning and 11-22 at the end (17°C) and around 7 at the beginning and 10-25 at the end (20°C).

Table 3. Percentage of germination and seedling emergence, and plumule length.

	Variety	Germination (%)	Seedling emergence (%)	Plumule length* (mm)
17°C	ANN	5^{d}	0^{c}	2.7± 2.4
	ARR	93^{a}	14^{b}	12.4± 5.8
	ITA	91^{a}	25^{a}	13.6± 7.9
	KAE	75^{b}	10^{bc}	10.3± 7.7
	KAG	64^{bc}	0^{c}	7.9± 3.7
	KOS	55^{c}	11^{bc}	11.2± 7.6
	HAT	71^{b}	2^{c}	6.5± 3.7
20°C	ANN	0^{e}	0^{e}	0.0
	ARR	93^{a}	36^{bc}	18.2± 9.1
	ITA	85^{a}	42^{b}	20.3±10.3
	KAE	93^{a}	64^{a}	23.9±10.3
	KAG	70^{cd}	24^{cd}	14.6± 7.8
	KOS	61^{d}	35^{bc}	17.2± 7.1
	HAT	76^{bc}	14^{de}	10.6± 6.2

Values followed by the common letter within a column are not significantly different at the 1% level according to ANOVA.
*Mean±standard deviation of only germinated seeds.

eral, germination percentage was much the same between 17°C and 20°C or a little higher at 20°C. 17°C- and 20°C-germination percentage were highly correlated ($r=0.969$, $p<0.01$), showing that germination response to temperature was not markedly different between the varieties.

Seedling emergence percentage was generally very low at 17°C and that at 20°C was high compared with that at 17°C, except for Annan V_1. Seedling emergence percentage tended to be higher in excellent seedling establishment varieties than in other ones at both temperatures, though the percentage itself was not so high. This was probably because of the relatively deep sowing depth of 2 cm. Plumule length exceeded 20 mm, which was equivalent to sowing depth, only in Italica Livorno and Kaeu-N17 at 20°C. Although it is quite natural, plumule lengh was highly correlated to seedling emergence percentage ($r=0.873$, $p<0.05$ at 17°C and $r=0.950$, $p<0.01$ at 20°C).

Kaeu-N17 showed drastic decline in seedling emergence percentage at 17°C, while the decline in Italica Livorno at the same temperature was relatively small. In this way, varietal difference of seedling emergence response to temperature was observed, and the correlation between 17°C- and 20°C-seedling emergence percentage was not significant ($r=0.624$). The correlation between germination- and seedling emergence-percentage at 20°C ($r=0.767$, $p<0.05$) was higher than that at 17°C ($r=0.649$, not significant). These results show that emergence percentage was more affected by the factor existing in the process after germination at 17°C than at 20°C.

Discussion

Since dissolved O_2 in soil disappears within almost one day after submergence[2,7,9], it is reasonable to consider that seeds germinated under anaerobic conditions in this experiment and that soil reduction around a seed was not due to O_2 uptake by a seed during germination. Then, varietal difference in the reduced area size would be brought about by the difference in the amount or composition of exudate from a seed, which stimulates siol microbe activity, and, as a result, promotes soil reduction.

As we previously observed[5], seedling emergence of rice sown into flooded soil generally declines at low temperature whether the seed is coated or not with CaO_2. Seedling emergence percentage of CaO_2-coated seed declined when reduced area around it was formed earlier and become larger[4]. Soil reduction also inhibited seedling emergence of seed without CaO_2-coating[6,11]. Therefore, results obtained in this experiment, that (1) seed was exposed to local soil-reduction around it for a longer period before germination at 17°C than at 20°C and that (2) reduced area size at the time around germination at 17°C was not conspicuously smaller than that at 20°C, seem to be closely related to the poor seedling emergence and establishment of rice sown into flooded soil at low temperature. These results seem to be also related to the result that seedling emergence percentage at 17°C was not alwatys high even when germination percentage was high. The influence of local soil-reduction on seedling emergence was considered to be relatively stronger at lower temperature. On the other hand, as germination percentage of each variety was much the same between 17°C and 20°C, germination percentage seemed to be less susceptible to local soil-reduction compared with seedling emergence percentage.

In the case of a certain variety, local soil-reduction around a seed was more promoted in viable than in inviable seed especially in germinated one[4]. Local soil-reduction and germination are thus apparently correlated. However, the varietal difference of germination percentage was not explained from reduced area size, and the correlation between gemination percentage and reduced srea size was not significant when Annan V_1 was excluded. Reduced area size was therefore associated not with germination percentage but presumably with exudation due to catabolism during germination. The relation between exudation and reduced area size will have to be examined.

Previously, we proposed a hypothesis that seedling emergence percentage is influenced by two factors: (1) the length of coleptile elongation in the soil before seedling emergence and (2) the oxidation-reduction state of soil with which coleoptile contacts during the period[5]. This means that seedling emergence percentage becomes lower when coleoptile elongates through soil with lower redox potential (Eh) and when the period of its elongation through the soil becomes longer. However, the correlation between seedling emergence percentage and reduced area size was negative but not significant at both temperatures. Varietal difference of seedling emergence percentage could not be simply explained from reduced area size, although we supposed it to be related to the above mentioned factors. This may be partly because Eh, though its decline was associated with the enlargement of reduced soil area around a seed[3], was not evaluated enough only by measuring reduced area size, and also be because of the varietal difference of tolerance to soil reduction. In order to clarify the mechanism of the expression of varietal difference of seedling emergence, not only reduced area size but also Eh and tolerance to soil reduction, such as the coleoptile elongation rate in reduced soil, are to be investigated. The relation between reduced area size and coleoptile elongation rate in reduced soil seems to be an important factor determining the varietal difference. In addition, the influence of local soil-reduction before germination on seedling emergence must be clarified. Further investigations into these problems will supply useful information about the selection of excellent seedling emergence and establishment varieties.

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* In Japanese with English summary or abstract.
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*** In Japanese. The title is translated by the present authors.