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Response of the Seminal Root Elongation to NH_4-Nitrogen in Several Rice Cultivars*

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Abstract : The aim of this study was to examine the effect of various NH_4-nitrogen concentrations in culture solution on the seminal root elongation of the rice plant. Ten rice cultivars with differing adaptabilities for heavy manuring were grown in Kasugai rice culture solution at 30°C for 12 days. First, the nitrogen concentration was set at four levels, 0, 4, 40 and 240 mg L^{-1}. In all the cultivars, seminal root elongation was exponentially inhibited with increasing nitrogen concentration and thus the inhibitory effect per unit increase of nitrogen concentration was much greater in the range of 0 to 4 mg L^{-1} than in the higher range. In a separate experiment, nitrogen concentration was set at six levels, 0, 0.4, 1, 2, 3 and 4 mg L^{-1}. In this range, seminal root elongation was linearly inhibited with increasing nitrogen concentration. Comparing the cultivars, a clear trend was seen. The seminal root elongation of the rice cultivars, which are reputed for their low adaptability for heavy manuring, was more severely inhibited as nitrogen concentration increased compared to cultivars with high adaptability. Additionally, the seminal root axis length of the former cultivars tended to be greater than that of the latter cultivars when nitrogen concentration was at 0 mg L^{-1}.
Key words : Adaptability, Heavy manuring, NH_4-nitrogen, Rice, Root elongation, Seminal root.

アンモニア態窒素に対する水稲種子根の伸長反応の品種間比較 : 田中実秋・山内　章・河野恭廣（名古屋大学農学部）

要　旨 : 植物の根の形態は養分条件によって変化する．この実験では，水耕液中のアンモニア態窒素の濃度が水稲種子根の伸長に及ぼす影響を検討した．耐肥性の異なる水稲 10 品種を 30°Cのグロースキャビネット中で，春日井氏 A 液を用いて 12 日間生育させた．先ず，窒素濃度を 0，4，40，240 mg L^{-1} の 4 段階に設定した．全ての品種の種子根は窒素濃度が上がるにつれて伸長は指数関数的に抑制された．その抑制反応は 0～4 mg L^{-1} で発現し始め，抑制程度も顕著であることを認めた．そこで，窒素濃度を 0，0.4，1，2，3，4 mg L^{-1} と設定して再度実験を行った．その結果，種子根の伸長は窒素濃度が上がるにつれて直線的に抑制された．そこで窒素濃度に対する種子根の伸長抑制程度を数値化し，品種間比較を容易にするために，窒素濃度と種子根長との関係を回帰直線式に整理した．それぞれの回帰直線の勾配の値は，各品種の種子根の伸長の抑制程度を表しており，この値に明白な品種間差異が認められた．勾配の値は，耐肥性の小さい品種群に比べて耐肥性の大きな品種群で小さい傾向を認めた．また，0 mg L^{-1} での種子根長にも同様の傾向を認めた．
キーワード : アンモニア態窒素，種子根，水稲，耐肥性，根の伸長.

Morphology of the plant root system is often altered by the surrounding environmental conditions[7]. The nutrient condition of the growth medium is one of the major factors that affect root morphology. In particular, nitrogen (N) application greatly affects the development of plant root systems and thus their functions.

In rice plants, only a few studies have been conducted on this subject, most of which have dealt with root elongation responses to different N concentrations. Kawata *et al.*[4] observed that root growth was markedly inhibited in paddy soil where the amount of applied N fertilizer was high. Doi *et al.*[2] compared cvs. Kameji and Shinriki, which are known to differ in tolerance to rice blast and N absorption ability, and found that the two rice cultivars differed in the response of root elongation to different NH_4-N concentrations of a culture solution. Tsunoda[10] reported that the high concentration of N inhibited the root elongation of several rice cultivars grown in a culture solution using NH_4NO_3-N as the N source, but the effect also differed among the cultivars of different adaptability for heavy manuring (AHM).

The latter two reports discussed that the root growth response to various concentrations of N can be related to the AHM of the cultivars. The concept of AHM implies various growth responses of a whole plant such as tolerance to rice blast, lodging resistance, and

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morphological and physiological characteristics under heavy manuring conditions[1,6]. Cultivars with high AHM sharply respond to heavy manuring, especially N application, which leads to increased yield. Cultivars with low AHM in turn respond to heavy N application in such ways that they tend to be susceptible to lodging, rice blast and so on, and decrease grain-straw ratio (harvest index), which results in the reduction of yield. The adaptability can also be considered to reflect the tolerance of plants to the heavy application of N.

