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# EFFECT OF NITROGEN SOURCE ON GROWTH AND MINERAL UPTAKE IN PLANTS UNDER CONSTANT pH AND CONVENTIONAL CULTURE CONDITIONS*

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Many studies have been made in plant nutrition concerning nitrogen forms. These works have shown that in general most plants grow better on nitrate nitrogen than on ammonium nitrogen, except for a few species of ammonium preferring plants like rice.

In such studies, the plants were often grown by a solution culture. However, the solution culture has the disadvantage that the pH of the ammonium type nutrient solutions falls rapidly and the pH of the nitrate type nutrient solutions rises with the increase in plant size. Consequently, it is very difficult to compare the effect of the two nitrogen sources on the growth or mineral uptake of plants without taking into consideration the effect of pH.

Thus, many methods have been proposed to keep the pH of a nutrient solution constant; the methods adopting 1) thin planting to a large pot[39,46], 2) frequent renewal of the nutrient soution[32,44], 3) frequent pH adjustment of the nutrient solution[3,4,39,43], 4) flowing solution culture[1,6,13,17,27,30,31,42,45,49,59], 5) optimal composition of nutrient solution (*e. g.* optimal ratio of ammonium to nitrate or phosphate concentration for pH stabilization)[53,57], 6) addition of buffer agents to the nutrient solution (*e. g.* Tris buffer)[58], 7) addition of ion exchange resin to the nutrient solution[16,18,47], 8) automatic pH regulation[5,10,20,21,22,24,29,37,38,56].

Such methods except the last one have several disadvantages such as: 1) they require much hard labour for the maintenance of accurate solution pH, 2) the flexibility in the use of the components of nutrient solution is lost, 3) the accurate solution pH can not be maintained especially in the latter stages of vegetable growth.

Automatic regulation systems can be divided into two types; a direct neutralization method[5,10,20,21,22,24,37,38,56], and an electrolysis method through a diaphragm[29]. The diaphragm electrolysis method has the disadvantage of requiring a long response time which causes inaccuracy. On the other hand, the direct neutralization method has the disadvantage that the

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salt concentration is increased by the neutralization. However, this method is convenient in practice, when the effect of the neutralizer can be evaluated as small.

As reported previously[37,38], we designed an apparatus for automatic pH regulation of the nutrient solution suitable for the experiments on plant nutrition. In our culture method, cucumber plants, which are characterized by a remarkable preference to nitrate nitrogen[33,34,44], grew rapidly in the ammonium type nutrient solution, when the pH was kept constant at 5.0. In addition, the appearance of ammonium-fed cucumber plants was similar to that of nitrate-fed plants.

Accordingly, it was necessary to carry out further experiments on nitrogen sources by the constant pH culture method employing ammonium or nitrate ion as the sole source of nitrogen. Prior to these experiments, the optimal pH for plant growth was checked by the constant pH culture with the ammonium type and the nitrate type nutrient solutions[40,41], because it has been generally said that the optimal pH is not the same in nutrient solutions with different nitrogen sources[13,28,45,53,55]. Our previous results demonstrated that the many species of plants have similar optimal pH (about 5.5) in the constant pH solution culture[40,41].

In the present paper, the plant growth and mineral uptake under optimal pH condition were examined using both nitrogen sources. Plants were grown by the constant pH culture with three types of nutrient solutions containing either ammonium alone, nitrate alone, or ammonium nitrate as a nitrogen source. The conventional solution culture was also examined to compare our results with those obtained by others[9,17,25,28,44,45,52].

## MATERIALS AND METHODS

Thirteen test plants were used: rice (*Oryza sativa* L., subsp. *japonica*; cv. Akebono), barley (*Hordeum vulgare* L.; cv. Akashinriki), corn (*Zea mays* L.; cv. Nagano 1), sorghum (*Sorghum vulgare* Pers.; cv. Dual), bean (*Phaseolus vulgaris* L.; cv. Masterpiece), cucumber (*Cucumis sativus* L.; cv. Chihai), tomato (*Lycopersicon esculentum* Mill.; cv. Beiju), lettuce (*Lactuca sativa* L.; cv. New York 515), cabbage (*Brassica oleracea* L.; cv. Natsu-maki nigatsu-dori), chinese cabbage (*Brassica pekinensis* Rupr.; cv. Haru-maki goku-wase), spinach (*Spinacia oleracea* L.; cv. Nippon), carrot (*Daucus carota* L.; cv. Toki-nashi gosun), and radish (*Raphanus sativus* L.; cv. Kouhaku hatsuka and Mino-wase).

The constant pH and the conventional culture methods were used. The constant pH culture at 5.5 was carried out using the apparatus for the constant pH culture, consisting of four pots (3.5 $\ell$ capacity) attached to a reservoir (containing 17.5 $\ell$ of nutrient solution) and pH regulation mechanism. The conventional culture was performed using a/5000 cul-

TABLE 1. Season, duration and temperature of the culture experiments

| Plants | Days*1 in nursery | Experimental period: Initial and final days | Experimental period: Duration (days) | Mean temperature at 9:00 (°C): Room | Solution: Const. | Solution: Conv. |
|---|---|---|---|---|---|---|
| Rice | 15 | Apr. 30 – Jun. 8 | 39 | 26 | 25 | 21 |
| Barley*2 | 13 | Apr. 12 – May 13 | 31 | 23 | 22 | 18 |
| Corn*3 | 7 | Jun. 13 – Jul. 3 | 20 | 33*6 | — | — |
| Sorghum*5 | 10 | Jul. 10 – Aug. 1 | 22 | 35*6 | — | — |
| Bean*3 | 7 | Jun. 13 – Jul. 3 | 20 | 33*6 | — | — |
| Cucumber*5 | 13 | Apr. 12 – May 6 | 24 | 23 | 22 | 18 |
| Tomato*2 | 13 | Apr. 12 – May 6 | 24 | 23 | 22 | 18 |
| Lettuce*5 | 14 | May 14 – Jun. 5 | 22 | 29 | 27 | 23 |
| Cabbage*5 | 19 | May 14 – Jun. 13 | 30 | 28 | 26 | 22 |
| Chinese cabbage*4 | 9 | May 8 – May 31 | 23 | 26 | 25 | 23 |
| Spinach*5 | 11 | Oct. 29 – Dec. 13 | 45 | 20 | 19 | 15 |
| Carrot*4 | 9 | May 8 – Jun. 10 | 33 | 27 | 25 | 23 |
| Radish | 7 | Jun. 4 – Jun. 30 | 26 | 28 | 26 | 24 |

*1 Days from seeding to transplanting.

