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Traces of ^{15}N Applied to Deciduous Fruit Trees

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Abstract
In the studies on nutrition of and fertilization for deciduous fruit trees in Japan, the ^{15}N tracer method has been effectively used in the last 25 years. Through that method, absorption rates of fertilized nitrogen in apple, grape, and peach trees were well identified, ad translocation and distribution of absorbed nitrogen were clearly separated from nitrogen reserved in plants and stored in soils. In the course of long-term cultivation of fruit trees, the applied nitrogen moves around the orchard among soils, grass and trees. In the growth of fruit trees, contributions of soil nitrogen are very large, while in so culture, surface grass plays an important role in controlling nutrient circulation. The results of these analytical studies have been effectively utilized in rationalizing practices of fertilization and soil management in orchards in Japan.

Discipline: Soils, fertilizers and plant nutrition/Horticulture
Additional key words: apple, fertilization, grape, peach, soil nitrogen

Introduction

Studies on nitrogen nutrition in an orchard require more comprehensive considerations as compared with those in paddy and upland fields, since fruit trees in the orchards are perennial in growth nature, very large in plant size, wide and deep in root zone, and abundant in reserved nutrients. The large plant type implies a long distance from roots to fruits. In pursuing nutritional physiology and effectiveness of fertilizer nitrogen applied to those fruit trees, a ^{15}N tracer method has been intensively used in Japan for the last 25 years. The use of ^{15}N in the fruit tree studies was initiated for evergreen species, followed by an extensive use for deciduous trees.

During the period 1955 to 1965, there had been a great increase in planted areas and yields of fruit trees in Japan from year to year. That increase caused an enormous rise of the amount of chemical fertilizers applied to orchard, which replaced the traditional use of organic manures. The continuous input of a large amount of acidic chemical fertilizers rendered, as a consequence, soil conditions highly acid and unbalanced in composition of cations. Since 1965, some incidences caused by physiological disorders such as internal bark necrosis in apple trees and abnormal defoliation in satsuma mandarins widely took place in orchard. In that circumstance, it was vital for fruit tree growers to establish an improved fertilization method in their orchards. For effective studies on fertilizer application, the ^{15}N tracer method has been very useful in directly pursuing the movement of fertilizer nitrogen in fruit trees.

Introduction of ^{15}N methods to fruit tree studies

In the field of fruit tree studies, uptake of ^{15}N–$(NH_4)_2SO_4$ applied to grape trees grown in pots was tested by Hiroyasu in 1960[1]. In 1964, the mass spectrometer (HITACHI RMS-3B) was introduced to Hirosaki University, with which equipment Mochizuki et al. undertook studies on ^{15}N movement in apple trees grown in pots[7–9]. The first experiment under an orchard condition regarding the uptake of ^{15}N–labelled fertilizer was tested by Shibuya et al. with satsuma mandarin and persimmon in cooperation with National Institute of Agricultural Sciences, Japan and some prefectural experiment stations[15].

The first introduction of the simple mass spectrometer (YANACO MSI-1 isotope analyzer) was initiated by Fukushima Horticultural Experiment

