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Comparison of Absorption Rates between Ammonium and Nitrate Nitrogen in Plants

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Absorption rates of ammonium ion (NH_4^+) and nitrate ion (NO_3^-) for 24 hours were compared using two absorption solutions, which were a single salt solution of ammonium nitrate (NH_4NO_3) and a complete nutrient solution containing NH_4NO_3. Test plants were *Oryza sativa* (Rice), *Hordeum vulgare* (Barley), *Lactuca sativa* (Lettuce), *Cucumis sativus* (Cucumber), *Daucus carota* (Carrot), *Brassica pekinensis* (Chinese cabbage), *Spinacia oleracea* (Spinach) and *Raphanus sativus* (Radish). From the absorption characteristics of NH_4^+ and NO_3^- between a single salt solution of NH_4NO_3 and a complete nutrient solution containing NH_4NO_3, the test plants were classified into group 1 (rice, barley and lettuce), which absorbed NH_4^+ more rapidly than NO_3^- in both absorption solutions, group 2 (cucumber and carrot), which absorbed NH_4^+ slightly more than NO_3^- in the single salt solution of NH_4NO_3, the tendency of which was reversed in the complete nutrient solution containing NH_4NO_3, and group 3 (Chinese cabbage, spinach and radish), which absorbed NO_3^- clearly more than NH_4^+ in the complete nutrient solution, whereas the absorption of NH_4^+ or NO_3^- was almost equal in the single salt solution of NH_4NO_3.

The above classification of plants could be explained by the balance of a repressive or competitive characteristic of NH_4^+ absorption mainly associated with a capacity for absorption of calcium ion (Ca^{2+}) and magnesium ion (Mg^{2+}), and the relative root affinity to NO_3^- that can be evaluated by the relative absorption of NO_3^- to mono-phosphate ion ($H_2PO_4^-$) in plant roots. The group 1 plants are the so-called acid tolerant plants, which appeared to be tolerant to NH_4^+, and showed a marked pH decrease during the 24 hours of the absorption experiments in those plants. By contrast, the group 3 plants seemed to prefer NO_3^- and divalent alkaline earth cations to

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the other nutrients in the complete nutrient solution containing NH_4NO_3, and the pH decrease during each absorption experiment was small.

Key words: Alkaline earth, Ammonium, Ion balance, Nitrate, Phosphate

INTRODUCTION

The absorption characteristics of NH_4^+ and NO_3^- have been compared frequently, and the reports on short term absorption experiments within a day became increased recently (Criddle *et al.* 1988, Henriksen *et al.* 1990, Jackson *et al.* 1972, Marcus-Wyner 1983, Youngdahl *et al.* 1982). However, a direct comparison of NH_4^+ and NO_3^- absorption between plants exposed to a single salt solution of NH_4NO_3 and a complete nutrient solution containing NH_4NO_3 has not been performed yet. Absorption of NH_4^+ or NO_3^- was affected by several ions including their counter ion or pH (Criddle *et al.* 1988, Deane-Drummond 1984, Henriksen *et al.* 1990, Jackson *et al.* 1972, Marcus-Wyner 1983, Neyra and Hageman 1975, Youngdahl *et al.* 1982). When a single salt solution of NH_4NO_3 is used to compare the absorption of both nitrogenous ions, the absorption of each ion can be evaluated under a simple condition except for the effect of its counter ion (Criddle *et al.* 1988, Henriksen *et al.* 1990, Pan *et al.* 1985). However, the use of this simple medium seems to have another weakness, for example, lack of environmental Ca^{2+}, only one minute of Ca-free treatment, gave a negative effect on ion (rubidium) absorption in excised barley roots (Kawasaki *et al.* 1974). Therefore, the absorption rates of NH_4^+ and NO_3^- were simultaneously compared between a single salt solution of NH_4NO_3 and a complete nutrient solution containing NH_4NO_3 to accumulate critical results concerning the present subject.

