

## Utilization of Nitrogen by Vegetable Crops

Hideo IKEDA

Institute of Agriculture and Forestry, University of Tsukuba (Tsukuba, Ibaraki, 305 Japan)

### Abstract

The present paper reviews some results of the studies on utilization of nitrogen specifically by vegetable crops, which were conducted in Japan in the 1980s. Those studies employed mainly a  $^{15}\text{N}$  tracer method. The topics included in this review are: absorption, reduction and/or assimilation, translocation and partitioning of nitrogen, ammonium toxicity and its alleviation by nitrate. Application of nitrogenous fertilizers and its utilization by plants are also discussed. Based on the results of those studies, it is concluded that the  $^{15}\text{N}$  tracer method is easy and harmless in dealing with and useful in pursuing dynamic movements of nitrogen in soils and plants as well as those from soils to plants.

**Discipline:** Soils, fertilizers and plant nutrition/Horticulture

**Additional key words:** ammonium toxicity, nitrogen, absorption, nitrogen source,  $^{15}\text{N}$  tracer method, xylem sap

### Introduction

Nitrogenous fertilizers applied in a large quantity for the production of vegetable crops give great influences on their growth, yields and qualities. Regarding N fertilizers, amount and time of application are of particular concern for crop management, especially in cultivation with soils, in maintaining long-term and stable productivity. There are two types of nitrogenous fertilizers generally used in field fertilization: organic and inorganic. Among the inorganic N sources, nitrate and ammonium (or ammoniacal) are two main N components as plant nutrients. These two forms of N have different characteristics in their chemical and physiological roles not only in plants but also in soils. The present paper reviews results of the studies on nitrogen nutrition specifically of vegetable crops, which were conducted in Japan in the 1980s. In reviewing those studies, attempts are made so that the difference of the two forms of nitrogen as above-mentioned could be fully taken into account.

### Absorption reduction and/or assimilation

The first step of utilization of nitrogen is absorption by plants. In general, plants absorb inorganic

N through their roots. Almost all of the N absorbed by the plants are ammonium or nitrate. Some plants have a preference of either  $\text{NH}_4\text{-N}$  or  $\text{NO}_3\text{-N}$  in N absorption. In order to identify such a preference, a great number of species of vegetable crops were grown in the nutrient solution containing  $^{15}\text{NO}_3 + \text{NH}_4$  or  $\text{NO}_3 + ^{15}\text{NH}_4$  as an N source and the amount of  $^{15}\text{N}$  absorbed was measured in the seedling stage<sup>3)</sup>. It was observed that the preference in N absorption at the seedling stage varied among the vegetable species and the solution pH<sup>2)</sup>. Those vegetables examined were classified on the basis of their N absorption as follows:

(1) The vegetables which absorbed  $\text{NH}_4\text{-N}$  selectively or dominantly irrespective of solution pH: strawberry, sweet corn, melon, cucumber, lettuce, mitsuba (*Cryptotaenia japonica* Hassk.), celery, garland chrysanthemum, and seri (*Oenanthe javanica* DC.).

(2) The vegetables which absorbed  $\text{NH}_4\text{-N}$  dominantly at pH 7.0 but absorbed both forms of N almost equally at pH 5.0: eggplant and tender soybean.

(3) The vegetables which absorbed  $\text{NO}_3\text{-N}$  selectively or dominantly irrespective of solution pH: spinach, chinese cabbage, and turnip.

(4) The vegetables which absorbed  $\text{NO}_3\text{-N}$  dominantly at pH 5.0 but absorbed both forms of

N almost equally at pH 7.0: pea, kidney bean, watermelon, tomato, and cabbage.

(5) The vegetables which absorbed  $\text{NH}_4\text{-N}$  dominantly at pH 7.0 but absorbed  $\text{NO}_3\text{-N}$  dominantly at pH 5.0: sweet pepper.

