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Uptake and Translocation of Nitrogen in Satsuma Mandarin Trees

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Abstract

With the purpose of analyzing uptake and translocation of fertilizer N in Satsuma mandarin, ^{15}N-labelled ammonium sulfate was applied as a fertilizer to experiment tree of about 20 years old in the following four seasons each: i.e. before harvest in autumn, after harvest in autumn, spring and summer. The translocation of ^{15}N to leaves tool place within the year of application when it was supplied before harvest in autumn, whereas ^{15}N applied before harvest in the autumnal season was translocated only at almost the same time with that applied in the following spring season. The translocation rate of applied ^{15}N to leaf organs in the tree plants reached a peak about 25 days after fertilization when the soil temperature was about 10°C of higher. The greatest contribution or applied ^{15}N to fruit organs was observed under the summer N-fertilization. However, the summer application distributed more ^{15}N to peel tissue than to flesh in the late autumn. These results were effectively incorporated in the improvement of cultivation practices of Satsuma mandarin in various parts of Japan, particularly in rationalizing fertilizer application in production centers.

Discipline: Soils, fertilizers and plant nutrition/Horticulture

Additional key words: absorption rate, heavy nitrogen, rationalization of fertilizer use

Introduction

In the course of increased production of satsuma mandarin in Japan, soil acidity of orchards has been increased due to the heavy manuring practices aiming at a high yield, and as a consequence, damages caused by excess manganese were accompanied in many parts of the production centers. In addition, the overproduction of satsuma mandarin in the country brought about the first drastic decline of prices in 1968, since then there has been a great competition among the mandarin producing centers, in special regard to fruit quality.

Under such an economic background, research activities for cultivation improvements were strengthened in Japan, including a study on the utilization of ^{15}N in Japanese satsuma mandarin, starting in Saga Prefectural Fruit Tree Experiment Station in 1967. Their activities have been subsequently followed by various research institutes such as Shikoku National Agricultural Experiment Station, Nagasaki Prefectural Fruit Tree Experiment Station, and Ehime Prefectural Fruit Tree Experiment Station. In the ^{15}N experiments undertaken by Shikoku Nat. Agr. Exp. Sta., large-sized pots were used for testing both of young and adult trees. A process of absorption and translocation of fertilizer N in each fertilization time was pursued to analyze utilization and distribution patterns of the applied nitrogen in various parts of the trees in connection with the issues relating to sink and source[1,7–15]. In the tests of Nagasaki Pref. Fruit Tree Exp. Sta., the utilization of fertilizer N by satsuma mandarin at some related growing stages was analyzed under the field condition with sod culture[2–5]. In the experiment at Ehime Pref. Fruit Tree Exp. Sta., the uptake and utilization of fertilizer N in two weeding systems, i.e. herbicide and clipping, in a young tree field was analyzed[18]. Under the test at Saga Pref. Fruit Tree

Exp. Sta. which used adult trees in the high productive stage, analyses were made in regard to the movements of fertilizer N applied under a usual condition[6,16,17].

This paper attempts to review the results of the experiments conducted by the Saga Pref. Fruit Tree Exp. Sta. on uptake and translocation of nitrogen in satsuma mandarin trees. In the test at the Saga Pref. Fruit Tree Exp. Sta., the nitrogen movements were pursued for the whole tree plants within a year after the application of labelled-^{15}N. This paper, however, reviews part of the results obtained, with emphasis placed on the movement of applied ^{15}N in leaves, flowers and fruits, following the passage of time.

Materials and methods

An experimental field of Saga Pref. Fruit Tree Exp. Sta. was used for the relevant test. The plots for the tests were situated on a terraced field consisting of a parent material of granite, where satsuma mandarin trees of about 20 years of age were grown with an annual harvest of 50 t/ha or even more. A planting density was 900 tree/ha. The mixed fertilizers generally used in Saga Prefecture were applied in the tests with a standard application rate recomended by the local government, except for the inorganic nitrogen that was substituted with ^{15}N-labelled ammonium sulfate. The boundary of each fertilized area was set in the middle with the adjacent trees. Application rates of fertilizers are shown in Table 1.