Table 1. Absorption rates of ^{15}N fertilizer in fruit trees

Species (Tree age)	Exp. conditions	Rate of ^{15}N absorption (%)	Treat. term: dressing – excavating	^{15}N conc. used (atom % excess)	Reference
Grape	1/10,000 a pot	37.0 45.8	1 year 3 years		Hiroyasu[1] (1964)
Grape "Kyoho" (3 years)	Pot Volcanic ash soil	9.8 25.2 34.7	Apr. 15 – Nov. 17 Jun. 14 – Nov. 17 Sep. 18 – Nov. 17	10.1 10.1 10.1	Kasuya[3] (1981)
Grape "Kyoho" (3 & 5 years)	Field (3×3 m) Volcanic ash soil	47.1 46.9 57.8 56.5	Dec. 17 – Oct. 20 Jun. 16 – Oct. 20 Apr. 27 – Oct. 20 Apr. 27 – Oct. 20	10.3 10.3 10.1 10.1	Nakada[10] (1979)
Persimmon "Fuyu" (9 years)	Field	0.9 3.1	Jan. 28 – Jun. 1 Jun. 30 – Oct. 19	7.1 7.7	Shibuya[15] (1975)
Peach "Hakuho" (3 years)	Field (2×2 m) Brown Forest soil	35.5 48.4 43.8 29.9	Dec. 13 – Jun. 17 Apr. 11 – Aug. 7 Sep. 5 – Nov. 27 Sep. 30 – Nov. 27	5.1 3.1 5.1 5.1	Sasaki[11] (1978)
Apple "Fuji/M26" (7 years)	Field (2×2 m) Brown Forest soil	13.5 16.0 26.5 24.0	Early Dec.– Mid Nov. Early Dec.– Mid Nov. Mid Mar. – Mid Nov. Mid Mar. – Mid Nov.		Miyakawa[6] (1988)
Apple "Fuji/M26" (4 years)	Field (1.4×1.4 m) Brown Forest soil	34.6 1.0[a]	Apr. 6 – Nov. 21 Apr. 6 – Nov. 21	3.1 10.1	Sato[12] (1982)
Apple "Starking Delicious/M26" (7 years)	Field (2×2 m) Brown Forest soil	16.1	Apr. 4 – Jun. 24 (1980) (1981)	10.1	Suzuki[16] (1985)
Apple "Fuji/M26" (6 years)	Field (2×2 m) Brown Forest soil	19–20 23 21 42	Sep. 20 – Dec. 5 Mar. 20 – Dec. 5 Mar. 20 – Jun. 11 Sep. 20 – Jun. 11	5.0 3.1 3.1 7.1	Komamura[5] (1989)

a): Sod culture, no mark: clean culture.

Station in 1973, followed by employment of the same or modified equipment by many other research stations. For the purpose of effective determination of ^{15}N, an emission spectroscopic method (JASCO NIA-1 ^{15}N analyzer) was developed. In recent years, several types of optical ^{15}N analyzers such as JASCO N-150 and AN-150 have been widely adopted for micro analyses. At present, about 15% of the national and prefectural experiment stations engaging in fruit tree studies use any type of these ^{15}N analyzers.

Nitrogen uptake and distribution in fruit trees

For nutritional control of fruit trees, an amount and rate of the nitrogen uptake from applied fertilizer, should be identified separately from the soil nitrogen for each of the different soil condition. Table 1 presents reported values of the absorption rate (utilization rate) of fertilized nitrogen by fruit trees, all of which are measured with a ^{15}N tracer.

Among those values, the smallest rates, or 0.9% and 3.1%, are observed in a persimmon tree[15]. It may possibly be attributed to the root system of persimmon tree, which distributes very deeply as compared with the other fruit trees in the list. Very large absorption rates are found in grape trees. About 40% in pots[1] and more than 50% of spring dressing in orchard[10] are absorbed by 3-year-old grape trees. A young peach tree also absorbs a large amount of fertilizer N[11]. In apple trees, absorption rates are 14–42% under clean culture[5,6,12,16].

The absorption rates vary among the growing seasons because of the differences in physiological growth stage as well as in environmental conditions, including soil properties, temperature, rainfall, and method of fertilization. The 3-year-old peach trees grown in the Brown Forest soil orchard were subjected to studies by Sasaki and Sato in regard to their absorption and distribution of ^{15}N fertilizer applied at different times[11]. The absorption rates of fertilized nitrogen were 48.4% in 4 months after application in spring (Apr. 11), 43.7% in 2.5 months after application in early autumn (Sept. 5), 35.5% in 7 months after application in winter (Dec. 13) and 29.9% in 2 months after application in middle autumn (Sept. 30). Distribution patterns of absorbed ^{15}N in various parts of the plants varied among these treatments. Patterns of total nitrogen and fertilized nitrogen also differed among the plant organs, as shown in Fig. 1.

Absorption and distribution of nitrogen applied to apple trees at different times were pursued by Mochizuki et al.[7–9]. Ammonium sulfate containing 57.4 atom % excess ^{15}N was applied to a variety "Jonathan" of apple trees grown in sand pots. Those trees were sampled in 15 days after applications, in the middle of July, middle of August and late September for analyses of ^{15}N concentrations. Out of the nitrogen absorbed, 44% was located in leaves in July. The rate decreased as the plants grew up, reaching only 10% at the end of September. On the contrary, the distribution rate of nitrogen absorbed in the underground parts increased[7]. In the experiment using 6-year-old "Jonathan" apple trees under sand culture, where labelled fertilizers were applied at 5 growing stages as shown in Fig. 2, the contents of ^{15}N were high in shoots and spurs and low in trunk and 3-year-old branches during the period of May to July. In September and October, however, this order was reversed[8].

