CHUGOKUGAKUEN J. 2003
Vol. 2, pp. 13-18

CHUGOKUGAKUEN
Journal

http://www.cjc.ac.jp/

Original Article

Effects of Root Environments on Mineral Composition of Vegetable Foods

Masumi Moritsugu*, Michihiro Itano, Mikiko Nose, Yohko Kitajima and Yoshie Manabe

Department of Human Nutrition, Faculty of Contemporary Life Sciences, Chugokugakuen University, Okayama 701-0197, Japan

Effects of root environments on absorption of mineral nutrients in plants are examined using excised roots of barley (*Hordeum vulgare* L.). Radioisotopes and multi-compartment transport boxes [see method column] were used to understand separately absorption and translocation in cases of several ions.

Effects of hydrogen ions (pH) and calcium ions (Ca^{2+}) have been studied as important factors of root environments. At pH 3, substantial ion absorption has been lost except in the case of iron. Iron absorption looks rather like adsorption, because negligible radioactive iron can be found in the outer sections of excised roots examined. At pH 3.0 where a quick adsorption or absorption of iron is found, the hydrogen ion concentration is equivalent to 1.0 mM. Even though this low pH level is fatal to plants, similar severe condition can be seen in a solution culture experiment, after the renewal of complete nutrient solution containing a few mM of ammonium, whenever ammonium-tolerant plants have grown up sufficiently.

Calcium disturbed absorption of other ions as like a commonly accepted theory in the field of plant nutrition. Calcium interruption is more severe to sodium, monovalent cation, than to iron and manganese, polyvalent cations. However there is exception that an available fraction exuded into the terminal compartment through xylem is rather stable between non- and 0.5 mM calcium levels. Besides the difference of carried fractions between the non- and the low calcium treatment is not clear in the roots apart from the radio-activated tip section. The calcium effect to reduce the acid injury can be observed by its decreasing tendency in the leak of sodium or manganese during its translocation at pH 3.5.

Key Words: Food mineral, Mineral absorption, Root environments

Introduction

Industrial pollution is a world wide problem at present. Large areas of forests are being lost due to acid rain caused by exhaust emission from automobiles and from factories. In addition, the popularity of the organic non-pesticide treated food is increasing. However, organic farming which uses neither chemical fertilizers nor

*Corresponding author.
Masumi Moritsugu, PhD.
Department of Human Nutrition, Faculty of Contemporary Life Science, Chugokugakuen University, 83, Niwase, Okayama 701-0197, Japan
Tel. & FAX; +81 86 293 0247

pesticides can not support the earth's population. Moreover, the present materials used to make organic compost are usually prepared from side products of livestock farming where considerable amounts of chemical fertilizers are used to get livestock feed.

An independent of other organisms in respect of organic nutrition, able to fix carbon dioxide by photosynthesis to form carbohydrates is essential to prepare our daily food. When a perfect autotrophic life system including nitrogen fixation is requested, it can be found only in a limited number of species, e.g., a combination of leguminous plants with rhizobia and some unicellular living organisms like blue green algae, sulfur bacteria and so on. To obtain sufficient food bat reasonable costs, we will permit the use of a proper quantity of chemical fertilizers or pesticides.

Absorption of mineral nutrients in plants is highly influenced by the condition of the root environment such as temperature, oxygen saturation and composition of the surrounding soil solution. This has been an area of general agreement in plant nutrition. For example, cation absorption is depressed by the presence of the other cations [4], according to the order of importance in fertilizer elements except for hydrogen ions. Hydrogen ions are the most poisonous to plant roots, therefore, potassium absorption is severely restricted by more than 0.1 mM of hydrogen ion level, i.e. lower than pH 4.0 [3, 5].