The adherent position of a leaf for analyses was earmarked by its address number manifested in a numerical value with seven figures, the top of which indicated the number of a tree under testing. At the beginning of the experiment, the leaves for sampling were classified by ages on the basis of the respective address numbers as follows: aged leaves beyond one-year-old (older leaves), young leaves below one-year-old (new leaves) and the following year-new leaves. The numbers of leaves in each age to be sampled were determined proportionally. The regions of leaf-sampling for analyses in the first primary scaffold branch are shown in Fig. 1. The abundance of ^{15}N was analyzed with a mass spectrometer.

Since percentages of ^{15}N atom varied among the labelled fertilizers used, the comparisons of the concentrations of fetilizer N among the trees tested were made on the following formula:

^{15}N contribution rate = (content of fertilizer N in sample) ÷ (total content of N in sample) × 100 = (^{15}N atom % excess of sample) ÷ (^{15}N atom % excess of used ammonium sulfate) × 100.

Results and discussion

1) Changes in ^{15}N remaining in leaves after absorption

Table 1. Rates of fertilizer applications for each tree under the experiments

Autumn fertilization after harvest (Applied on Dec. 5, 1967)	
^{15}N labelled ammonium sulfate (^{15}N atom % 7.1) .... 290.0 g	
Fused magnesium phosphate .... 131.4 g	Potassium sulfate .... 63.0 g
Fish meal .... 58.5 g	Rapeseed meal .... 152.6 g
Autumn fertilization before harvest (Applied on Nov. 5, 1969)	
^{15}N labelled ammonium sulfate (^{15}N atom % 5.1) .... 290.0 g	
Fused magnesium phosphate .... 131.4 g	Potassium sulfate .... 63.0 g
Fish meal .... 58.5 g	Rapeseed meal .... 152.6 g
Summer fertilization (Applied on Jun. 10, 1968)	
^{15}N labelled ammonium sulfate (^{15}N atom % 7.1) .... 297.0 g	
Superphosphate .... 297.0 g	Potassium chloride .... 130.0 g
Magnesium sulfate .... 195.0 g	
Spring fertilization (Applied on Mar. 14, 1970)	
^{15}N labelled ammonium sulfate (^{15}N atom % 5.1) .... 393.0 g	
Superphosphate .... 488.0 g	Potassium sulfate .... 187.2 g
Rapeseed meal .... 412.0 g	

Source: Nakahara et al. (1985)[17].