*2~4 The same number shows co-planting in the same apparatus for the constant pH culture.

*5 In the constant pH culture, those plants were co-planted with another plant species in the same apparatus. But, the data of other plants were included only in TABLE 3.

*6 Those temperatures were measured by a recording thermometer which had a bimetal sensor.

ture pots (3.5 ℓ capacity). Accordingly, the relative volume of nutrient solution per plant in the constant pH culture was 2.25 times as large as that in the conventional culture. While, in the conventional culture, the solution pH was adjusted to 5.5 every other day.

Culture periods and temperature conditions are given in Table 1. Plants were co-planted in most of the constant pH culture experiments. In such cases, two species planted in separate pots were put in one apparatus. Room temperature was usually measured by a recording thermometer at one meter height with a thermister sensor. In some cases, the temperature was measured by a recording thermometer which had a bimetal sensor, but the bimetal temperatures were 3 to 4°C higher than the temperatures measured by the thermister sensor. Solution temperature was measured by a thermometer with the thermister sensor dipped into the nutrient solution, and continuously recorded.

Table 2 shows the composition of the ammonium type, the nitrate type, and the ammonium nitrate type nutrient solutions used. Iron

TABLE 2. Composition of nutrient solutions

| | | | | | |
|---|---|---|---|---|---|
| N. P. K composition | | | | | |
| 1. Ammonium type | | | 2. Nitrate type | | |
| [$NH_4$-N 5 mM] | | | [$NO_3$-N 5 mM] | | |
| $(NH_4)_2SO_4$ | 2.5 mM | | $KNO_3$ | 4.0 mM | |
| $KH_2PO_4$ | 1.0 | | $NaNO_3$ | 1.0 | |
| $K_2SO_4$ | 1.5 | | $NaH_2PO_4$ | 1.0 | |
| 3. Ammonium nitrate type | | | | | |
| [$NH_4$-N 2.5 mM, $NO_3$-N 2.5 mM] | | | | | |
| $NH_4NO_3$ | 2.5 mM | | | | |
| $KH_2PO_4$ | 1.0 | | | | |
| $K_2SO_4$ | 1.5 | | | | |
| Common composition | | | | | |
| $CaCl_2$ 2.0 mM | | $MgSO_4$ 1.0 mM | | $SiO_2$ 2.0 mM* | |
| Fe(Citrate) | 1.0 ppm | | Zn($ZnSO_4$) | 0.05 ppm | |
| B($H_3BO_3$) | 0.5 | | Cu($CuSO_4$) | 0.02 | |
| Mn($MnCl_2$) | 0.5 | | Mo($Na_2MoO_4$) | 0.01 | |

* Silica was added when only rice was planted.

(1 ppm) was added every other day as Fe-citrate, before every pH adjustment in case of the conventional solution culture. Nutrient solutions were aerated continuously and renewed once a week. The pots and reservoirs were thoroughly washed before every renewal.

Two to four pots were used for a treatment of each experiment. In many species of plants, such experiments were repeated two to four times as indicated in Table 3. Planting density was six plants per pot for rice and barley, or two plants per pot for the other plants as shown in Plate 1.

After dry ashing, contents of potassium, calcium, magnesium, manganese and zinc were determined by atomic absorption spectrophotometry. Phosphorus was analysed by the molybdovanadophosphate method. Total nitrogen was determined by the Kjeldahl method. Nitrate-fed plants were decomposed by the sulfuric-salicylic acid digestion procedure.

Details of the apparatus for the constant pH culture or methods of culture experiments and mineral determination were as described previously[37,38,41].

## RESULTS

### 1. *Effect of the Nitrogen Source on Plant Growth under Constant pH Condition*

Plants were grown by the constant pH and the conventional cultures using an ammonium type, ammonium nitrate type, or nitrate type nu-

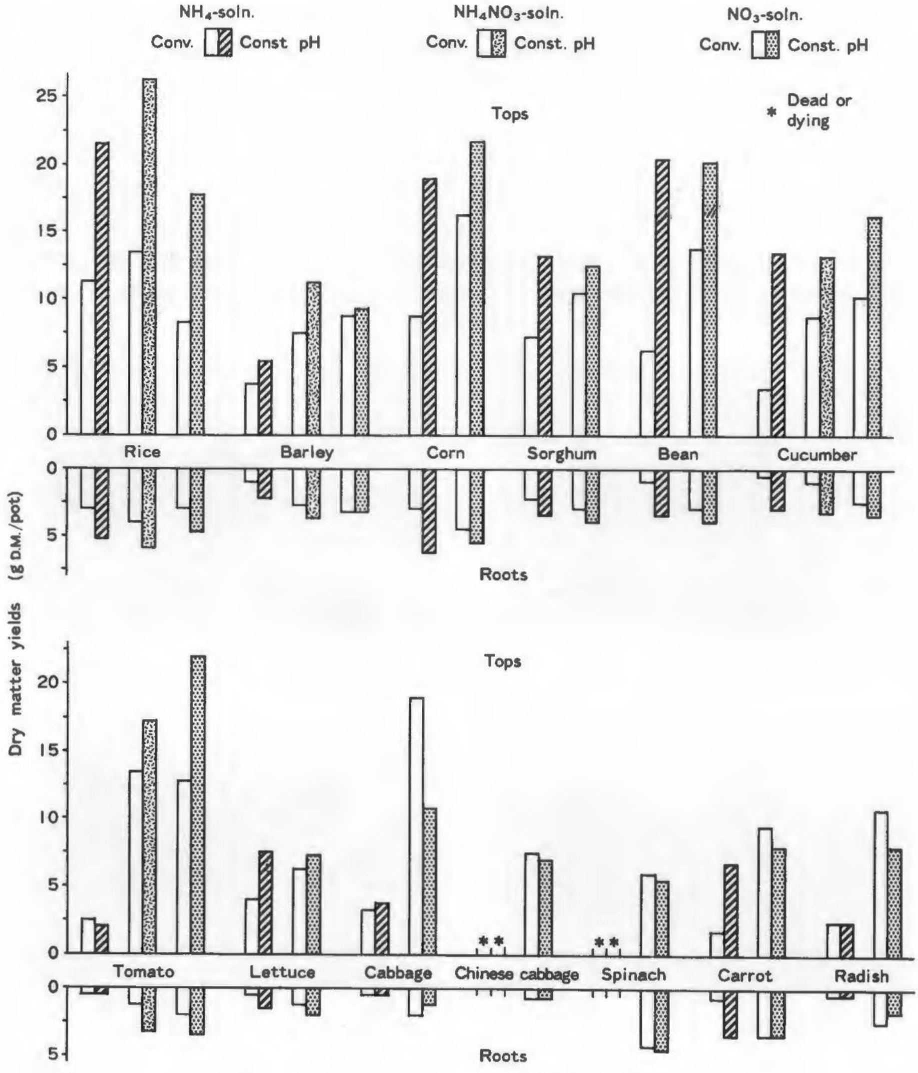
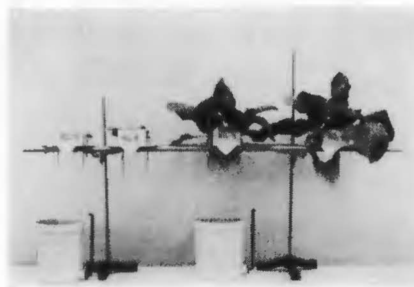