Long exposure of plants to a low solution pH or NH_4^+ often induces stunted growth (Blacquiere *et al.* 1987, Moritsugu and Kawasaki 1982, Moritsugu *et al.* 1983, Tanaka and Hayakawa 1974), but, many plants grow vigorously at moderate pH conditions in the presence of NH_4^+ (Cox and Reisenauer 1973, Moritsugu *et al.* 1983). To obtain vigorous test plants and to acclimate them to NH_4^+ and NO_3^-, the method of a constant pH solution culture (Moritsugu and Kawasaki 1979) in a complete nutrient solution containing NH_4NO_3 at pH 5.5 was applied to the pre-cultures of the test plants in this work.

MATERIALS AND METHODS

Rice (*Oryza sativa* L. cv. Akebono), barley (*Hordeum vulgare* L. cv. Akashinriki), lettuce (*Lactuca sativa* L. cv. New York 515), cucumber (*Cucumis sativus* L. cv. Chihai), Chinese cabbage (*Brassica pekinensis* Rupr. cv. Harumaki-Gokuwase), spinach (*Spinacia oleracea* L. cv. Nippon), carrot (*Daucus carota* L. cv. Tokinashi-Gosun) and radish (*Raphanus sativus* L. cv. Kohhaku-Hatsuka) were used as test plants.

The pre-cultures and the absorption experiments were performed in a green house where the air temperature was regulated, maximum 38°C in summer and minimum 16°C in winter. Young seedlings germinated and grown in wet sand were transplanted to a hand-made plant-supporting plastic frame set on a plastic pot, which was attached to the constant pH solution culture system (Moritsugu and Kawasaki 1979). The test plants were pre-cultured for the respective duration shown in Table 1, in an aerated complete nutrient solution containing 2.5 mmol/l of NH_4NO_3. Table 1 shows the date of sowing, transplanting and absorption experiment, duration of pre-culture, and season for regular field culture in western Japan for each plant.

Table 1. Dates and duration of pre-culture

Plants	Date			Duration of	Season[1]
	Sowing	Transplant	Abs. Expt.	pre-culture	Pr, Reg
Rice	07/28	08/09	09/11	32 days	S, S~A
Barley	12/12	12/22	01/27	36	W, A~Sp
Lettuce	10/03	10/29	12/08	40	W, A~Sp
Cucumber	10/10	10/18	11/14	27	A, S
Tomato	07/16	07/25	09/01	37	S, S
Carrot	11/25	12/13	01/27	45	W, An
Chinese cabbage	09/08	09/13	10/16	33	A, A~Sp
Spinach	11/25	12/13	01/27	45	W, A~Sp
Radish	11/25	12/13	01/15	33	W, An

[1]: Season for pre-culture (Pr) and regular field culture (Reg) for each plant in western Japan
An, A,W, Sp and S mean annual, autumn, winter, spring and summer, respectively.

The composition of the complete nutrient solution was as follows: NH_4NO_3 2.5 mmol/l, KH_2PO_4 1.0 mmol/l, K_2SO_4 1.5 mmol/l, $CaCl_2$ 2.0 mmol/l, $MgSO_4$ 1.0 mmol/l, Fe (citrate) 1.0 ppm, B (H_3BO_3) 0.5 ppm, Mn ($MnCl_2$) 0.5 ppm, Zn ($ZnSO_4$) 0.05 ppm, Cu ($CuSO_4$) 0.02 ppm, Mo (Na_2MoO_4) 0.01 ppm. Iron was added on alternating days, and the nutrient solution was fully renewed once a week. The pH of the nutrient solution was adjusted automatically to 5.5 with an accuracy of ± 0.1 units by the constant pH solution culture system (Moritsugu and Kawasaki, 1979).

During the initial few days of the pre-culture, six plants, composed of two groups (3+3) per pot for rice and barley or two plants per pot for the other species were selected and remained through a thinning process. Healthy plants were selected for uniformity for each absorption experiment. In the cases of rice and barley, the plants were analyzed including tillers. On the day before the start of every absorption experiment, the complete nutrient solution must be renewed.

The absorption experiments began in the morning and continued for 24 hours. At the start of every absorption experiment, culture pots (a/5,000 area, 3.5 *l* volume) for two to four replications were prepared, and the absorption solutions, i.e., the single salt solution of 2.5 mmol/*l* NH_4NO_3 and the complete nutrient solution containing 2.5 mmol/*l* of NH_4NO_3, were made up in those pots. After rinsing the roots twice with bubbling deionized water, the test plants were transferred together with each plant-supporting plastic frame, which was used during each pre-culture. Solution pH was not regulated during the 24-hour absorption experiment, while the pH was measured and recorded at each sampling time.