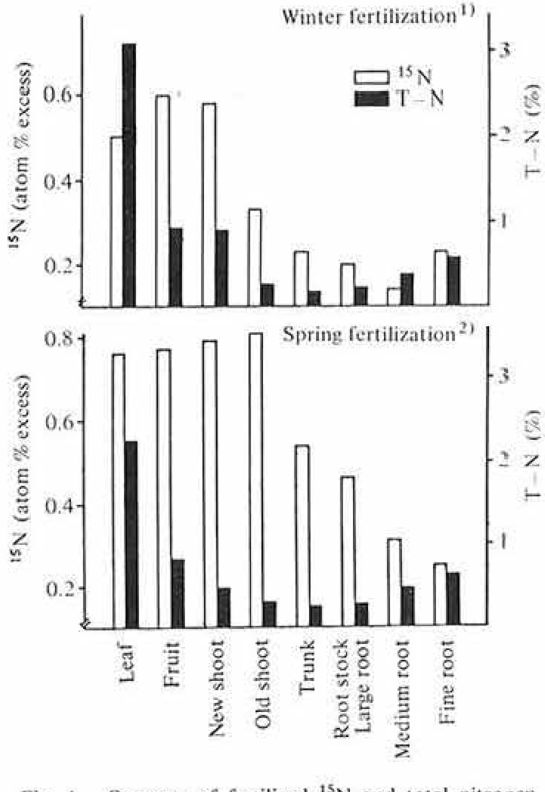

Fig. 1. Contents of fertilized ^{15}N and total nitrogen in peach trees
1): 5.1 atom % ^{15}N fertilized on Dec. 13.
2): 3.1 atom % ^{15}N fertilized on Apr. 11.
Source: Sasaki et al. (1978)[11].

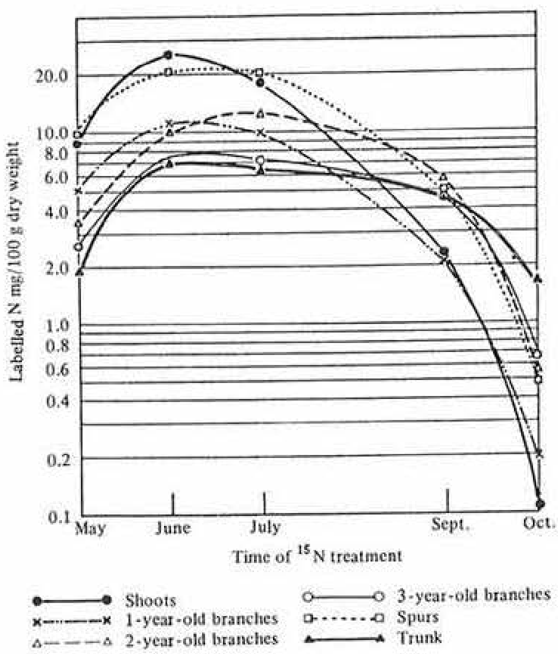

Fig. 2. Labelled nitrogen content in "Jonathan" apple trees treated with ^{15}N-containing ammonium sulfate in excess at the different stages of plant growth
Source: Mochizuki et al. (1971)[9].

Effective time of fertilization in orchard

Basal dressings are often applied in Japan in later autumn or winter, when it is a slack season in labor. It is however recognized that the dressing in this season is not so effective for deciduous trees. Komamura et al. examined the difference of ^{15}N distributions in dwarf apple trees, to which nitrogen was applied at different times[5]. The samplings were made in different seasons. Miyakawa also surveyed the effects of fertilizing time in apple orchard in a snowy area[6]. Through the comparison of absorption rates of basal dressings by apple trees within a year in the snowy area, the spring fertilizer was more absorbed than the autumn dressing. The nitrogen of autumn dressing was mainly distributed to roots, as shown in Fig. 3. The period of time between harvest and defoliation is very important in giving nutritional control for deciduous trees. Production of excessive fruits results in a great loss of nutrition, which requires recovery of nutritional level of the tree in advance to the dormancy for reproduction and new growth in the next spring. In the autumn season, roots grow again and uptake nutrients, storing them mainly in large roots, rootstocks, trunks and big branches, as shown in Fig. 4. The distribution of absorbed nitrogen varies in the course of time in autumn, as shown in Fig. 5. Topdressing just before harvest is effective.