FIG. 1. Effect of nitrogen source on plant growth.

trient solution under the conditions given in Table 1. Fig. 1 shows the dry matter yields of all the plants cultured in this experiment. Plate 1 shows the appearance of the plants, just before they were harvested. Table 3 shows the relative plant growth in the ammonium type and the ammonium nitrate type nutrient solutions as compared with the plant growth in the nitrate type nutrient solution. The relative growth was expressed as percentages of total dry matter yields of tops and roots in ammonium-containing nutrient solutions to the corresponding total dry matter yields in the nitrate type nutrient solution.

With the conventional culture, the growth of the plants, except that of rice, was stunted in the ammonium type nutrient solution as had been generally indicated[9,17,25,28,44,45,52]. On the other hand, with the constant pH culture, growth of corn, sorghum, bean, cucumber, lettuce and carrot in the ammonium type nutrient solution was actually accelerated to the growth level of the plants in the nitrate type nutrient solution. In Fig. 1, the growth acceleration of ammonium-fed barley plants in the constant pH culture was slight, while the barley growth in this condition was hastened considerably in the other culture exper-

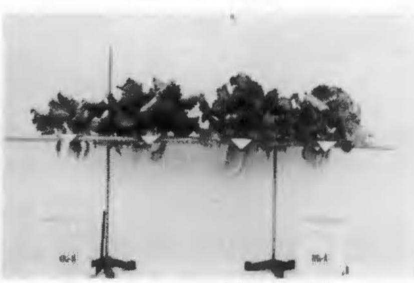
(1) (2) (3) (4)
A. Rice (cv. Akebono)



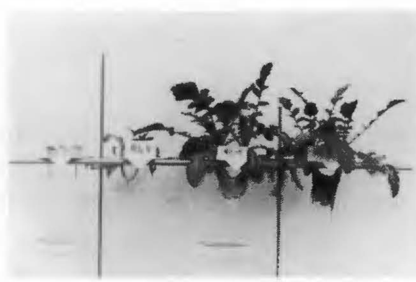
(1) (2) (4) (3)
B. Chinese cabbage (cv. Haru-maki goku-wase)

(1) (2) (3) (4)
C. Tomato (cv. Beiju)

(1) (2) (4) (3)
D. Carrot (cv. Toki-nashi gosun)



(1) (2) (3) (4)
E. Lettuce (cv. New York 515)



(1) (2) (4) (3)
F. Radish (cv. Mino-wase)

PLATE 1. Effect of nitrogen source and culture method on growth of plants.

(1) Conventional culture, (2) Constant pH culture } $NH_4$; (3) Constant pH culture, (4) Conventional culture } $NO_3$

TABLE 3. Relative plant growth in ammonium type and ammonium nitrate type nutrient solution as compared with plant growth in nitrate type nutrient solution (%)

| Plants | Culture method | Relative growth in $NH_4$-soln. Min. | Av. | Max. | Repeat | Month*1 | Relative growth in $NH_4NO_3$-soln. Min. | Av. | Max. | Repeat | Month*1 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Rice | Conv. | 65 | (110) | 125*2 | 4 | May<br>Jul., Oct. | 95 | (126) | 156*2 | 2 | May |
| | Const. | 103 | (113) | 127 | | Oct. | 143*2 | (156) | 169 | | Jul. |
| Barley | Conv. | 40*2 | ( 50) | 67 | 3 | Jan.<br>Apr. | 62 | ( 75) | 87*2 | 2 | Apr. |
| | Const. | 61*2 | ( 80) | 99 | | Apr. | 92 | (105) | 121*2 | | Apr. |
| Corn | Conv. | 55 | ( 66) | 87 | 3 | Jun.<br>Aug. | | 144 | | 1 | Aug. |
| | Const. | 80 | ( 85) | 92*2 | | Dec. | | 87 | | | |
| Bean | Conv. | 38 | ( 41) | 43*2 | 2 | Jun. | | 78 | | 1 | Jun. |
| | Const. | 67 | ( 83) | 99*2 | | Jun. | | 121 | | | |
| Cucumber | Conv. | 28 | ( 35) | 44 | 4 | Apr.<br>May, Jul. | 65 | ( 76) | 81 | 3 | Apr.<br>May |
| | Const. | 65 | ( 87) | 112 | | Sep. | 84*2 | (103) | 126 | | Jul. |
| Tomato | Conv. | 20*2 | ( 25) | 30 | 4 | Jan.<br>Apr., Jul. | 84 | ( 94) | 104*2 | 2 | Apr. |
| | Const. | 2 | ( 18) | 45 | | Oct. | 80*2 | ( 95) | 110 | | Jul. |

*1 expressed as the main month in which plants were grown practically.
*2 calculated from the data shown in FIG. 1. The other values were calculated from the data of experiments excluded from FIG. 1.

iments as in Table 3. However, the growth of tomato, cabbage, chinese cabbage, spinach, and radish, fed with ammonium, was not hastened even by the constant pH culture.