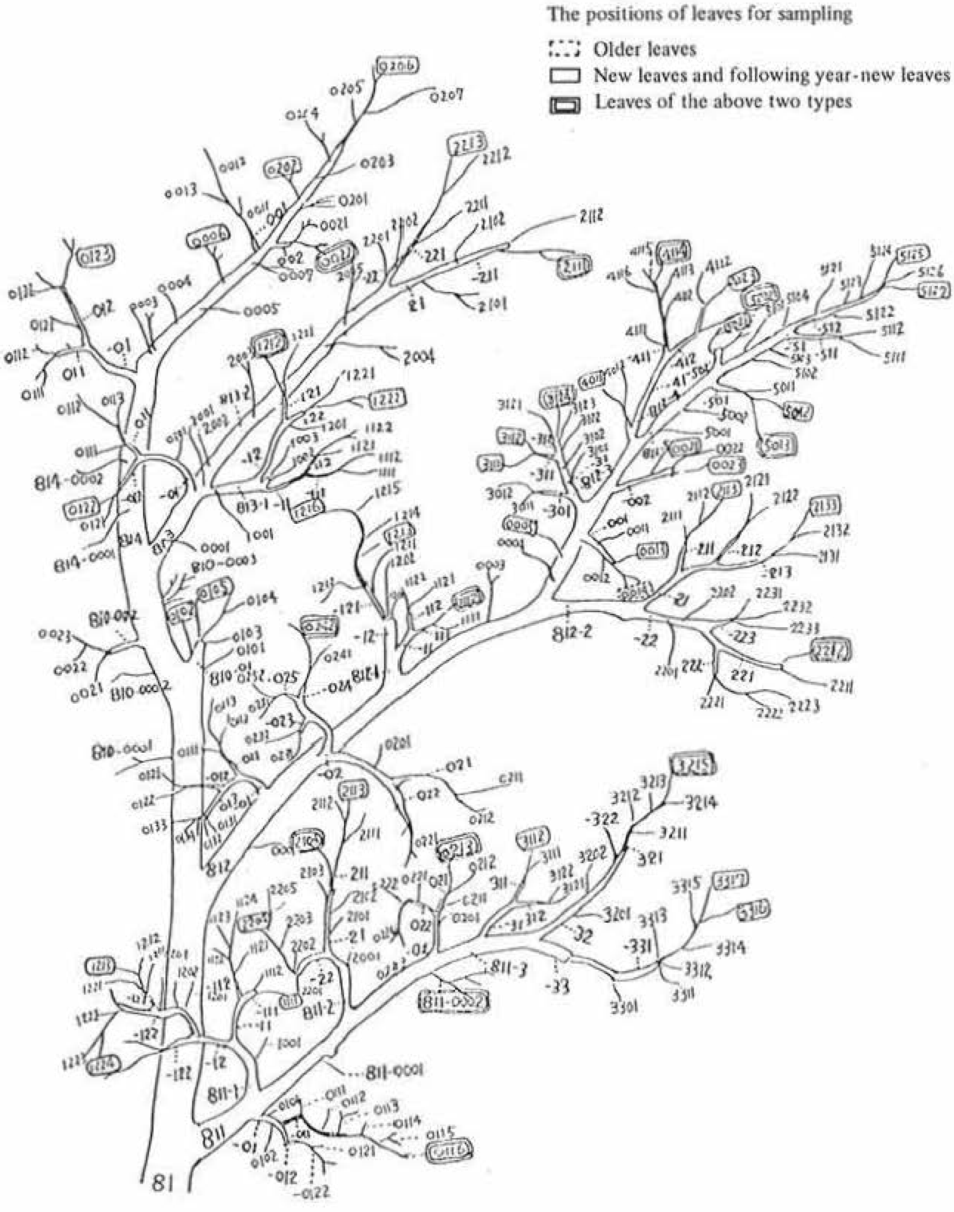

Fig. 1. Address numbers of leaves and positions of leaves for sampling on the first primary scaffold branch
Source: Nakahara et al. (1985)[17].

The changes in percentages of ^{15}N remaining in leaves after absorption in the autumnal fertilization of N before and after fruit harvest are shown in Figs. 2 and 3. The remaining ^{15}N at a given time is expressed in terms of a percentage of the ^{15}N translocated to leaf organs against the total amount of applied heavy nitrogen. In the autumnal application of N before harvest, a large amount of the fertilizer N moved to leaves before the coldest season, while in the case of fertilization after harvest, translocation of the fertilizer N was greatly delayed, starting in March in the following year. It was observed that as far as the peak of remaining ^{15}N was concerned, it was higher in the before-harvest fertilization than

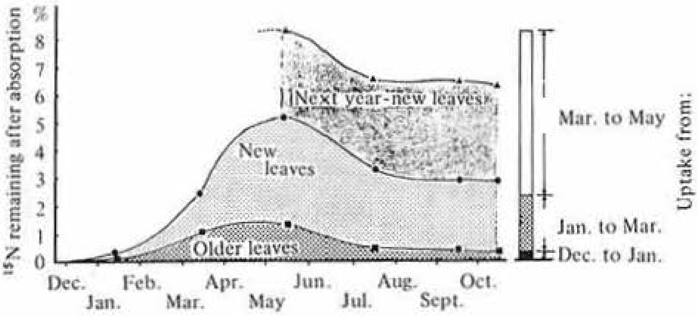

Fig. 2. Changes in remaining ^{15}N in the after-harvest fertilization
Source: Nakahara et al. (1985)[17].