In grape trees, the distribution patterns of absorbed nitrogen are similar to those in apple trees. Kasuya

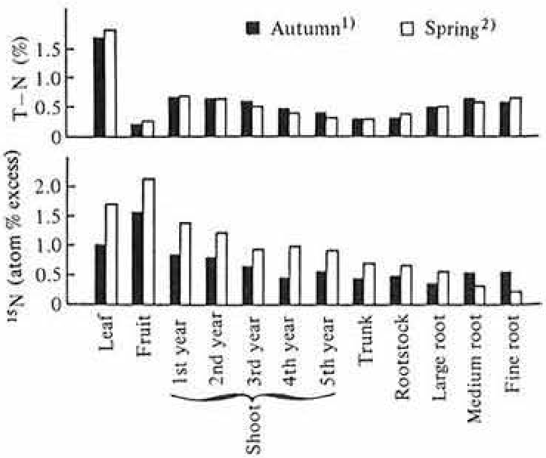

Fig. 3. Contents of fertilized ^{15}N and total nitrogen in apple trees sampled in Nov. after harvest
1): ^{15}N-nitrogen applied in early Dec.
2): ^{15}N-nitrogen applied in middle Mar.
Source: Miyakawa et al. (1988)[6].

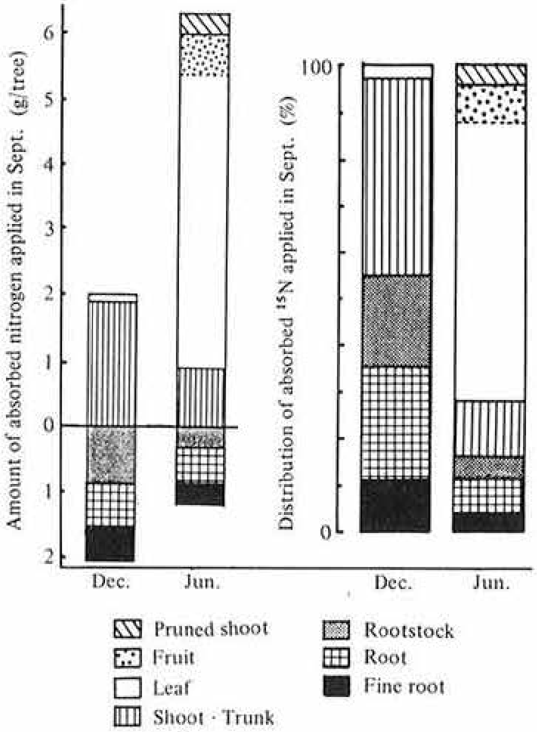

Fig. 4. Absorption and distribution of nitrogen fertilized in autumn (Sept.) in apple trees
Source: Komamura et al. (1989)[5].

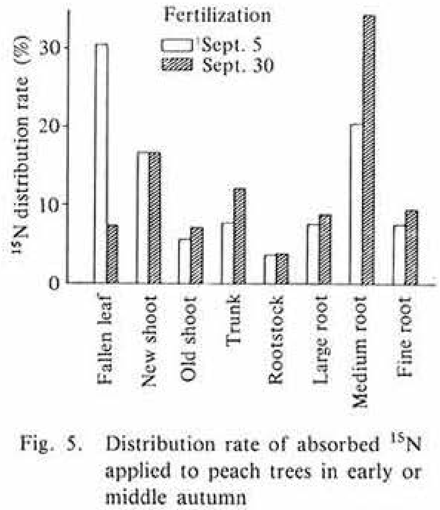

Fig. 5. Distribution rate of absorbed ^{15}N applied to peach trees in early or middle autumn
Source: Sasaki et al. (1978)[11].

et al. estimated the absorption rates of ^{15}N basal dressing in different growth stages of "Kyoho" grape trees grown in pots[3]. The absorption rate of nitrogen was high in the first half of growing period, or before blooming, which declined thereafter. Total amount of nitrogen in the whole tree at the matured time was 1.68 times as much as the nitrogen stored before fetilization. The nitrogen contents particularly increased in proportion to the increment in their dry matters. The ^{15}N contents were also high in these parts.