In this aspect, the objective of this study was to examine the responses of root elongation of several rice cultivars with various degrees of the AHM to different NH_4-N concentration levels of a culture solution. Mitsui and Kumazawa[5] reported that NH_4-N in the culture solution inhibited the root elongation, while it was promoted by NO_3-N. Besides, most inorganic N compounds in paddy fields exist in NH_4-N form. Hence, in this study, we used NH_4-N as the N source to avoid confusion in interpretation of the results.

Materials and Methods

Experiment 1

Table 1 shows the cultivars used in this study. The AHM has been documented for the cultivars from Kinmaze to Tamanishiki as listed in the table. Oochikara and Habataki were developed at Hokuriku National Agricultural Experiment Station as high yielding cultivars in 1989, leading us to suppose that the two cultivars have a high AHM. Arborio is a Javanice type cultivar, but its AHM is unknown.

Seeds of the cultivars were soaked in tap water and placed in a dark chamber at 30°C for 2 days. Then the pregerminated seeds were planted on a stainless wire net which was floated in a container. The size of the container was 20×25×15 cm and was filled with 6 L of Kasugai rice culture solution[3], which contains $(NH_4)_2SO_4$ as the N source. The N concentrations of the culture solution were prepared at four levels, *i.e.* 0, 4, 40 and 240 mg L^{-1}. Other nutrient concentrations were at one-tenth strength Kasugai rice culture solution for each N concentration (treatment).

The culture solution was renewed every 2 days. The pH of the culture solution was adjusted to 5.5 with 0.1 N of HCl and NaOH when the culture solution was renewed. One container was used for each treatment and 20 seeds of each cultivar were sown in a row in each container. The plants were grown in a growth chamber at 30°C with 12-h photoperiod for 12 days. Ten plants for each cultivar that showed average growth were sampled and their plant height, leaf number, number of nodal root axes and length of seminal and nodal root axes were determined.

Experiment 2

This experiment was conducted to examine

Table 1. Characteristics of the cultivars used in this experiment.

Cultivar	Adaptability for heavy manuring	Plant type	Literature
Kinmaze	+	S−PN	Osada (1966)[6]
Norin 25	+	S−PW	Osada (1966)
Ginbozu	+	M−M	Baba (1965)[1]
Norin 8	±	T−PW	Osada (1966)
Chibaasahi	−	S−PW	Osada (1966)
Gin-nen	−−	T−PW	Baba (1965)
Tamanisiki	−−	T−PW	Osada (1966)
Habataki		S−PN	
Oochikara		T−PW	
Arborio		T−PW	

+, Adaptable; ±, Medium; −, Less adaptable; −−, Least adaptable; T, Tall type; S, Short type; M, Medium type; PN, Panicle number type; PW, Panicle weight type.

the response of seminal root elongation of the cultivars to lower range of the N concentration. N concentrations of the culture solution were set at 0, 0.4, 1, 2, 3 and 4 mg L^{-1}, which were monitored by the Indophenol method[8] and the reduced amount of N, which was absorbed by the plants, was supplemented daily. The concentrations of other nutrients were the same as in Exp. 1. The culture solution was renewed every 4 days. The size of the container was 20×25×30 cm and was filled with 12 L of the same culture solution. The automatic pH controller was used for more accurate maintenance of pH, which was adjusted to 5.5 with 0.1 N of HCl and NaOH. Other growth conditions were the same as in Exp. 1 and the plants were also grown for 12 days.

Results and Discussion

In Exp. 1, a wide range of N concentration of the culture solution was set from 0 to 240 mg L^{-1} to examine which level of N concentration greatly affects the plant growth.

Fig. 1 shows plant height, number of nodal roots, total nodal root axes length and seminal root axis length of four cultivars grown under different N concentrations. Gin-nen and Tamanishiki are the cultivars with low AHM, while Kinmaze and Norin 25 are the cultivars with high AHM. Many of rice cultivars with low AHM sharply respond to heavy N application in a way that the shoot excessively elongates, which makes the light-intercepting characteristic worse and the plants more susceptible to lodging. However, in this experiment, although only the young seedling stage was studied, no such response was observed, *i. e.*, plant height was scarcely affected by the different N concentrations except they were greatly reduced at 240 mg L^{-1}. Leaf number of all the cultivars (data were not shown) were in the range of 3 to 4 at all N applications except Gin-nen, whose leaf number was markedly decreased to 2.2 at 240 mg L^{-1}. As for roots, the number of nodal roots was also scarcely affected by the different N concentrations, except at 240 mg L^{-1}.