Ammonium, potassium, nitrate, dihydrogenphosphate, chloride and sodium are quickly absorbed by plant roots. Calcium, magnesium and sulfate are absorbed at the next rank velocity. The absorption speed of micro-nutrients, such as iron, manganese, zinc, etc. which are not abundant in soil solution, is slow to compared to previously mentioned macronutrients. Vegetables are not rich in minerals because the mineral content in plants is strongly affected by their root environment and soil solution, which usually includes only a small amount of minerals. Since the industrial revolution the rapid increase of world population has been supported by the increase of food production, due to development of the nitrogen fixation industry, and that of the technology of fertilizer application.

Organic agriculture or organic food is fashionable in today's world, however, livestock fed by pure organic foods or vegetable foods which are cultured by only organic manure are not really organic. Whenever enough amounts of leguminous plants can be prepared to make a sufficient amount of manure, organic agriculture shall be realized.

Even though acidity levels of pH 3.0 are fatal to plants, such low pH conditions are sometimes found. For example, immediately after the renewal of the nutrient solution that contains a few mM of ammonium ion. On the contrary, an increase in pH occurs whenever a nutrient solution containing nitrate only is used as a nitrogen source. This pH increase, namely the decrease of hydrogen ions or the increase of hydroxyl ions, is not any more severe than the pH decrease accompanied by the ammonium absorption. Therefore, a considerable pH decrease was seen when ammonium nitrate was given to ammonium tolerant plants as the nitrogen source in a nutrient solution.

A similar condition should be present in the soil solution: however, the problem in soil would not be as serious, because the plant roots could be kept active outside of risky soil areas, acidified, alkalized, or salt-accumulated. In other words, soil is originally a heterogeneous aggregation. Therefore, fertilizer is given by the applicator, if the rate and time of application are somewhat unreasonable: it is thought to be no problem on the whole. However, fertilization or topdressing that has been carried out by skillful propaganda from the business side or from agricultural cooperatives is a problem. In the 1970's and 1980's, topdressing at the maturing stage of rice had been recommended by a higher chief researcher of the Ministry of Agriculture, Forestry and Fisheries. Those changes had been forced on farmers and ignored common sense in that a little nitrogen topdressing immediately before the panicle formation stage of rice is complete, cause bad taste in rice and a decrease in yield. The Ministry of Agriculture, Forestry and Fisheries continued the policy of reducing areas under rice cultivation due to a sharp decrease of rice consumption, however nobody bears the responsibility.

On the other hand, over dressing results in low mineral vegetables because a thinning due to vigorous plant growth should be produceed by excess of nitrogen. Decreases of several cation contents have seen as a severe interruption by ammonium, because this is the strongest cation in the nutrient absorption mechanism of plants.

There are some difficulties relating to environmental factors connected with mineral contents in food. Almost all of marine productions depend on autotrophic growth of phytoplankton. Food of land life is originally vegetable. It has been experienced that leguminous plants, likely to autotrophic ones depending on root nodule bacteria, need a little of nitrogen fertility for initial quick growth and succeeding increased yields. This study has been planned to clarify the relationship between mineral absorption including translocation and root environment which can be changed easily by human power, for example, the loss of forestry caused by acid rain and acidification or alkalization of field soil by fertilizers, etc. at present.

Materials and Methods

Excised roots of 4-day old etiolated seedlings of barley (*Hordeum vulgare* L., v. *Akashinriki*, a short-culmed variety) were used. After disinfecting with 20% hydrogen peroxide for 2 min., barley seeds were germinated for 24 h. The germinated seeds were put on a 5 mm stainless steel screen, and grown on aerated calcium sulfate 0.25 mM solution for 72 h at 25 °C in the dark. For the other explanation about roots, see elsewhere [2, 3, 6]. A multi-compartment transport box, convenient to observe ion absorption and translocation at the same time was shown there [2, 3, 6]. Radioactivity of sodium, calcium, chlorine, iron or manganese was put into the first compartment, only 10 mm of root tip section in the present experiments. Of course, less than 50 mm roots from each tip were used here to evaluate absorption and translocation of each mineral ion. In the case of micronutrients, basal strength was 10 μM. and radioactivity given was about 4 kBq per each active compartment

Basal compositions of ambient solution were 2.0 mM disodium monohydrogen phosphte and 0.5 mM calcium chloride. Ion strength was 4.0 mM sodium, 2.0 mM phosphate, 0.5 mM calcium and 1.0 mM chlorine. For the pH adjustment, tartaric acid was used in general, however nearly 0.4 mM sulfuric acid was used as a supplement of tartaric acid of low electrolyzed. In the non-calcium treatment, calcium chloride was not used; 1.0 mM sodium chloride was given if necessary.