The growth of rice plants in the ammonium nitrate type nutrient solution was rapid as compared with the growth in the other two types of nutrient solutions. Growth of barley, cucumber and tomato plants in the ammonium nitrate type nutrient solution was similar to that in the nitrate type nutrient solution, especially with the constant pH culture (Fig. 1 and Table 3).

### 2. *Effect of the Nitrogen Source on Mineral Uptake under Constant pH Condition*

As described previously[40,41], mineral uptake was evaluated by its contents in plants. The mineral contents of the plants cultured in the ammonium nitrate type nutrient solution are not presented here, because most of the mineral contents were intermediate between the other two types of nutrient solutions. Figs. 2 to 8 show mineral contents of the plants grown by the culture experiments in Table 1 and Fig. 1. Some of the mineral contents given by the experiments in Table 3 are not presented here, because they were similar to those shown in Figs. 2 to 8.

Contents of potassium, calcium, magnesium, manganese, and zinc are illustrated in Figs. 2 to 6 successively. The uptake of calcium, magnesium and manganese was severely depressed in the conventional culture with ammonium, as had been reported[9,17,25,52], whereas the suppression of the uptake of those cations in the ammonium type nutrient

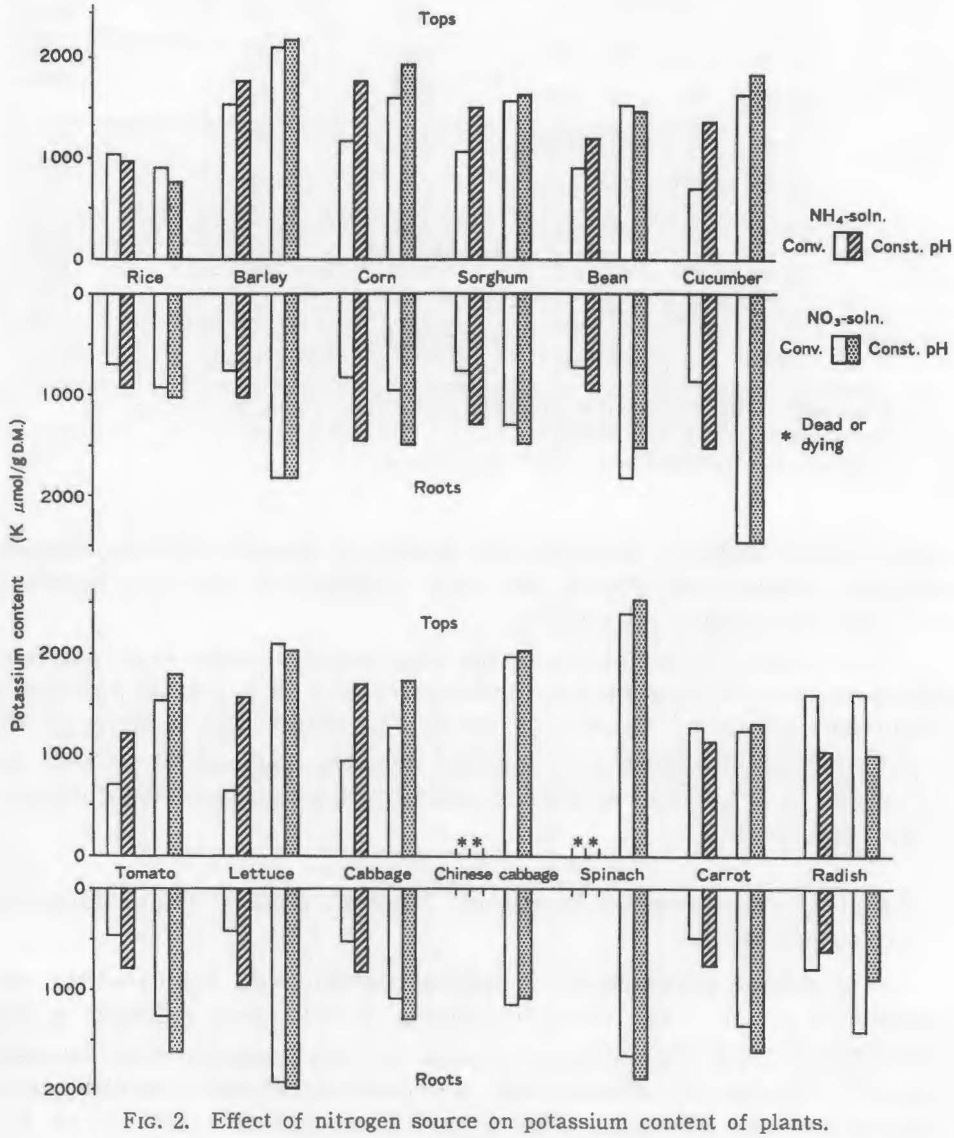



FIG. 2. Effect of nitrogen source on potassium content of plants.

solution was lightened considerably in the constant pH culture.

Calcium and magnesium were contained abundantly in vegetable plants as compared with cereal plants. Especially in spinach plants, the magnesium content was higher than the calcium content, though the reverse was the case for the other plants (Figs. 3 and 4).