The concentrations of NH_4^+, NO_3^- and some other nutrient ions in the absorption solutions were measured at each sampling time, i.e., at 3, 8 and 24 hours, 5 and 24 hours, and 8 and 24 hours after the start of the respective absorption experiments. The concentrations of NH_4^+ in the absorption solution were determined by the micro-Kjeldahl method, and those of NO_3^- were evaluated by the ultraviolet absorption method (Bastian *et al.* 1957). Potassium (K^+), Ca^{2+} and Mg^{2+} concentrations were determined by the atomic-absorption spectrophotometry. The concentration of $H_2PO_4^-$ was determined by the vanado-molybdate spectrophotometric method.

RESULTS

Table 2 shows the pH values of both absorption solutions at each sampling time. Compared between the single salt solution of 2.5 mmol/*l* NH_4NO_3 and the complete nutrient solution containing 2.5 mmol/*l* NH_4NO_3, the pH decline in rice, barley, spinach and radish during the initial few hours was greater in the single salt solution of NH_4NO_3. In the cases of lettuce, cucumber and carrot, the initial pH decrease was greater in the complete nutrient solution containing NH_4NO_3. However this tendency did not always continue for 24 hours. The initial pH decreasing tendency reversed between the two absorption solutions in the cases of barley and carrot. In

Table 2. Changes in solution pH during absorption experiments

Plants	Single salt solution				Complete nutrient solution			
	3	5	8	24 h	3	5	8	24 h
Rice	3.8		3.1	3.1	4.0		3.3	3.2
Barley	4.1		3.9	3.3	4.3		4.1	3.1
Lettuce	4.1		3.9	4.1	3.8		3.5	3.3
Cucumber		4.5		4.1		4.4		3.8
Carrot	5.3		5.1	4.3	5.1		5.0	4.7
Chinese cabbage		5.6		5.2		5.6		5.0
Spinach	4.7		4.7	4.2	5.1		5.2	5.2
Radish	5.8			5.0	5.9			5.7

rice, carrot, spinach and radish, the pH decline in the single salt solution of NH_4NO_3 after 24 hours was greater than that in the complete nutrient solution containing NH_4NO_3. The decrease of pH in the complete nutrient solution after 24 hours was substantial in rice, barley and lettuce, while the pH decrease was slight in radish, spinach and Chinese cabbage.