Results and Discussion

Fig. 1 to 5 showed the effect of hydrogen ions on absorption and translocation of sodium, calcium, chlorine iron and manganese ions in excised barley (*Hordeum vulgare* L., a short-culmed variety) roots. Outlines about those pictures are explained here.

The vertical axes in those figures showed respective pH used in each experiment, the starting pH was fixed at

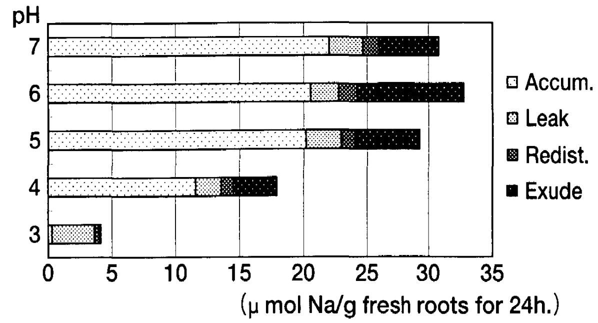

Fig. 1 Effect of pH on Na absorption in excised barley roots.

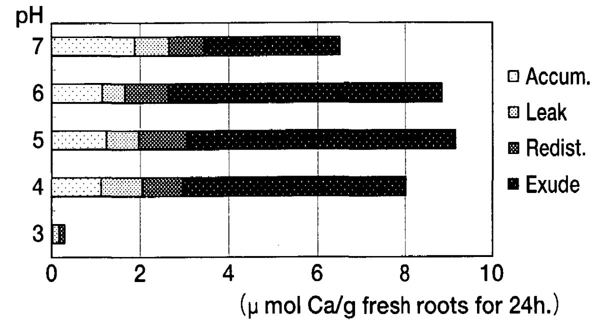

Fig. 2 Effect of pH on Ca absorption in excised barley roots.

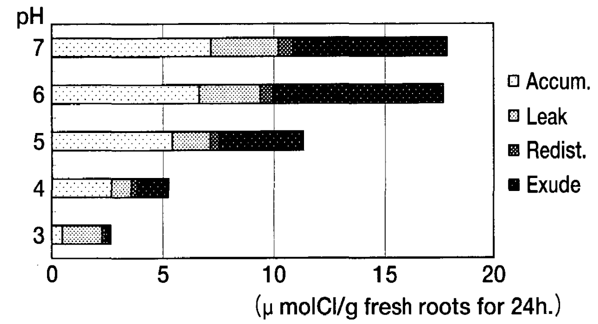

Fig. 3 Effect of pH on Cl absorption in excised barley roots.

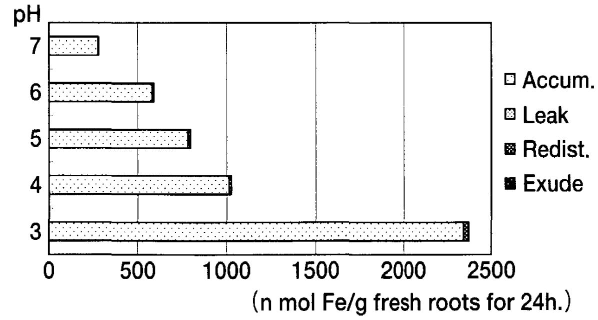

Fig. 4 Effect of pH on Fe absorption in excised barley roots.