In contrast, the seminal and the total nodal root axes length were decreased with increasing N concentration (Fig. 1). In the responses of total nodal root axes length, Kinmaze (high AHM) and Tamanishiki (low AHM) showed a similar trend, their elongation growth of nodal root were more severely inhibited than those of Gin-nen (low AHM) and Norin 25 (high AHM). As such, the responses of nodal roots could not be clearly related to the degree of AHM of each cultivar. This could be attributed to the possible difference in the

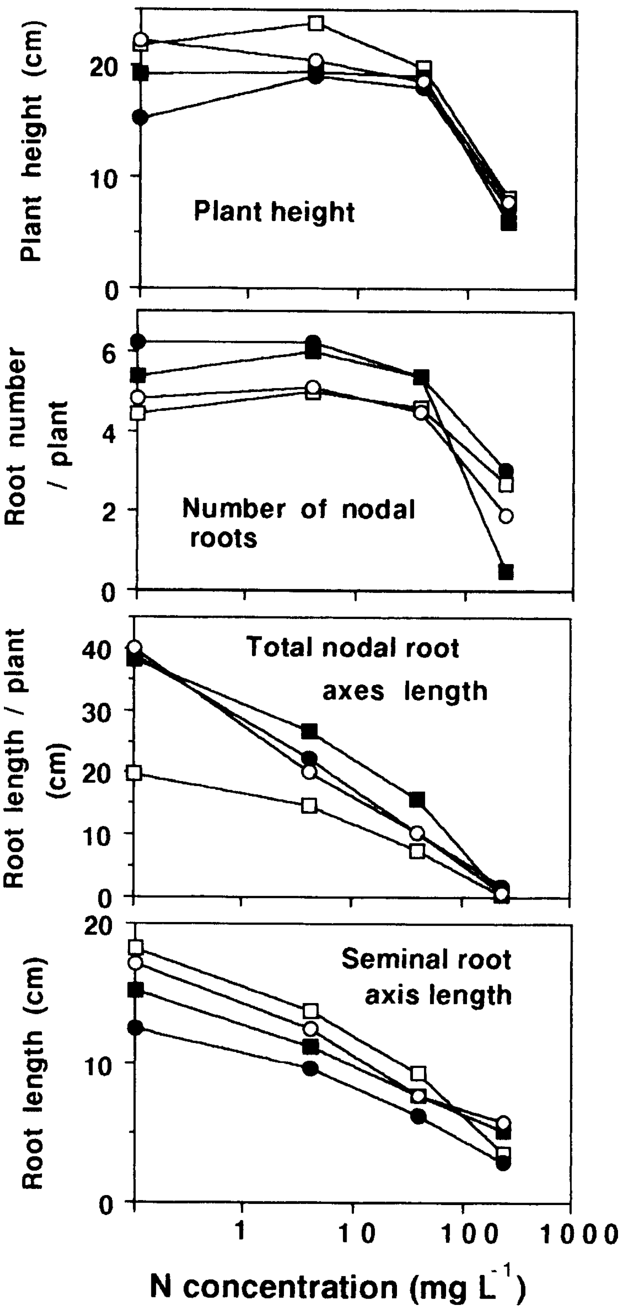

Fig. 1. Plant height, number of nodal roots per plant, total nodal root axes length per plant and seminal root axis length of four cultivars grown in the culture solution of different N concentrations. □ : Gin-nen, ○ : Tamanishiki, ■ : Norin 25, ● : Kinmaze.

habit and timing of rooting for the nodal roots among the cultivars, which may make the comparison rather complicated. Therefore, for further detailed examination, the analyses were mainly performed on the responses of seminal roots whose ages were almost uniform for all the cultivars examined.

In all cultivars, the seminal root axis length was decreased exponentially with increasing N concentration as stated earlier (Fig. 1). The inhibitory effect by NH_4-N was already distinct, even at 4 mg L^{-1}, and the seminal root axis length was about 75% of that at 0 mg L^{-1}, and it was about 50% and 25% at 40 and 240 mg L^{-1}, respectively. Therefore, within the range of N concentration in this experiment, the inhibitory effect of NH_4-N per unit increase of N concentration on the seminal root axis elongation was more drastic from 0 to 4 mg L^{-1} as compared to that in the higher range.

Experiment 2 was then conducted to examine in detail the inhibitory effect of NH_4-N on the seminal root axis elongation in the lower range of N concentration *i.e.*, 0 to 4 mg L^{-1}. This range of N concentration is also practically important because the N concentration that normally occurs in paddy field is less than 3 mg L^{-1} [9]. In contrast, the N concentrations used in the studies of similar nature were considerably high, *e.g.*, 0 to 10,000 mg L^{-1} in the work by Doi *et al.*[2] and 4 to 400 mg L^{-1} by Tsunoda[10].

In Exp. 2, similar trends to Exp. 1 were evident for all growth parameters examined (data are not shown). The results of the two experiments showed that shoot growth was relatively stable, but especially the elongation of the roots was substantially affected by different N concentrations, at least in the range of 0 to 40 mg L^{-1}.