In Figs. 1 to 3, the decreases of NH_4^+ and NO_3^- concentrations in the

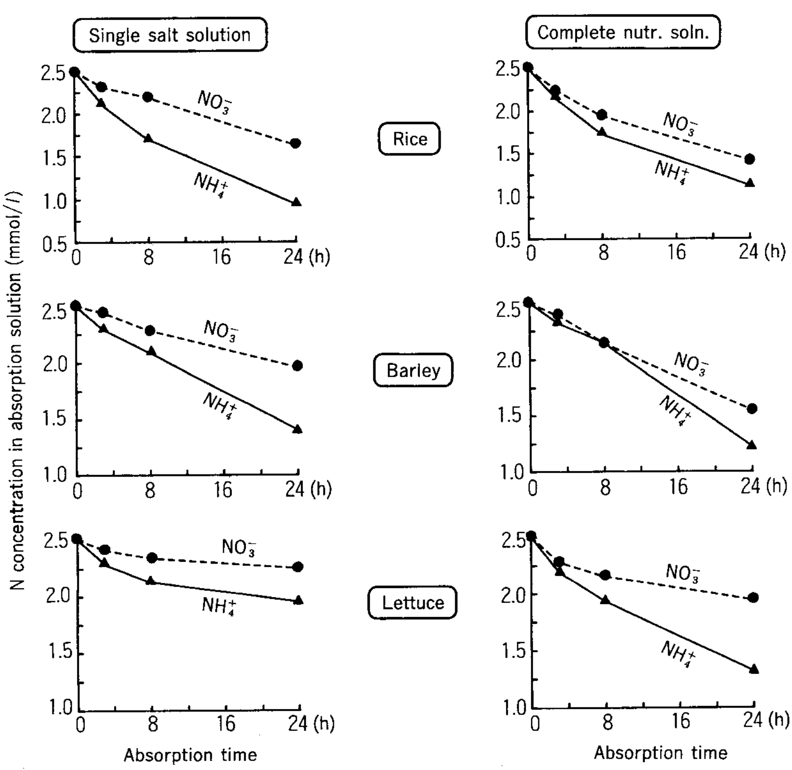

Fig. 1. Absorption of NH_4^+ and NO_3^- by rice, barley and lettuce plants.

single salt solution of NH_4NO_3 are illustrated at the left charts; and the decrease in the complete nutrient solution containing 2.5 mmol/l of NH_4NO_3 at the right ones. The horizontal axis of their charts indicates the time course. The vertical axis indicates the concentrations of NH_4^+ and NO_3^- in both absorption solutions.

Fig. 1 shows the decrease of NH_4^+ or NO_3^- during the absorption experiments of rice, barley and lettuce plants. The decrease of NH_4^+ was more rapid than that of NO_3^- in those plants in both absorption solutions, and the difference between NH_4^+ and NO_3^- absorption increased with time. In the complete nutrient solution, there was little difference between NH_4^+ and NO_3^- absorption in rice and barley, but there was a clearer difference in lettuce.

Fig. 2 shows the decreasing pattern of NH_4^+ and NO_3^- concentrations in the absorption experiments of cucumber and carrot. In the single salt solution of NH_4NO_3, the decrease of NH_4^+ concentration was slightly greater, while the decrease of NO_3^- concentration was greater in the complete nutrient solution containing NH_4NO_3. In the case of cucumber, the difference between NH_4^+ and NO_3^- absorption was rather small between the two absorption solutions. However, the reverse tendency between the two absorption solutions found in the NH_4^+ and NO_3^- absorption was clear in the case of carrot.

Fig. 3 shows the decrease of NH_4^+ or NO_3^- concentration in each absorption solution in the cases of Chinese cabbage, spinach and radish. The decrease of the NH_4^+ and NO_3^- concentrations was similar in the single salt solution of NH_4NO_3. However, in the complete nutrient solution, the

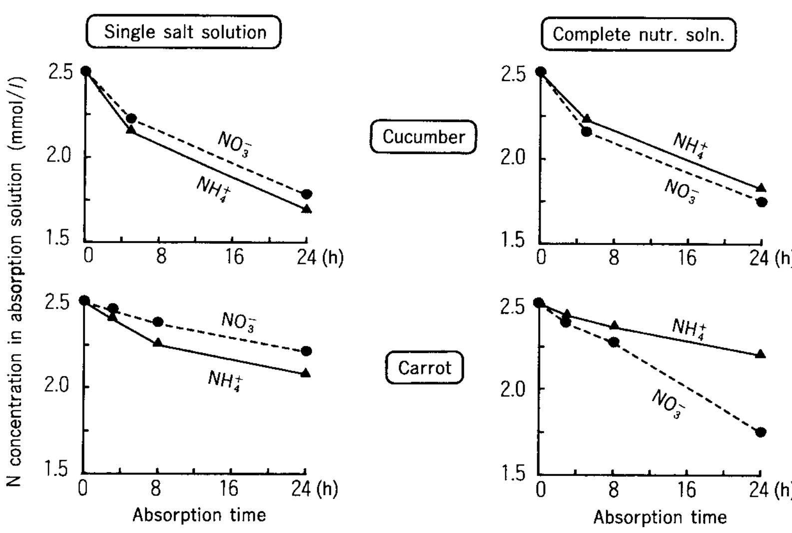

Fig. 2. Absorption of NH_4^+ and NO_3^- by cucumber and carrot plants.