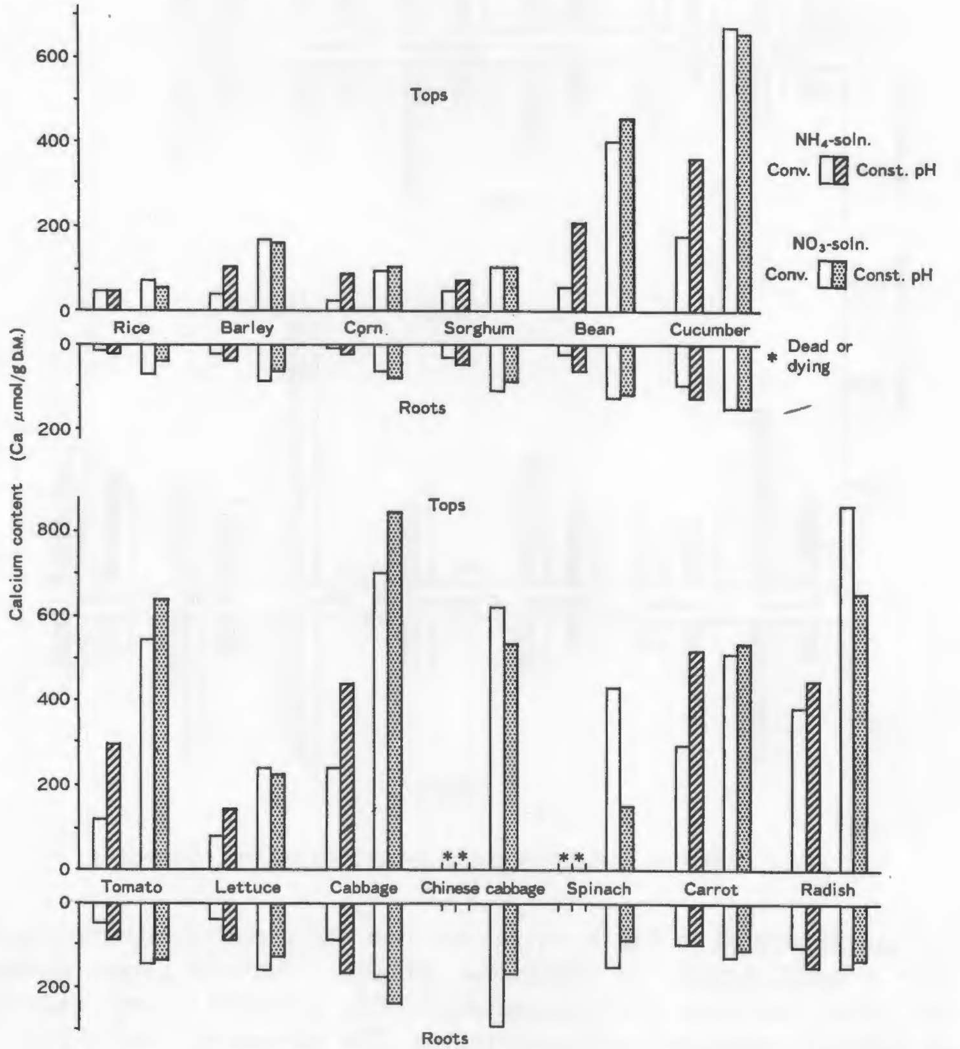



FIG. 3. Effect of nitrogen source on calcium content of plants.

The difference in plant potassium contents between the two types of nutrient solutions was small as compared with that of other cations (Figs. 2 to 4). This difference was minimized further in the constant pH culture compared to the conventional culture.

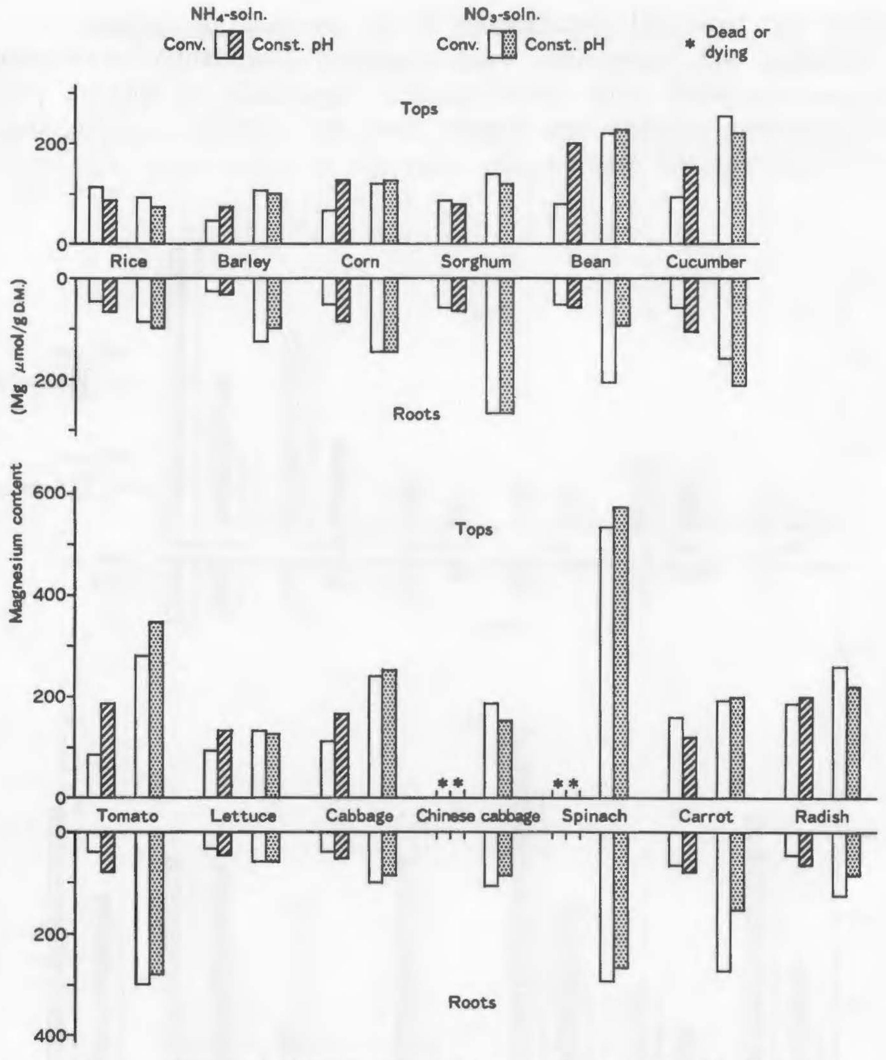



FIG. 4. Effect of nitrogen source on magnesium content of plants.

As illustrated in Fig. 5, except for rice, the cereal plants contained only a small amount of manganese, whereas vegetable plants, except for radish, contained much manganese. Rice contained a large amount of manganese compared to the vegetables. The manganese level of radish was low as was that of barley, corn and sorghum.