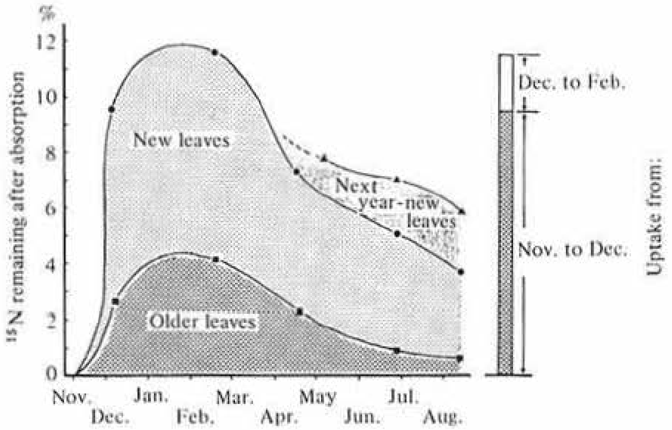

Fig. 3. Changes in remaining ^{15}N in the before-harvest fertilization
Source: Nakahara et al. (1985)[17].

in the after-harvest one and that the former was much higher than those cases in spring and summer fertilizations.

Satsuma mandarin trees absorb a nitrogen nutrient even in the very cold season. The nitrate is assimilated into amino acid and transformed to protein without its accumulation in roots. In this low-temperature season, however, the translocation of nitrogen absorbed by roots to leaves takes place very scarcely[9,10]. Taking into account the variations in soil temperature in the period after the autumnal fertilization, it was concluded that the soil temperature of at least 10°C continuing over a month during that period would be required for the movement of absorbed nitrogen to leaves.

2) Absorption rate of applied ^{15}N in leaves

The ^{15}N remaining in all of the sampled leaves were measured every 10 days. Based on those measurements, absorbed amounts of the applied ^{15}N per day are plotted in Fig. 4, in which ^{15}N absorption rates in the leaves are pursued. Each curve in the figure implies that the applied ^{15}N is translocated to leaves if the curve is on a positive side, whereas it moves to other organs than leaves if the plot is on a negative side, assuming that there is no significant variation in leaf size. A zero level indicates a turning point of translocation; in other words, at this point the moving-in and -out of the applied ^{15}N are equal or the translocation does not take place in a leaf.

Fig. 4 indicates that regarding the number of days required for the ^{15}N absorption rate in a leaf to reach the maximum, they were about 135 days in the before-harvest fertilization, while only 25 days both in the after-harvest application in autumn and in the spring fertilization, and about 35 days in the summer application. In the case of summer fertilization, however, approximately 10 days were shortened in reaching the maximum level, if translocation to fruits were also taken into account. This result suggests that the maximum absorption rate be attained within a month when adequate rainfalls and soil temperature are provided after fertilization.

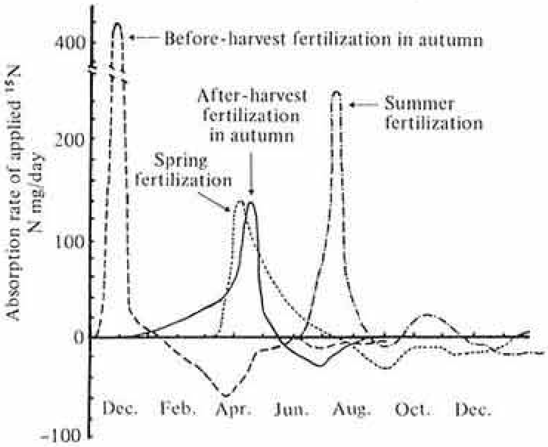

Fig. 4. Changes in ^{15}N absorption rate in the leaves of satsuma mandarin
Source: Nakahara et al. (1985)[17].