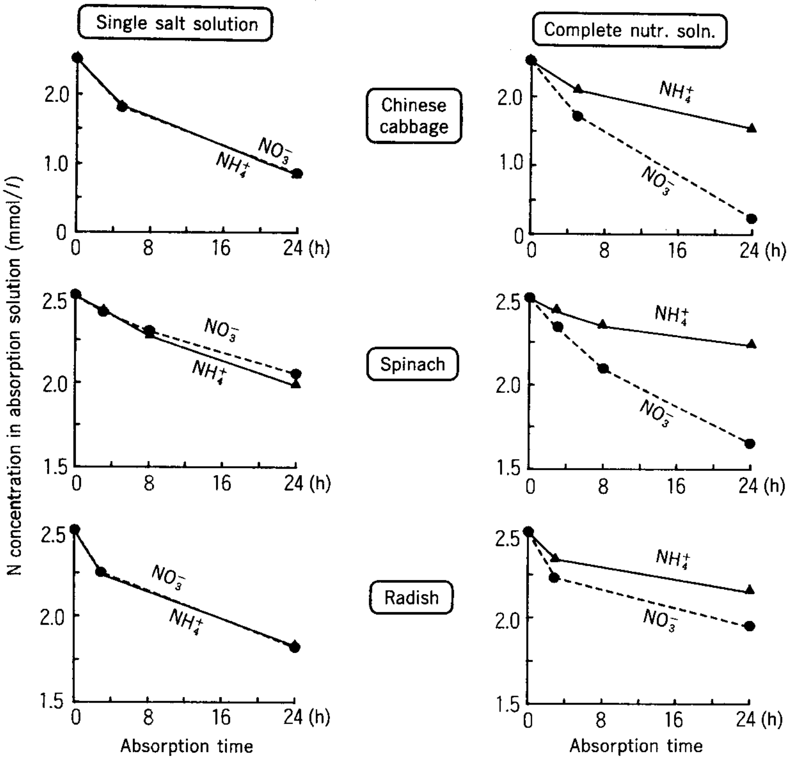

Fig. 3. Absorption of NH_4^+ and NO_3^- by Chinese cabbage, spinach and radish plants.

decreasing rate of NO_3^- concentration was clearly greater than that of NH_4^+. This tendency was marked in the cases of Chinese cabbage and spinach.

When the single salt solution of NH_4NO_3 was supplied to plants, the absorption rate of NH_4^+ was greater in rice, barley, lettuce, cucumber and carrot, but the absorption rates of NH_4^+ and NO_3^- were similar in Chinese cabbage, spinach and radish. When the complete nutrient solution containing NH_4NO_3 was supplied, the rate of NH_4^+ absorption was clearly higher in rice, barley and lettuce, while the rate of NO_3^- absorption was higher in cucumber, carrot, Chinese cabbage, spinach and radish. However, in the case of cucumber, the difference in NH_4^+ and NO_3^- absorption was small in both absorption solutions.

DISCUSSION

In order to minimize the effect of temperature on the plant mineral nutrition in our green house experiments, extremely high and low environmental temperatures were moderated by an attached air conditioner. The test plants apparently grew normally and vigorously at the constant pH (5.5) (Moritsugu and Kawasaki 1982). The vigorous growth of the plants seems to be due to the constancy of the pH and the weakening of toxicity of NH_4^+ by the mixing of NO_3^- (Ikeda and Yamada 1984). The initial slow rate of NO_3^- absorption that was found frequently in the NO_3^--depleted plants (Breteler and Nissen 1982, Deane-Drummond 1984, Jackson *et al.* 1972, MacKown and McClure 1988, Neyra and Hageman 1975) was not found in the present experiments (Figs. 1 to 3). This means that enough NO_3^- was supplied by the nutrient solution renewal that was carried out directly before every absorption experiment.