Zinc contents were higher in the plants grown by the constant pH culture than by the conventional culture (Fig. 6). Especially the ammonium-fed tomato and cabbage plants grown by the constant pH culture contained a large amount of zinc, compared to that of nitrate-fed plants. With respect to the plants grown by the conventional culture, the nitrate-

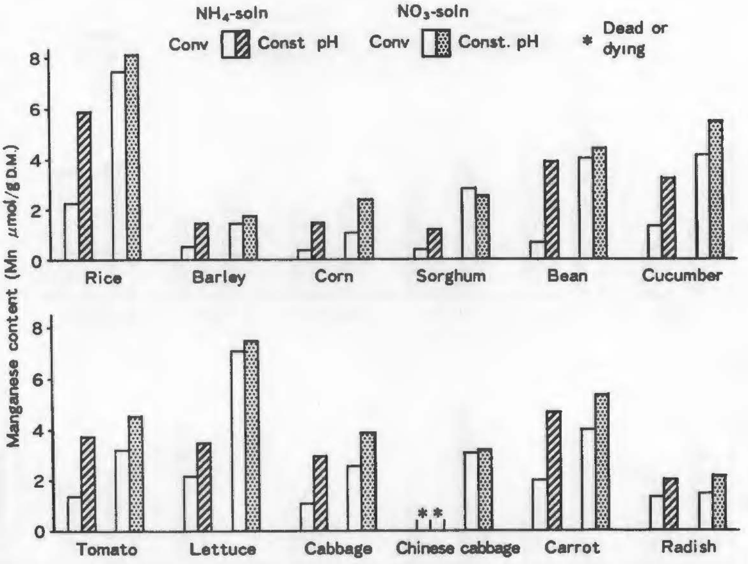



FIG. 5. Effect of nitrogen source on manganese content of plant tops.

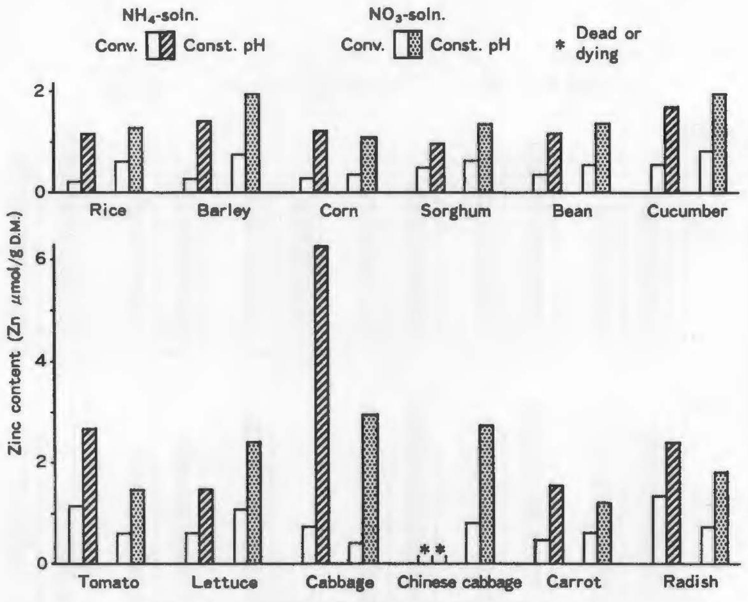



FIG. 6. Effect of nitrogen source on zinc content of plant tops.

fed plants contained generally abundant zinc as compared with that in the ammonium-fed plants.

As shown in Fig. 7, the phosphorus content was higher in the ammonium-fed plants than in the nitrate-fed plants by both culture methods.

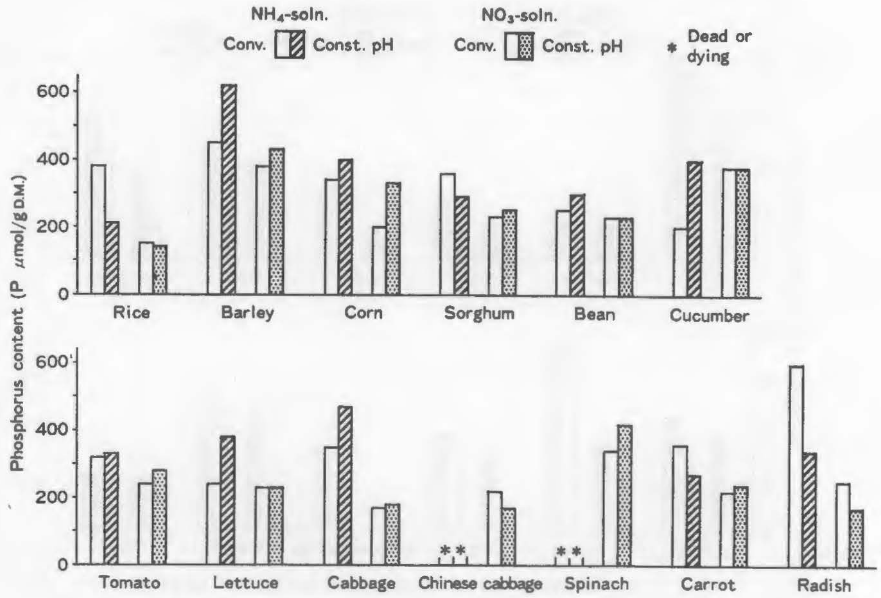



FIG. 7. Effect of nitrogen source on phosphorus content of plant tops.