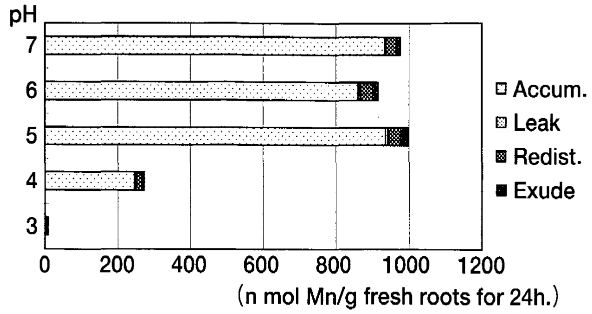

Fig. 5 Effect of pH on Mn absorption in excised barley roots.

every 5 level from 3.0 to 7.0. It means that hydrogen ion concentrations were set 5 gradations between 10^{-3} and 10^{-7} molar strength, namely every difference between neighboring concentrations is 10 times. The lowest pH level is lethal to plants. At pH 3.0 we had an experience by solution culture experiment that the rice plants which were tolerant to acidity had died after stunting for 3 weeks. In the present experiments, root sections became somewhat soft caused by dehydration at pH 3.0; however, the maximum iron accumulation is at pH 3.0. The highest pH 7.0 is highly risky to rice and corn plants with iron deficiency, except iron, ion absorption or adsorption did not particularly decreased at pH 7.0. The change of pH values for an experimental term was rather small in this experiment, less than 0.5 pH even in high pH levels (pH 5-7), namely low hydrogen ion levels.

The horizontal axes indicate the amount of absorbed ions for 24 h., or the absorption velocity of ions into roots, in order of root age, from a young tip to old sections, from epidermis to xylem or the down side to the upside in excised roots. The amount of each absorbed ion was classified as follows. Firstly, an accumulated fraction (abbreviated to "Accum." in charts), secondly, a leaked out fraction from epidermis during translocation (the cortical efflux, cut down to "Leak" in charts), thirdly a redistributed fraction to the upper root sections from the radio-activated root tip section (cut down to "Redist." in charts) and an exuded fraction through root xylem at the cut end (the xylem exudation, cut down to "Exude" in charts). Total absorption includes the absorbed fraction, the following translocation in 35 mm or more of root tissue keeping each inside, the leaked out one unavoidably from each cortex during translocation and clearly absorbed and transported from cut end, i.e. the exuded one or xylem exudation.

Differences were present among those ions; however, disturbance caused by hydroxyl ions appeared clearly in the case of iron which absorption or adsorption, mainly the accumulation, decreased remarkably with pH increase. In fact, a small amount of iron is found in the transported part from the accumulated root section, root tip. In the case of calcium, sodium, and manganese, their absorption decrease at higher pH levels occurred in a small scale, not always found. A small decrease in the xylem exudation, the net absorption here, was found in the cases of calcium and sodium. The xylem exudation is the fraction of sent out from the cut end for 24 h., therefore, the xylem exudation is thought to be the most important and substantial fraction from the view point of the ion absorption, however, the important exudation was also checked by high pH condition in the case of calcium and sodium.

Chlorine absorption was increased sharply by the increasing environmental pH, although the increasing power appears to weaken at the highest pH level. With the exception of iron, the increase of the ion absorption with increasing pH, decreasing hydrogen ion, was found common to all the elements examined here, although pH levels to be suitable to their absorption differed a little in respective elements. The suitable pH levels for the calcium absorption looked like pH 4 to 6, those for sodium and manganese seemed to be between pH 5 and 7, those for chlorine, anion, seemed to be about pH 6 or 7.

In the cases of iron and manganese, trace elements, the accumulated fraction was absorbed into roots at the radio-activated root sections; however, the accumulated one was thought to be important, even though the fraction was kept within excised roots. When the root tissue containing minerals reactivated by rain fall or top dressing, fixed fractions of such ions were expected to carry upward relatively even by root elongation.

Fig. 6 to 8 showed effects of hydrogen and calcium ions on the absorption and the translocation of sodium, iron and manganese ions. Values of pH examined were 3.5 and 5.5, those pH values were the lower limit to survive [4] and the comfortable root condition for many plants [5].