The pH decline during the absorption experiments shown in Table 2 was marked in the cases of so-called *acid tolerant* plants (Tanaka and Hayakawa 1974), such as rice, barley and lettuce. However, in the cases of other plants, so-called *middle* and *acid sensitive* plants (Tanaka and Hayakawa 1974), such as cucumber, carrot, Chinese cabbage, spinach and radish, the pH decline was small. Rice and barley were tolerant to NH_4^+, while radish, spinach and Chinese cabbage were sensitive to NH_4^+ (Moritsugu *et al.* 1983). Eventually, there may be a close relationship between H^+ and NH_4^+ sensitivities. In barley and cucumber plants, pH decreased to the same level that causes growth stunting in a long-term culture (Moritsugu and Kawasaki 1982). However, the effect of temporal exposure to low pH within 24 hours does not seem to be serious compared to the case of a long exposure. Radish, spinach and Chinese cabbage, that is, NH_4^+-sensitive plants (Moritsugu *et al.* 1983) appeared to be normal even after a 24-hour exposure to the single salt solution of 2.5 mmol/l NH_4NO_3. This normality is reasonable because the plants grew vigorously in the complete nutrient solution containing 2.5 mmol/l NH_4NO_3. In spite of the abnormal root environment caused by the lack of many nutrients in the single salt solution containing 2.5 mmol/l NH_4NO_3, the pH declined rapidly during the 24 hours in the single salt solution and sometimes exceeded the degree of the pH decline in the complete nutrient solution containing NH_4NO_3 as shown in Table 2. This active condition of the test plants was the main reason to select a short term absorption experiment in this work.

The rates of NH_4^+ and NO_3^- absorption were generally rapid during the initial stage and gentle during a later period (Figs. 1 to 3). This may be ascribed to our experimental time schedule that started in the active daytime and ended after the inactive night. It was also related to the lack of nutrients and to the effect of consumption of the absorption solutions including their pH drop. The absorption of NH_4^+ and NO_3^- in the present experiments showed a tendency similar to the data from other workers with a single salt solution of NH_4NO_3 (Jackson *et al.* 1972), and with a complete nutrient solution containing NH_4NO_3 (Muhammad and Kumazawa 1974, Tadano and Tanaka 1976). However in the present experiment using both absorption solutions, NH_4^+ absorption was faster in the single salt solution, while NO_3^- absorption was predominant in the complete nutrient solution except for rice, barley and lettuce (Figs. 1 to 3).

From the present experiments, the test plants were classified into the following three groups by their nitrogen absorption characteristics. Rice, barley and lettuce belong to group 1. These plants could absorb NH_4^+ rapidly in both absorption solutions (Fig. 1). Cucumber and carrot belong to group 2. These plants can absorb NH_4^+ rapidly from the single salt solution of NH_4NO_3, whereas they can absorb NO_3^- rapidly in the complete nutrient solution containing NH_4NO_3 (Fig. 2). The Chinese cabbage, spinach and radish belong to group 3 and which can absorb NO_3^- rapidly from the complete nutrient solution, and the difference between the rates of NH_4^+ and NO_3^- absorption increased with time; while the rates of NH_4^+ and NO_3^- absorption were nearly the same in the single salt solution of NH_4NO_3 (Fig. 3).

The group 1 plants always prefer NH_4^+ to NO_3^-, and these plants seem to be tolerant to a low pH and NH_4^+, because of the marked pH decline during the absorption experiments (Table 2). However, in the case of lettuce, the decreasing slope for NH_4^+ and NO_3^- in the single salt solution became gentle during the initial several hours, while NH_4^+ was absorbed rapidly in the complete nutrient solution (Fig. 1). Therefore, lettuce seems to be more sensitive to a temporary lack of some nutrients than to NH_4^+ or H^+ toxicity, because the pH decline that seemed to cause a general activity of plants in the single salt solution was clearly less than that in the complete nutrient solution. This trend differed from the cases of rice and barley in the group 1 (Table 2).

The group 2 plants showed the reversed tendency of nitrogen absorption between the single salt solution of NH_4NO_3 and the complete nutrient solution containing NH_4NO_3. This tendency was stronger in carrot than in cucumber (Fig. 2). In the case of cucumber, the alternation of nitrogen preference seems to occur within the initial several hours, because the later decreasing slopes appear to be almost parallel between NH_4^+ and NO_3^- decreases (Fig. 2). This may be caused by the change of the relative affinity of roots to NH_4^+ or NO_3^- in each root environment. Even though the group 2 plants prefer NH_4^+ to NO_3^-, these plants have other preferable cations in the complete nutrient solution, which can compete with NH_4^+ in the process of absorption. The group 2 plants seemed to prefer NO_3^- markedly to other anions. At any rate, the alteration of NH_4^+ and NO_3^- absorption characteristics was caused by a rapid absorption of NO_3^- compared to many other nutrients, that was noticed in the complete nutrient solution containing 2.5 mmol/l of NH_4NO_3.