Similarly to Exp. 1, the seminal root axis length of all the cultivars was decreased with increasing N concentration, but their relationship was almost linear in the narrow range on N concentrations (0 to 4 mg L^{-1}). Then, in an attempt to compare quantitatively the response of seminal root to the N concentrations among the cultivars, a linear regression equation between the N concentration and the seminal root axis length was computed for each cultivar (Table 2). For Exp. 1, the equation was computed in the range of 0 to 40 mg L^{-1} of N concentration in which the seminal root elongation was severely inhibited, while it was calculated in the whole range examined for Exp. 2. We considered that the regression coefficient can be used to evaluate the inhibition rate of the seminal root axis length by the different concentrations of NH_4-N in the culture solution. The value were all negative, but differed among the cultivars.

Table 2. Comparison of regression coefficient of linear regressions equations between seminal root axis length and N concentration in the culture solution in Exp. 1 and Exp. 2 among the cultivars.

Cultivar	Exp. 1 (0 to 40 mg L^{-1})		Exp. 2 (0 to 4 mg L^{-1})	
	Regression Coefficient	r	Regression coefficient	r
Oochikara	−0.22	0.951	−1.98	0.906*
Tamanisiki	−0.20	0.912	−2.22	0.896*
Gin-nen	−0.19	0.908	−1.96	0.769
Chibaasahi	−0.17	0.930	−2.18	0.886*
Arborio	−0.16	0.842	−2.11	0.871*
Norin 25	−0.16	0.893	−1.80	0.915*
Kinmaze	−0.13	0.924	−1.29	0.886*
Norin 8	−0.13	0.815	−1.85	0.918**
Ginbozu	−0.13	0.930	−1.61	0.835*
Habataki	−0.07	0.864	−1.43	0.844*

* and ** show significance at 5% and 1% level, respectively.

Comparing the values, the following trend was commonly evident for the two experiments : the cultivars which are reputed for their low AHM tended to show the greater absolute value of the regression coefficient, while the cultivars with the high AHM showed relatively small absolute value of the regression coefficient. In other words, the elongation growth of seminal root axis of the former cultivars was more sensitive to the changes in N concentrations and more severely inhibited as the concentration increased when compared to that of the latter cultivars. The only exception was Oochikara, which was developed as a high yielding cultivar and thus expected to have the high AHM as mentioned earlier. It showed the greater absolute value of the regression coefficient, *i.e.* the seminal root elongation was substantially inhibited by the higher N concentrations.

Another interesting finding was that the absolute length of the seminal root axis at 0 mg L^{-1} for the cultivars with low AHM tended to be greater as compared to that of the cultivars with high AHM (Table 3).

The equations used to obtain the regression coefficient also provide the Y intercept values which indicate the estimated length of seminal root axis grown at 0 mg L^{-1}. And the values well fit the actual lengths especially for Exp. 2 (Table 3). Therefore, both of the values obtained from the equation could be good indicators for the comparison of the AHM of the rice cultivars.

Table 3. Seminal root axis length at 0 mg L^{-1} N concentration and Y intercept of linear regression equation between seminal root axis length and N concentrations in the culture solution for Exp. 2.

Cultivar	Seminal root axis length (cm)	Y intercept
Oochikara	21.7±1.8	19.91
Tamanishiki	23.2±2.7	20.38
Gin-nen	23.9±1.6	19.86
Chibaasahi	20.4±1.4	17.88
Arborio	19.7±1.7	17.05
Norin 25	18.4±0.9	16.77
Kinmaze	14.7±1.5	13.28
Norin 8	17.3±2.5	15.63
Ginbozu	18.0±1.1	15.34
Habataki	13.4±1.0	11.67

Seminal root axis length are expressed in means of 10 plants ±S. D.

The results of this study agreed well with those by Doi *et al.*[2] and Tsunoda[10] in that the root growth inhibition by N in the growth medium can be related to the adaptability for heavy manuring of the cultivar. However, they only evaluated the root growth based on the length of the longest root at the time of sampling instead of specifying which root system component was determined.

In our study, care was taken on this aspect, and the seminal root was used for evaluation since for different cultivars the seminal roots should be almost the same in age and thus were expected to be exposed to different N concentration treatments for almost the same period. In fact, clear differences among the cultivars were shown in the growth response of seminal roots to the different N concentrations, according to the AHM. In contrast, although the nodal root axes elongation was similarly inhibited by higher N concentrations, the relationship between the degree of inhibition and the AHM of each cultivar was not as clear as in the seminal root. These findings, however, should be examined also at later gorwth stages.

The results of this study suggest the possibility that the cultivars with high AHM may be screened by investigating the seminal root growth response to relatively low N concentration during the very young seedling stage. A further study is needed using more cultivars whose AHM is known to validate this possibility.

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* In Japanese with English title.
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