Calcium decreased the available fractions, the accumulated, the redistributed and the exuded fractions (except the leaked out fraction), of sodium and manganese especially at 5.0 mM calcium level. On the other hand, calcium effect on the leak fraction was thought to be somewhat repressive in every case. Every leak fraction from the inside of roots was looked like to be reduced

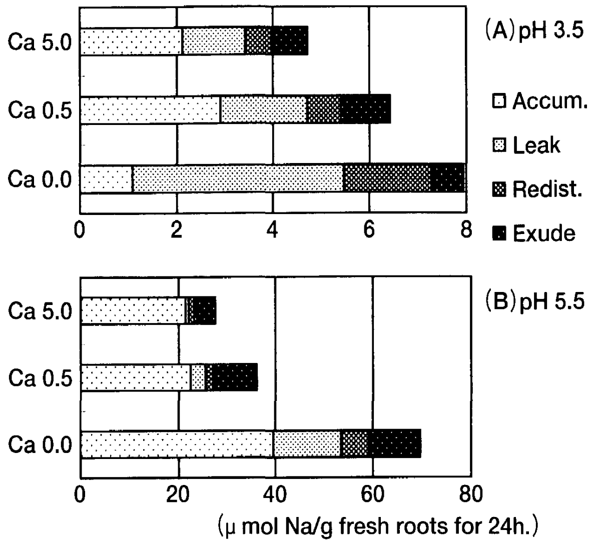

Fig. 6 Effect of Ca and pH on Na absorption in excised barley roots.

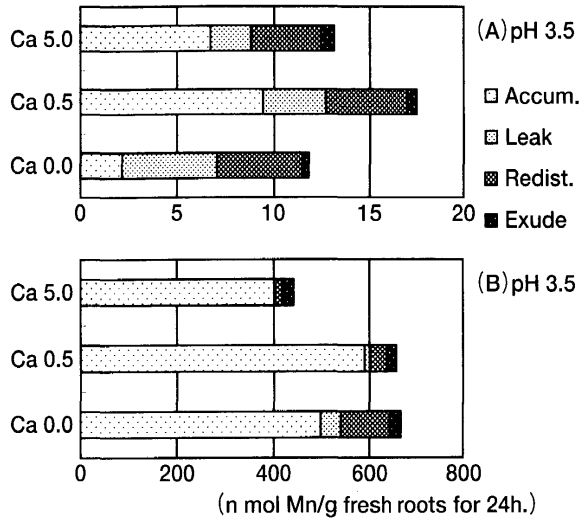

Fig. 8 Effect of Ca and pH on Mn absorption in excised barley roots.

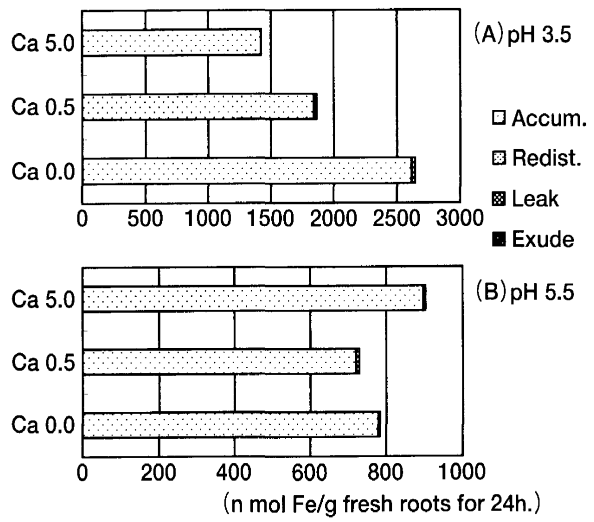

Fig. 7 Effect of Ca and pH on Fe absorption in excised barley roots.

against increasing calcium concentration in the external solution. Such results could be expected from our past excised roots experiments [1].