It was also observed that the solution pH decreased gradually while  $\text{NH}_4\text{-N}$  was being absorbed dominantly, but it remained unchanged or rather increased after the plants had exhausted  $\text{NH}_4\text{-N}$  in the culture solution. From the above results and others, Ikeda and Osawa<sup>2)</sup> conclude that those crops absorbing  $\text{NO}_3\text{-N}$  dominantly irrespective of the solution pH are sensitive to ammonium toxicity, whereas those absorbing  $\text{NH}_4\text{-N}$  dominantly are tolerant.

The preference of plants in N absorption is affected by environmental factors such as root- or air-temperature, aeration, solution pH, composition of the other elements in the culture solution, water stress and high concentration of salts in the root zone. In addition, it is reported that the preference is also changed by the plants themselves, more specifically according to their growing stage.

With the aid of  $^{15}\text{N}$ , absorption and assimilation of  $\text{NO}_3$  was compared between cucumber and figleaf gourd, which were both sensitive and tolerant to low temperature at 13 and 20°C of root temperature<sup>10)</sup>. The absorption of  $^{15}\text{NO}_3$  at 13°C was significantly lower than that at 20°C, especially in cucumber. However, in both species, the assimilation and translocation of absorbed  $^{15}\text{NO}_3$  were hardly affected by root temperature. The roots of both species accumulated a very small amount of reduced- $^{15}\text{N}$ . Assuming that most of the  $^{15}\text{N}$  translocated to leaves was carried in the form of  $\text{NO}_3$ , it was presumed that  $\text{NO}_3$  assimilation took place predominantly in leaves in both cucumber and figleaf gourd, and that the rate of  $\text{NO}_3$  absorption, rather than that of its assimilation, was related to the difference of growth response of cucumber and figleaf gourd to low root temperature.

Horiguchi and Chisaki<sup>1)</sup> examined effects of nitrogen deficiency and foliar application of urea on the protein turnover and nitrogen translocation in soybean seedlings with the  $^{15}\text{N}$  tracer method. The

Table 1. Distribution of labelled nitrogen in tomato plants

		(Unit: %)			
Position of plant parts <sup>a)</sup>		$^{15}\text{NO}_3$	$^{15}\text{NH}_4$	$^{15}\text{NO}_3 + \text{NH}_4$	$\text{NO}_3 + ^{15}\text{NH}_4$
Fruit	3	2.1	2.8	1.7	2.5
	2	3.9	8.7	5.8	7.4
	1	9.9	12.7	12.8	16.5
	Total	15.9	24.2	20.3	26.4
Leaf blade	3	12.2	9.3	12.1	9.6
	2	10.6	7.5	12.0	7.7
	1	8.8	6.4	10.3	5.5
	0	6.5	5.2	6.6	5.0
	Total	38.1	28.4	41.0	27.8
Petiole	3	3.3	2.7	3.7	2.8
	2	3.1	2.7	3.7	3.5
	1	3.2	2.6	3.8	2.9
	0	2.9	2.9	3.2	3.0
	Total	12.5	10.9	14.4	12.2
Stem	3	2.0	2.6	2.0	2.4
	2	2.1	2.6	1.9	2.2
	1	2.0	2.7	1.9	2.2
	0	3.9	5.0	4.1	6.0
	Total	10.0	12.9	9.9	12.8
Root		23.5	23.8	14.3	21.0

a): Sampling position in tomato plants.

0: below 1st cluster, 1: 1st cluster, 2: 2nd cluster, and 3: 3rd cluster.

result obtained indicates that N-supply via their roots might control the senescence and the protein degradation of the lower leaves, and that N-deficiency might promote the degradation.