In the before-harvest fertilization in autumn, the absorption rate was in a zero point in late January. This period of time corresponded to the season when the flower bud formation of satsuma mandarin could be morphologically identified under a microscopic observation. In the period of late March to April, when the buds began to emerge, the translocation of applied ^{15}N from leaves to other organs reached the maximum level.

3) *Effects of fertilizer N on fruits*

Rates of the applied ^{15}N contribution to flowers, young fruits, peels and fleshes are shown in Table 2. In regard to the contribution rate in the flowers of satsuma mandarin sampled at a flowering time, it was 5.0% in the after-harvest fertilization and 5.3% in the before-harvest application, while it was 5.9%, the highest among others, in the spring fertilization. The flowers of those mandarin trees that received a summer fertilization in June in the preceding year showed only 3.3%. The ^{15}N contribution rates in peels and fleshes at a fruit thickening period were 2.7 and 2.6%, respectively, in the before-harvest fertilization, but slightly higher, i.e. 3.1 and

Table 2. ^{15}N contribution rates in flowers, peels and fleshes

(%)

Time of application	Organs	Date of sampling							
		May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.
		22		17		18		15	
Autumn fertilization before harvest	Flowers, young fruits	5.28		3.97					
	Peels					2.76		2.83	
	Fleshes					2.62		2.58	
		13	17	15	15	15	14	11	1
Autumn fertilization after harvest	Flowers, young fruits	5.02	4.02	2.85	2.78				
	Peels					3.06	2.57	2.63	2.68
	Fleshes					2.83	2.24	2.45	2.60
		13			11	18		13	14
Spring fertilization	Flowers, young fruits	5.91			5.45				
	Peels					4.92		4.60	4.60
	Fleshes					4.46		4.27	4.35
		(next year)							
		(13)	26		10		11	15	11
Summer fertilization	Flowers, young fruits	(3.30)	0.76		4.33				
	Peels						5.73	5.66	5.57
	Fleshes						6.13	6.10	5.51

Source: Nakahara et al. (1985)[17].

Table 3. Absorption* of applied summer fertilization ^{15}N in autumn

(g)

Organ	Oct. 11	Nov. 15	Dec. 11
Whole peel	1.175	1.308	1.472
(Difference)	(0.133)	(0.164)	
Whole flesh	1.604	1.914	1.952
(Difference)	(0.310)	(0.038)	

* Absorbed fertilizer ^{15}N contained in peels and fleshes in a tree.
Source: Nakahara et al. (1985)[17].

2.8%, in the after-harvest fertilization. They reached as high as 4.6% in the spring fertilization, and the highest level of 5.7 and 6.1%, respectively, in the summer fertilization. In the last case, higher rates were observed in fleshes than in peels, unlike the other cases of N fertilizer application.

The absorption rates of applied ^{15}N in fruits reached the maximum level in July, when physiological drops of fruits ended, as well as in the period of August to September, when fruits grew rapidly as a consequence of completed thinning. Since the absorption rates of applied ^{15}N in leaves, flowers and fruits were always greater in the summer fertilization as compared with those in the other fertilizer applications, it was concluded that the effects of the summer fertilization would be highly significant on the overall growth of fruits.

In satsuma mandarin bearing peel-puffing fruits, their quality is greatly deteriorated. The damages with peel-puffing in fruits are caused primarily by weather conditions in the autumnal season. They are further aggravated by excessive fertilizations in a total amount, overmanuring in summer, and delayed application of fertilizers. A greater uptake of summer fertilization N was observed in peels as compared with the case in fleshes from November onward, when the peel-puffing came on in fruits (Table 3).

4) Effects of fertilizer N on growth of leaves

The living period of leaves in satsuma mandarin is 18 months on an average. The ratio of new leaves and old ones varies among the trees. Fig. 5 is a combined graph of the four curves, each of which indicates a variation in absorption rates of applied ^{15}N in leaves of different ages (100 g of dry matter) in the four fertilizer applications each.