The group 3 plants absorb NH_4^+ and NO_3^- with almost equal rates in the single salt solution of NH_4NO_3, while these plants absorb NO_3^- more rapidly than NH_4^+ in the complete nutrient solution containing NH_4NO_3. This is due to a relative preference of NO_3^- to NH_4^+ of those plants under the presence of many other nutrients, whereas their affinity to NH_4^+ or NO_3^- is similar in the single salt solution of NH_4NO_3. These plants seem to have more preferable nutrient cations rather than NH_4^+ in the complete nutrient solution, and these cations may disturb the absorption of NH_4^+ competitively. Therefore, the third group plants seem to have similar affinities for nutrient ions to the second group plants except for their apparent balanced affinity to NH_4^+ and NO_3^- in the single salt solution.

Table 3. Rates of cation absorption and anion absorption in rice, cucumber and Chinese cabbage plants

		Ammonium and nitrate			N/A Ratio[1]	Other nutrient ions				Rate[2]	N/P Ratio[3]
Rice		0~8h	8~24h	0~24h			0~8h	8~24h	0~24h		
(S)	NH_4^+	10.15	4.77	6.57	0.56	K^+	10.74	3.30	5.78		
	NO_3^-	3.92	3.54	3.67		Ca^{2+}	2.44	0.72	1.29		
(C)	NH_4^+	9.78	3.79	5.79	0.79	Mg^{2+}	1.87	0.69	1.08	2.37	
	NO_3^-	7.06	3.35	4.58		$H_2PO_4^-$	2.55	1.51	1.86		2.46
Cucumber		0~5h	5~24h	0~24h			0~5h	5~24h	0~24h		
(S)	NH_4^+	28.00	9.28	13.18	0.89	K^+	13.94	6.06	7.71		
	NO_3^-	22.16	9.06	11.79		Ca^{2+}	17.57	3.61	6.52		
(C)	NH_4^+	21.48	8.26	11.02	1.11	Mg^{2+}	6.91	1.89	2.94	9.46	
	NO_3^-	27.36	8.27	12.25		$H_2PO_4^-$	4.23	1.81	2.31		5.30
Chinese cabbage		0~8h	8~24h	0~24h			0~8h	8~24h	0~24h		
(S)	NH_4^+	27.72	10.88	14.39	0.99	K^+	15.79	6.67	8.57		
	NO_3^-	28.76	10.38	14.21		Ca^{2+}	15.76	6.93	8.77		
(C)	NH_4^+	16.99	6.03	8.31	2.34	Mg^{2+}	5.09	1.88	2.55	11.3	
	NO_3^-	32.37	16.06	19.46		$H_2PO_4^-$	2.65	0.77	1.16		16.8

Unit of values in this table is μeq/g(dry matter)/h except ratios, and dry matter is total dry matter of tops and roots.

(S) : single salt solution of 2.5 mmol/l NH_4NO_3

(C) : complete nutrient solution containing 2.5 mmol/l of NH_4NO_3 as a source of nitrogen

1): Ratio of NO_3^- absorption rate to NH_4^+ absorption rate for 24 h (Relative NO_3^- absorption to NH_4^+)

2): Sum of divalent cation (Ca^{2+} + Mg^{2+}) absorption rates for 24 h (Total divalent cation absorption rate)

3): Ratio of NO_3^- absorption rate to $H_2PO_4^-$ absorption rate for 24 h (Relative NO_3^- absorption to $H_2PO_4^-$)

For the further clarification of the cause of the above different reaction of plants, rice (group 1), cucumber (group 2) and Chinese cabbage (group 3) were selected as the representatives of each plant group. The concentrations of K^+, Ca^{2+}, Mg^{2+} and $H_2PO_4^-$ in the respective absorption solutions were determined a few times in addition to NH_4^+ and NO_3^- concentrations during the 24-hour absorption experiments. To compare the absorption characteristics directly between NH_4^+ and NO_3^- among the above plants, the absorption rates (μeq/g [dry matter]/h) of respective ions and the rates of total absorption of divalent cations (Ca^{2+} + Mg^{2+}) were calculated. Then, the ratios of the NO_3^- absorption rate to the absorption rates of the other nutrients, i.e., the relative absorption of NO_3^- to NH_4^+ and that of NO_3^- to $H_2PO_4^-$ for 24 hours were computed as shown in Table 3.