### Translocation and partitioning

There are great differences in the distribution of N originating from  $\text{NO}_3$  and  $\text{NH}_4$ <sup>3)</sup>. Tomato plants were grown with solution culture and supplied with  $^{15}\text{NO}_3 + \text{NH}_4$  or  $\text{NO}_3 + ^{15}\text{NH}_4$  for 48 hr at anthesis of the third cluster, in order to survey the partitioning

of the N absorbed by the plants (Table 1). Nitrogen from  $\text{NO}_3$  was mainly distributed in leaf blades and a little in petioles, fruits and stems, while nitrogen from  $\text{NH}_4$  was located in plenty not only in leaf blades but also in fruits.

Yoneyama et al.<sup>12)</sup> tried to make simulation of nitrate reduction and partitioning of N in komatsuna (*Brassica campestris* L. var. *rapa*) plants. In their study, the plants grown hydroponically with 2 mM nitrate in a greenhouse were fed with  $^{15}\text{N}$ -labelled nitrate for 2 hr in the light or in the dark, followed with non-labelled nitrate for 8 hr. At an interval of

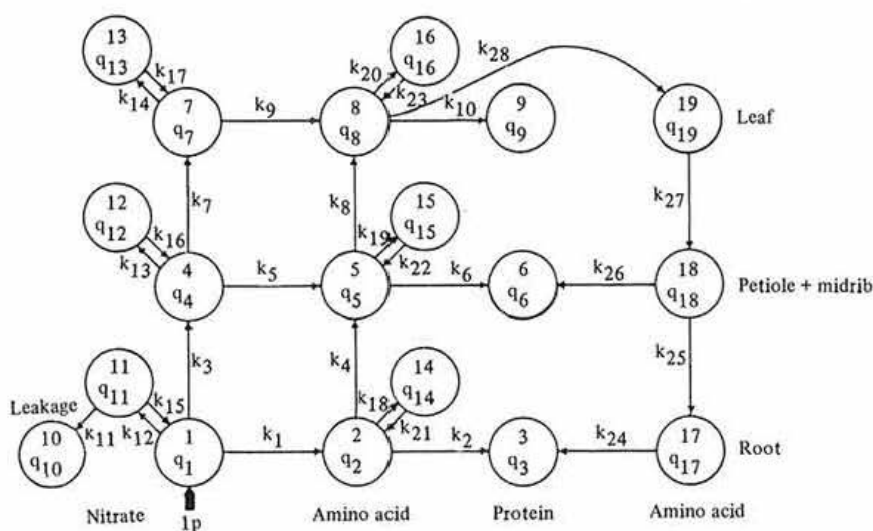


Fig. 1. Model for nitrate reduction and partitioning of N in komatsuna plants

A simulation model is constructed with 19 compartments and 28 transfer rate constants ( $k_i$ ). The term of  $q_i$  is time-dependent variables of tracer amounts in each compartment.

This model includes the following items:

- (1) The nitrate in each plant part is distributed into two pools; a short-lived pool which serves for active transport and/or assimilatory reduction to  $\text{NH}_4$  and amino acids (compartments 1, 4 and 7); and a pool which turns over more slowly and serves for temporary storage of  $\text{NO}_3$  (compartments 11, 12 and 13).
- (2) Amino acids in each plant part are distributed into three pools; a short-lived pool which serves for xylem transport and xylem-delivered amino acids used for protein synthesis (compartments 2, 5 and 8); a pool which turns over slowly and is involved in the temporary storage of amino acids (compartments 14, 15 and 16); and a pool for phloem transport and phloem-delivered amino acids used for protein synthesis (compartments 17, 18 and 19).
- (3) Amino acids are utilized for the protein synthesis (compartments 3, 6 and 9).
- (4) Leakage of nitrate from root tissues (flux to compartment 10) is from the storage pool of root nitrate (compartment 11).

Source: Yoneyama et al. (1987)<sup>12)</sup>.

2 hr, the plants sampled were analyzed to identify the distribution of  $^{15}\text{N}$  in the form of nitrate, amino acids, and proteins in the tissues of roots, petioles plus midribs, and leaves. Nitrate reduction and nitrogen fluxes were examined using a compartmental analysis with 19 compartments and 28 transfer rate constants (Fig. 1). Nitrate existed in the three types of tissues as a large storage pool and a small metabolic pool. Nitrogen reduction was generally observed in these tissues, and in the leaf tissue in particular.