New leaves are plotted on a negative side up to mid June. This negative rates might be attributed to the dilution effect caused by the expansion of new leaves. When those leaves are fully matured under summer fertilization, a significant decline in absorption rates toward a negative side is observed during the period of mid July to late October. Since this period corresponded to the time when the new leaves had fully expanded in size, it was presumed that in this period the fertilizer N moved from those new leaves to fruit organs. This translocation was clearly confirmed by the observation that the fruit thickening was greatly suppressed, when the new leaves were plucked off so that the fruits were nourished with old leaves only. The ^{15}N absorption rates were shifted again to the positive side in mid October under the effective summer fertilization followed by N uptake from the autumnal application.

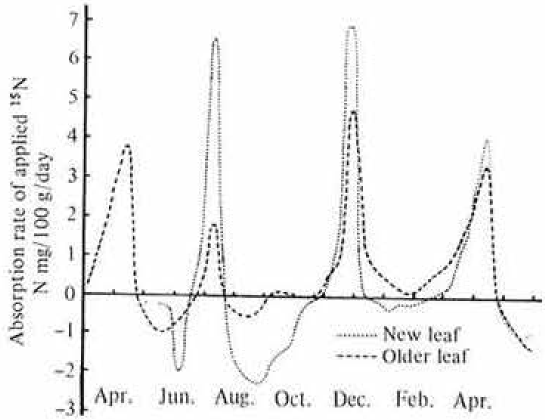

Fig. 5. Changes in ^{15}N absorption rate in the leaves of different ages
Source: Nakahara et al. (1985)[17].

In spring, the new leaves started taking up fertilizer N, but its movement to other organs was initiated only in late April, which was a sprouting time of buds. At this stage, the organs functioning as a sink are newly growing flowers and leaves, and those leaves which have grown up for a year are called older leaves. It is presumed that the translocation of N from older leaves to other organs is completed in late June and older leaves take up summer fertilization N, part of which is translocated to fruits in the fruit-thickening period. However, the amount of the translocation in this case is far less as compared with that from new leaves. It was observed that older leaves had absorbed again nitrogen applied in autumn as well as in spring, and that in late April, the translocation of N from those leaves to new organs took place.

5) Distribution of applied ^{15}N in canopy one year after fertilization

Each of the trees under testing was subjected to a whole tree analysis in a year after the application of ^{15}N fertilizer. One of the investigations pertained to the relationship between the ^{15}N atom % excess in the leaves and their regions within a tree as presented in Fig. 1. The whole tree analysis was made on satsuma mandarin which had received an after-harvest fertilization. The analysis indicated that the ^{15}N atom % excess was high in the secondary scaffold branches (refer to No. 813- and 814- in Fig. 1) linked with the extreme end of a primary scaffold limb, while it was the lowest in the secondary scaffold branch (No. 811- in Fig. 1) of the stolon close to the ground surface. However, in the regions where a cutting back pruning was employed, the ^{15}N atom % excess was higher than that in the tree crown. This indicates that in those regions, nutritional status in nitrogen was greatly recovered.

6) Implications for improving fertilization practices

Based on the results obtained as mentioned above, fertilization practices for satsuma mandarin in Saga Prefecture, Japan have been changed significantly as follows:

(1) As a new standard rate of fertilizer application, 250 kg/ha of nitrogen is recommended, instead of 300 kg/ha.

(2) Summer fertilization should not be applied in the orchards susceptible to peel-puffing in fruits and also in growing Wase satsuma mandarin.

(3) The fertilizer application in autumn should be practiced not after the harvest but earlier, i.e. in the period of mid October to early November.

Since the above results were publicized in Japan[16], the advanced producers in the mandarin orange production centers have strictly adopted the revised practice in applying an autumnal fertilization before harvest.

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