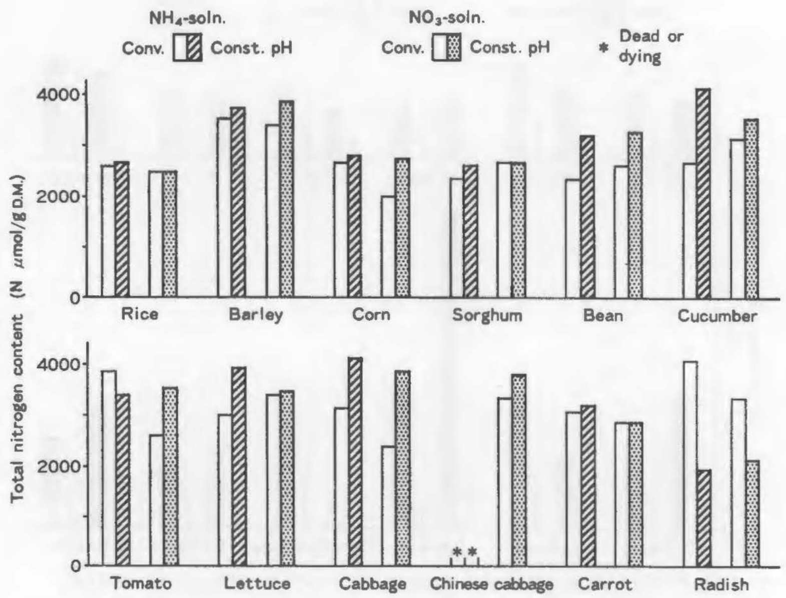



FIG. 8. Effect of nitrogen source on total nitrogen content of plant tops.

Fig. 8 shows the total nitrogen contents of plant tops. The nitrogen content of plants was not so different in both culture methods or in thirteen species tested.

## DISCUSSION

The nitrification of ammonium ions in the nutrient solution is liable to produce confusing results in the culture experiments concerning the nitrogen forms of the nutrient solution. To overcome this difficulty, pots and the reservoirs of nutrient solution were thoroughly washed every week in the present studies. In addition, the pH of the nutrient solution was maintained at 5.5. At the pH of 6.0 or more, the nitrification in the nutrient solution rapidly increased[19].

Many plants were examined by co-planting in the same apparatus for the constant pH culture, because the difference in resistance to inadequate solution pH between co-existing species were negligible in this culture method. However, rice plants were examined with mono-planting, because the nutrient solution for this plant was specific (Table 2). Plants were harvested before their nutrition was disturbed by the severe self shadowing. And, in order to prevent an abnormal decrease of minerals in roots, plants were harvested within a short term (two days) after the last renewal of the nutrient solution[40]. Moreover, to maintain the accuracy of culture experiments, plants were grown repeatedly as can be seen in Table 3.

Thus, growth or mineral uptake in plants seems not to be limitted by special culture conditions such as planting density, co-planting, duration of culture experiment or the volume of nutrient solution in the present experiments. This can be confirmed by the following facts. 1) Both big (corn, bean and cucumber) and small (lettuce and carrot) plants fed ammonium by the constant pH culture showed marked growth (Fig. 2); this means that the available space and the amount of nutrients for individual plants may be enough even for the big plants. 2) In the case of nitrate-fed plants that require more nutrients to grow rapidly, the difference in macronutrient content between the plants grown by the constant pH and those by the conventional culture methods was relatively small (Figs. 2 to 4, 7 and 8); this means that mineral uptake in plants may be independent of culture methods or conditions in the present experiments, even when plants grew rapidly.

As shown in Plate 1, Fig. 1 and Table 3, the growth of the plants cultured by the conventional method differed greatly from that of the plants cultured by the constant pH method. Culture conditions of those methods are discussed to explain such a difference.

As described above, neither the volume of nutrient solution nor the amount of nutrients in both culture methods was a limitting factor of plant growth. Solution pH in the constant pH culture was regulated within the range of $\pm 0.1$[37,38,40,41], whereas the pH in the conventional culture changed considerably as shown in Fig. 9; pH values changed

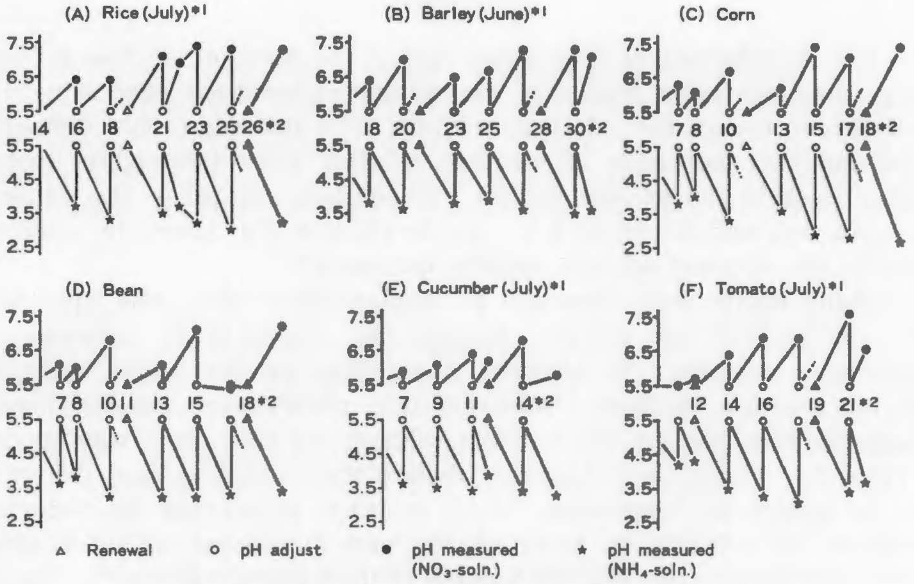



FIG. 9. pH change of nutrient solution in conventional culture.

*1 Examples of culture experiments excluded from FIG. 1. Parentheses indicate main month in which the plants were cultured.

*2 Days after transplanting.

from 7.5 to 2.6 within the 2-day culture. As indicated previously[40,41], pH 2.7 is a fatal condition even for rice, highly tolerant to acidity. Solution temperature was 2 to 4°C higher in the constant pH culture than in the conventional culture (Table 1).

From these differences between the two culture methods, the comparison was considered to be made between the plants cultured by the same method. For example, the growth of rice was more rapid in the constant pH culture than in the conventional culture (Plate 1 and Fig. 1). However, the rapid growth of rice plants cultured by the constant pH method might be induced by a high solution temperature as described above. Although the two culture methods caused a difference in growth, rice plants fed with ammonium or with ammonium nitrate grow rapidly as compared with those fed with nitrate alone in either culture method, that is, rice plants prefer ammonium rather than nitrate as indicated in other papers[7,26,28,43,50].