Nitrate uptake and reduction rates were smaller in the dark than in the light, and nitrate reduction in the shoot was particularly small in the dark. The rate of protein synthesis was much greater in the light. It is indicated that the simulation, using compartment models and  $^{15}\text{N}$  distribution data, might be useful for estimating actual rates of N transport and metabolism in the whole plant system (Fig. 2).

The major N components in the xylem streams of soybean are nitrate, amides (particularly asparagine)

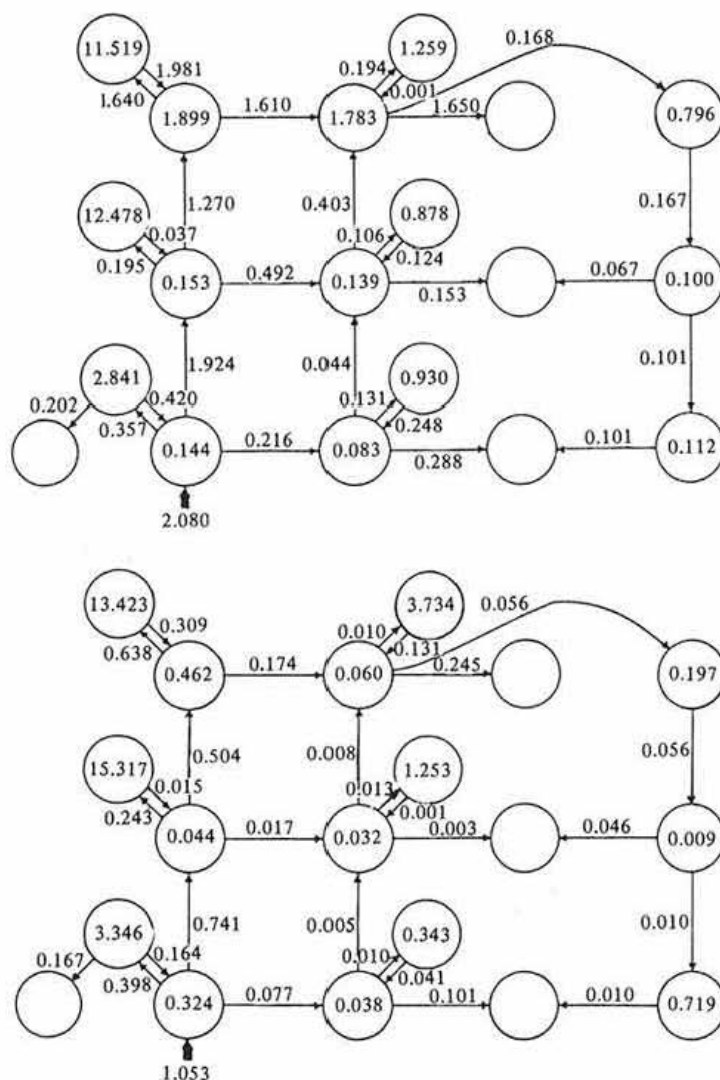


Fig. 2. Nitrogen fluxes and pool sizes in komatsuna plants estimated based on simulation in the light (above) and in the dark (below)

Refer to Fig. 1 in regard to the symbols employed.