Experimental results to given pH values were similar to cases of the former pH experiments here, pH 3 and 4, pH 5 and 6. After all, the iron accumulation increased by low pH, whereas the transported fractions of sodium and manganese which were composed of leaked, redistributed and exuded ones decreased by low pH to the level of 10 % or less in the sodium case, those of 2.5% or less in the manganese case, respectively.

Injury to forests caused by acid rain is world wide problem at present. Saline soil or alkaline soil caused by unsuitable irrigation or expansion of an arid region is also a problem. Accordingly, the acid soil, the saline soil and the alkaline soil looks likely to be causes of low mineral foods. Besides, low mineral foods have possibly occurred spontaneously in nature. For an example, a datum of zinc content in raw planted oyster has been decreased from 58.2 mg per 100 g in 1983 [8] to 13.2 mg per 100 g after 2000 [7], although it has been thought to be a gradual density elevation of oyster beds during the latter half of the 20 th century, excepting the difference of data sources.

In rice culture, oxidizing or deoxidizing condition of soil is important to the ion absorption, although that has not been examined here. Up to present, the reductive paddy soil had been actively used to prevent injury depending on soil pollution by copper or cadmium made use of a technique of combined manure and ever-flood rice field for a culture term. In the reducing soil condition, neutralized soil pH and low oxidation-reduction potential are chief characteristics. Those characters are caused by the reduction in soil of inorganic sulfate contained in fertilizer or change of organic sulfur to sulfide. Under such conditions, the repressed absorption of polyvalent cations is generally known, although there is almost no connection between the soil condition described above and the absorption of iron or manganese. Those recent environments linked to agriculture have been affected by the hateful basis of acid rain and much fertilizer farming. Consequently, the lasting interest in the low mineral foods shall be important and necessary.

Acknowledgement. The authors thank to Mr. Richard J. Lemmer, a lecturer of the Chugokugakuen who has read this manuscript carefully.

References

1. Kawasaki T and Moritsugu M: The role of calcium in selective cation uptake plant roots (Part 5). The effects of divalent cations on exchangeable and non-exchangeable fractions of monovalent cations in plant roots (I). Berichte des Ôhara Instituts für landwirtschaftliche Biologie, Okayama Universität (1974) **16**, 93-102. (in English)
2. Kawasaki T and Moritsugu M: Effect of calcium on the absorption and translocation of heavy metals in excised barley roots, Multi-compartment transport box experiment. Plant Soil (1987) **100**, 21-34.
3. Kawasaki T, Moritsugu M and Shimizu G: The absorption and translocation of ions in excised barley roots, A multi-compartment transport box experiment. Soil Science and Plant Nutrition, (1984) **30**, 417-425.
4. Moritsugu M and Kawasaki T: Effect of solution pH on growth and mineral uptake in plants under constant pH condition. Ber. Ôhara Inst. landw. Biol. Okayama Univ. (1982) **18**, 77-92. (in English)
5. Moritsugu M, Suzuki T and Kawasaki T: Effect of nitrogen source on growth and mineral uptake in plants under constant pH and conventional culture conditions. Ber. Ôhara Inst. landw. Biol. Okayama Univ. (1983) **18**, 125-144. (in English)
6. Moritsugu M Malkanthi DRR, Tajima S, Itano M and Manabe Y: Effects of metabolic inhibitors on Al-accelerated P and K uptake in excised barley (*Hordeum vulgare* L.) roots. J Chugoku Jr Coll (2001) **32**, 115-124.
7. Resources Council, Science and Technology Agency, Ministry of Education, Culture, Sports, Science and Technology, Japan: Standard Table of Food Composition in Japan, 5 th Revised Edition, Government Printing Office, Ministry of Finance. Tokyo (2000). p 198. (in Japanese)
8. Workshop of Food Ingredient: Content Table of Dietary Fiber, Minerals, Cholesterol and Fatty Acids in Food. IShiYaku Publication. Tokyo (1983). pp 78-79. (in Japanese)

Accepted March 31, 2003.