The total divalent cation absorption rates, the relative absorption of NO_3^- to $H_2PO_4^-$ and the relative absorption of NO_3^- to NH_4^+ are arranged with the plant order of rice, cucumber and Chinese cabbage. Although K^+ absorption rates showed the same order, the rate differences between the plants were as small as compared to the cases of divalent cations. Either the alkaline earth cations contained in a complete nutrient solution depress NH_4^+ absorption competitively according to the preference of divalent cations to NH_4^+ in plants, or a specific preference of NO_3^- absorption to $H_2PO_4^-$ by roots rules NO_3^- absorption in plants. Eventually, it can be emphasized that the findings on the preference to divalent cations as well as that to NH_4^+ and NO_3^- contributes to the characterization of nitrogen absorption in plants. Therefore, the predicted cations causing the alternation of NH_4^+ and NO_3^- absorbing tendency between both absorption solutions as indicated before are presumed to be divalent cations, Ca^{2+} and Mg^{2+}. The predicted strong affinity to NO_3^- in the group 3 and 2 plants in the complete nutrient solution proved to be the highest relative absorption ratio of NO_3^- to $H_2PO_4^-$ in Chinese cabbage (group 3) and a higher relative absorption ratio of NO_3^- to $H_2PO_4^-$ in cucumber (group 2) than in rice (group 1).

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数種植物におけるアンモニウムイオン及び硝酸イオンの吸収速度の比較

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硝酸アンモニウム2.5 mMの単塩溶液（以下，硝安単塩溶液）及び2.5 mMの硝酸アンモニウムを窒素源とする完全培地（以下，硝安完全培地）を吸収溶液とし，アンモニア態窒素及び硝酸態窒素について24時間の吸収実験を行った．実験材料はイネ，オオムギ，レタス，キュウリ，ニンジン，ハクサイ，ホウレンソウ，ダイコンであった．

硝安単塩溶液及び硝安完全培地における両形態窒素の吸収特性から，試験植物は次のように分類できた．(1)イネ，オオムギ，レタス：何れの吸収溶液からでも，硝酸態窒素に比較して常にアンモニア態窒素を速やかに吸収する植物群．(2)キュウリ，ニンジン：硝安単塩溶液ではアンモニア態窒素をやや速やかに吸収するが，硝安完全培地ではこの傾向が逆転し，硝酸態窒素の吸収がやや速やかになる植物群．(3)ハクサイ，ホウレンソウ，ダイコン：硝安単塩溶液では両形態の窒素の吸収速度はほゞ等しいが，硝安完全培地では明らかに硝酸態窒素の吸収が速やかになる植物群．

上記の分類は，それぞれの培地におけるアンモニア態窒素の吸収と拮抗する他のイオンの吸収特性，換言すれば，NO_3^-/NH_4^+吸収比，あるいは，Ca^{2+}とMg^{2+}の合計吸収速度，または，植物根の硝酸態窒素に対する相対的な根の親和性，つまり，$NO_3^-/H_2PO_4^-$吸収比によって説明できた．すなわち，第1群は1価陽イオン，特に，アンモニウムイオンに対する根の親和性は大きいが硝酸態窒素に対する根の親和性は小さく，また，耐酸性，耐アンモニア性の大きい植物と考えられ，24時間の吸収時間中の培地pHの低下は著しかった．これに対して，第3群は硝安完全培地中では硝酸態窒素，2価陽イオンに対する根の親和性の大きい植物であり，また，第2群は，アンモニア態及び硝酸態窒素，ならびに，2価陽イオンに対する根の親和性などが第1群と第3群の中間の植物であった．

キーワード：アルカリ土類イオン，アンモニウムイオン，イオンバランス，硝酸イオン，第一リン酸イオン