Source: Yoneyama et al. (1987)<sup>12)</sup>.

and ureides (allantoin and allantoic acid). The proportion of these components in the xylem sap vary depending on the forms of N which the soybean plants take up. In the plants dependent on the symbiotically fixed N, ureides are predominant N forms in the xylem sap, whereas the fraction of nitrate and/or amides increases in association with the decrease of ureides when combined forms of nitrogen (as nitrate, ammonium, or urea) are supplied. Yoneyama<sup>11)</sup> carried out an experiment, in which partitioning and metabolism of nitrate, asparagine, and allantoin in the soybean shoots, were examined at the grain-filling stage. In that experiment, <sup>15</sup>N-labelled nitrate, asparagine, or allantoin were fed via the cut stems of soybean shoots at the grain-filling stage, and the primary distribution and metabolism of these N compounds were investigated. The conclusion derived from this experiment is that at the grain-filling stage of soybean, nitrate-N is mostly transferred to and metabolized in the leaves, and asparagine-N is retained in the stem and petioles with a small transformation and translocation to the grains, while allantoin-N is transferred to and metabolized in both the leaves and the pods.

The concentration of NH<sub>4</sub>-N in xylem sap of kidney bean and tomato which were sensitive to ammonium toxicity was measured with the <sup>15</sup>N-dilution method<sup>3)</sup> (Table 2). From the result that high concentration of NH<sub>4</sub>-N was detected in xylem sap of plants soon after NH<sub>4</sub> application and before the incidence of ammonium toxicity symptoms, it was estimated that most part of the high NH<sub>4</sub>-N which was detected in the leaves of plants injured by am-

monium was directly translocated from the roots.

### Ammonium toxicity and its alleviation by nitrate

NH<sub>4</sub> nutrition generally resulted in higher NH<sub>4</sub>-N concentration in leaves and reduced plant growth as compared with NO<sub>3</sub> nutrition. This toxic effect of NH<sub>4</sub> was alleviated and the leaf NH<sub>4</sub>-N concentration was decreased with the combined application of a small amount of NO<sub>3</sub><sup>2,4,9)</sup>. As compared with NO<sub>3</sub> nutrition, growth enhancement was caused in tomato<sup>4)</sup>, as well as in lettuce, spinach, cabbage, green onion and many other vegetable crops<sup>2)</sup> with the addition of NH<sub>4</sub> to the solution containing an adequate amount of NO<sub>3</sub>.

### Application of nitrogenous fertilizers and its utilization by vegetable crops

Fertilizer application in a greenhouse is quite different from that in farming practices in an open field. In a greenhouse, plant growth takes place under a semi-closed environmental condition all year round. The available volume of media for roots in a greenhouse is rather limited as compared with that in an open field. In addition, soils are used continuously with sterilization. As a consequence, the excessive level and imbalance of fertilizer nutrients frequently accounts for the problems encountered. It is therefore necessary to know actual status and dynamics of nutrients in soils in a greenhouse so that adequate soil conditions can be maintained.

Table 2. Concentration of NH<sub>4</sub>-N and total N in xylem sap of plants grown with different forms and concentration of N

Crop	Sampling stage <sup>a)</sup>	NH <sub>4</sub> -N (ppm)			Total N (ppm)			NH <sub>4</sub> -N/Total N (%)		
		NO <sub>3</sub>		NH <sub>4</sub>	NO <sub>3</sub>		NH <sub>4</sub>	NO <sub>3</sub>		NH <sub>4</sub>
		12	2	12	12	2	12	12	2	12
Kidney bean	I	18.5	42.7	67.5	561.5	330.2	410.3	3.29	12.93	16.45
	II	23.5	30.8	53.2	522.9	303.7	276.9	4.49	10.14	19.21
	III	23.5	41.3	58.1	674.6	416.0	475.8	3.48	9.92	12.21
Tomato	I	36.7	102.9	130.7	387.6	710.9	602.2	9.47	14.47	21.70
	II	—	32.1	101.4	—	221.0	424.6	—	14.52	23.88
	III	49.8	51.1	125.5	596.0	320.6	624.3	8.36	15.93	20.10

a): I: NH<sub>4</sub> toxicity was not recognized.

II: Slightly visible symptom of NH<sub>4</sub> toxicity was recognized.

III: Visible symptom of NH<sub>4</sub> toxicity was clearly recognized.