In general, plants are often classified into ammonium preferring type (*e. g.* rice, tea etc.)[23,44,50], and nitrate preferring type (*e. g.* most of vegetable plants)[25]. For example, cucumber has been classified as a typical nitrate-preferring plant[44], and the stunted growth of cucumber in the ammonium type nutrient solution has been attributed to the ammoniacal disorders in metabolic process[33,34,44,51]. In the present investigation, however, cucumber growth was accelerated in the ammonium type nutrient solution by the constant pH culture. Therefore, it is thought that the stunted growth of cucumber plants generally seen in ammonium feeding condition is mainly induced by a pH decrease of nutrient solution rather than the metabolic disorders.

Barley, corn, sorghum, bean, cucumber, lettuce, and carrot showed rapid growth in the ammonium type nutrient solution, when the plants were cultured by the constant pH method. The growth acceleration of the plants in this group in the constant pH culture with ammonium is attributed to the same reason as for cucumber plants (Fig. 1, Plate 1 and Table 3).

On the other hand, in the case of tomato, cabbage, chinese cabbage, spinach, and radish, the growth of the ammonium-fed plants in the constant pH culture was stunted as was that of those grown by the conventional culture (Plate 1, Fig. 1 and Table 3), as indicated by others[9,17,25,28,44,45,52]. This may be attributed to ammonium poisoning.

Thus, a new classification can be proposed here.

1) Plants which are tolerant to ammonium ion and low pH (hydrogen ion): rice.

2) Plants which are tolerant to ammonium ion, but sensitive to low pH: barley, corn, sorghum, bean, cucumber, lettuce, and carrot.

3) Plants which are sensitive to both ammonium ion and low pH: tomato, cabbage, chinese cabbage, spinach, and radish. The high sensitivity to low pH in those plants in group 3 was demonstrated by Tanaka *et al.*[56].

It has been said that the growth of plant roots is accelerated by nitrate[15,35]. However, this is doubtful, because the root growth of the ammonium-fed plants was similar to that of the nitrate-fed plants, when the plant tops grew rapidly in the constant pH culture (Plate 1, Fig. 1 and Table 3). In other words, root growth seems to be the same in both types of nitrogen sources, when ammonium poisoning and difference in solution pH are negligible.

There are two kinds of reports on the plant growth in the ammonium nitrate type nutient solution; 1) the growth is rapid in the ammonium nitrate type nutrient solution as compared with the other two types of nutrient solutions containing nitrate or ammonium as the sole nitrogen source[11,52], and 2) the growth in the ammonium nitrate type nutrient solution is retarded as compared with that in the nitrate type nutrient solution[25,45].

In the present experiments, however, the above two types of growth were found in the ammonium nitrate type nutrient solution with barley, cucumber and tomato plants (Table 3). This may be caused by the variation of the ammonium tolerant capacity in each plant species depending on environmental conditions such as temperature and light[17,36,43,45].

In the conventional culture, the effect of the nitrogen source on the nutrient uptake was similar to those reported by many workers[2,6,8,9,11,12,17,25,30,31,45,48,55,60]. Cation uptake was depressed considerably in the ammonium type nutrient solution, and phosphate uptake was depressed in the nitrate type nutrient solution.

However, in the constant pH culture, cation contents of ammonium-fed plants increased remarkably. This may be attributed to the low and constant concentration of hydrogen ion in this culture method. Therefore, the difference of cation contents in this method between the plants cultured in the ammonium type and the nitrate type nutrient solutions decreased as compared with that in the conventional culture (Figs. 2 to 6). This tendency was seen commonly between the two culture methods, even when the growth of ammonium-fed plants was not accelerated in the constant pH culture. This means that the suppressed growth of ammonium-fed plants is not directly induced by the decrease of cation uptake.

Cox *et al.*[12] showed that zinc uptake was severely depressed by ammonium ion. However, in the present investigation, zinc content was not always lower in the ammonium-fed plants; it differed with species. Especially in ammonium sensitive plants such as tomato and cabbage, zinc uptake was likely accerelated in the ammonium type nutrient solution. Moreover, zinc uptake was stimulated by the constant pH culture as compared with the conventional culture. This can be explained partially by the increased zinc uptake at a higher pH range[40,41], although the difference in culture conditions such as solution temperatures in the two culture methods may not be neglected.

It is said that the ammonium-fed plants contained more nitrogen than the nitrate-fed plants[25,30,36,52,55]. In the present investigation, total nitrogen contents were similar in both nutrient solutions with different nitrogen sources, especially in the constant pH culture. This is similar to the results reported by Frith *et al.*[14] in which the uptake of nitrogen was found to be similar when ammonium or nitrate alone was given as a nitrogen source.

## SUMMARY

Thirteen plant species were grown by the constant pH and the conventional culture methods, and the effect of the nitrogen source on the growth and mineral uptake in plants were examined. The results were as follows.

1) From the experiments on the effect of the nitrogen source on plant growth, thirteen plants were classified into the following three groups. a) The plants characterized by high resistance to both ammonium and hydrogen ions: rice; it grew rapidly in the ammonium type nutrient solution under both culture conditions. b) The plants characterized by high resistance to ammonium ion and low resistance to hydrogen ion: barley, corn, sorghum, bean, cucumber, lettuce, and carrot; they grew rapidly by the constant pH culture even in the ammonium feeding condition. c) The plants characterized by a low resistance to ammonium and hydrogen ions: tomato, cabbage, chinese cabbage, spinach, and radish; they were stunted in growth in the ammonium type nutrient solution even by the constant pH culture.

2) Ammonium ion was apt to depress cation uptake, and nitrate ion to depress phosphate uptake, even in the constant pH culture. However, the difference in mineral contents between the ammonium-fed and the nitrate-fed plants was reduced in the constant pH culture as compared with that in the conventional culture.

3) It was considered that the decrease of cation uptake did not directly induce the ammonium poisoning in plants, because the growth of ammonium-fed plants, classified in group (c) mentioned above, was not accelerated even when the cation contents of ammonium-fed plants were increased considerably by the constant pH culture.

4) Manganese uptake was slightly inhibited by ammonium ion in the constsant pH culture. Zinc uptake was not inhibited so much, and sometimes even stimulated.

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