Ito and Araki<sup>5)</sup> reported results of the study pertaining to the distribution and utilization of N applied to soils in the greenhouse cultivation of tomatoes. In this experiment, dynamics of N, including  $^{15}\text{NH}_4\text{NO}_3$ ,  $\text{NH}_4^{15}\text{NO}_3$  and labelled organic N from rice straw applied, was subjected to analyses with

a  $^{15}\text{N}$  tracer method. The mode of absorption and translocation of N by tomato plants varied according to the form of N applied (Fig. 3). The appropriation of N from rice straw was as follows: 13–17% of N was taken up by the tomato plants, 64–84% remained in the soils and 0–23% could not be

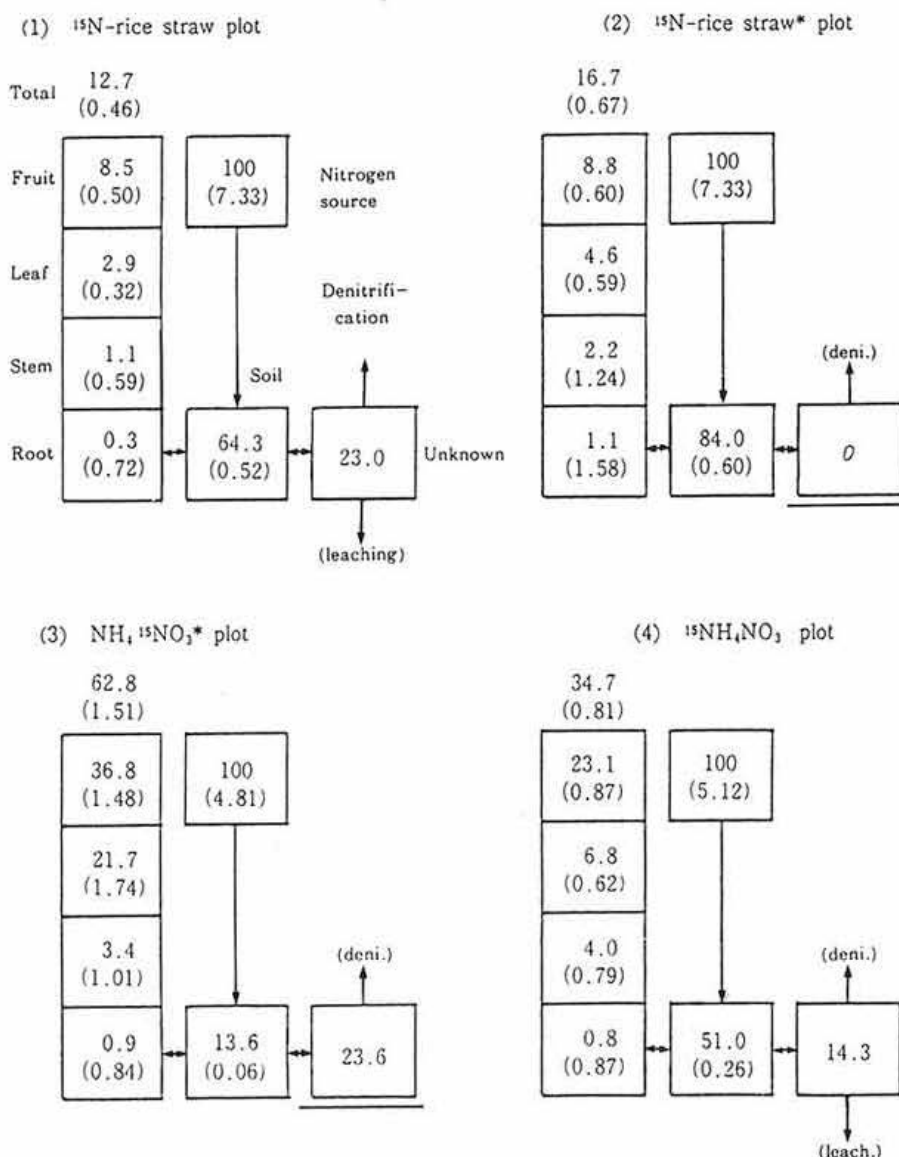


Fig. 3. Nitrogen flux and balance sheet of applied fertilizer and rice straw labelled by  $^{15}\text{N}$

( ): Atom % excess.

\* Plow layer was isolated at a depth of 20 cm from subsoil by polyethylene film.

Source: Ito & Araki (1984)<sup>5)</sup>.



recovered. When the plow layer was isolated from the subsoil, the rate of recovery of N was about 100%. From this result, it was presumed that without the isolation of the plow layer, about 23% of the N which could not be recovered, would have been transferred under the plow layer. When the plow layer was isolated from the subsoil, 62% of the  $\text{NO}_3\text{-N}$  from  $\text{NH}_4\text{NO}_3$  was absorbed by the tomato plants, 14% remained in the soil and 24% could not be recovered presumably due to denitrification. The appropriation of  $\text{NH}_4\text{-N}$  originating from  $\text{NH}_4\text{NO}_3$  was as follows: 35% was taken up by the tomato plants, 51% remained in the soils and 14% was not recovered presumably due to its movement to subsoils. Based on these measurements, it was estimated that the rate of N absorbed by the tomato plants from each N source, i.e. rice straw, ammonium, nitrate and soils, was 6–9, 16–20, 22–31, and 40–56%, respectively.

Masuda et al.<sup>7)</sup> also investigated the efficiency of utilization of fertilizer nitrogen applied to greenhouse tomatoes with six clusters in forcing culture. In this experiment,  $(^{15}\text{NH}_4)_2\text{SO}_4$  was used as an N source and amounts of supplied N were 6.3 and 5.6 g/plant for basal fertilizer and topdressing, respectively. The amount of N derived from basal fertilizer was 41.2% of the total N in fruits on the first cluster and about 30% on the other clusters. On the other hand, the N derived from topdressing showed a range from 11.8 to 16.8% on all of the clusters. Recoveries of  $^{15}\text{N}$  were 41.8% for basal fertilizer and 23.8% for topdressing, while the residual N in the soil layer of 30 cm depth was 23.3 and 40.6%, respectively. The estimated amount of N absorbed by plants to obtain 1 kg of fruit yield was in a range from 1.7 to 1.9 g. It was estimated that 34.5% of N absorbed came from basal fertilizer and 13.2% from topdressing, and 47.7% of total N was derived from fertilizer N and 52.3% from soil N, including applied N during the nursery period. In the pot experiment, however, the efficiency of fertilizer N ( $^{15}\text{N}$ ) applied to plants was higher in both basal fertilization and topdressing than that in the greenhouse experiment<sup>6)</sup>.

Using a  $^{15}\text{N}$ -dilution method, effects of excessive nitrogen supply on the growth and nitrogen metabolism of crops were studied by Matsumaru et al.<sup>8)</sup> In their experiments, tomato plants were grown on potted soils with the application of nitrate, ammonia,

and organic nitrogen (peptone) at an excessive level with basal fertilizer and topdressing. The results obtained were as follows: the plant growth was depressed with an increase in N supply by topdressing. An adverse effect of nitrate was the most severe, followed by organic N and ammonia. Supply of ammonia and nitrate increased N concentration in plants, but organic N did not show such an effect. The rates of N absorption were the largest in ammonia-fed plants, followed by organic-N and nitrate-fed plants. It was presumed that this difference might have been caused mainly by the diverse pattern of absorption of N supplied by topdressing.

## Conclusions

As described above, a great number of issues are relevant to the utilization of nitrogen by vegetable crops. There have been some technical developments in  $^{15}\text{N}$  tracer methods in Japan during the 1980s. The above results reveal that those methods are simple, easy and harmless in dealing with and very useful in pursuing dynamic movements of N in soils and plants as well as those from soils to plants.

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