Nakada et al. examined the absorption and distribution of fertilizer nitrogen applied in different seasons in a vine yard, using 10.3 atom % excess ^{15}N-labelled ammonium sulfate as a tracer[10]. Grape variety "Kyoho" was very sensitive to nitrogen nutrition. Under a high level of nitrogen contents, flowers did not grow well and fruiting was abnormal, called "shatter". Under volcanic ash soils with rich humus on a surface layer, grape trees absorbed nitrogen from soil stock and the rates of absorption from applied fertilizer were 11–22%. A greater amount of fertilization induced a large rate of absorption from fertilizer, as shown in Table 2. When the vigor of trees was low, application of nitrogen before blooming accelerated time of fruiting and growth, while for the plants with high vigor, it gave an adverse effect.

Nitrogen pool of grass in orchard

In many apple and peach orchards, soil surface is covered by grass in a form of sod. Under such a condition, fertilized nitrogen is mainly absorbed by the grass. Sato et al. pursued circulation of the fertilizer nitrogen applied to orchardgrass in the apple orchard[13]. The grass was cut 5 times a year. It was estimated that the nitrogen absorbed by orchardgrass was composed of 53% from soils, 38% from fertilizer and 9% from returned grass. This implies that the absorbed nitrogen in grass circulates slowly around the surface layer of soils and plays just as nitrogen of slow-release fertilizers.

Sato made a comparative study on the movements of fertilizer nitrogen in apple orchards between clean culture and sod culture[12]. A rate of 36% of the fertilizer nitrogen was absorbed by apple trees under clean culture within a year, while 70% of the fertilizer nitrogen was absorbed by orchardgrass and only 1% by apple tree under sod culture, as shown in Fig. 6. This result indicates that the nutrition of apple trees under sod culture depends heavily on

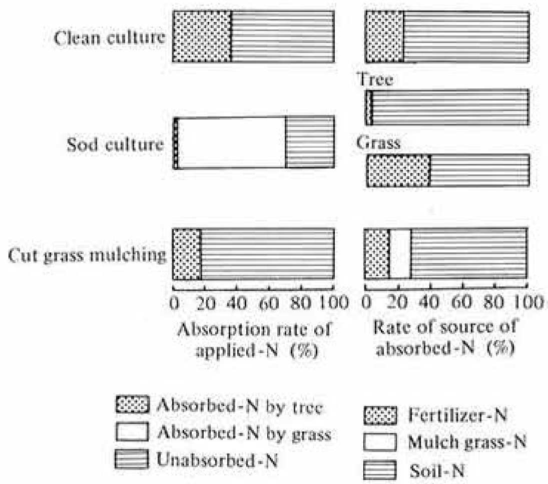

Fig. 6. Absorption rate and source of absorbed-N in apple trees
Source: Sato et al. (1982)[12].

Table 2. Amount and rate of nitrogen from different sources in 2 levels of fertilization in grape trees[a)]

N source	Amount of N in tree (g)		Rate of N source (%)	
	1N	3N	1N	3N
Total amount of N	138.32	210.27	100	100
Reserved N	33.79	33.79	24.4	17.4
Absorbed N from fertilizer	15.61	45.73	11.3	21.7
Absorbed N from soils	88.92	130.75	64.3	62.2

a): Amount of ^{15}N-labelled $(NH_4)_2SO_4$ applied on Apr. 27.
1N: 27 g N/tree, 3N: 81 g N/tree.
Source: Nakada et al. (1979)[10].

nitrogen fertility of soils rather than on nitrogen from fertilizer.

Komamura et al. examined competition in absorption of ^{15}N applied in autumn between apple trees with dwarf rootstocks and a few species of grass[4]. The order in the nitrogen absorption rate of grass was as follows: orchardgrass > perennial ryegrass > Italian ryegrass > ladino clover. The ^{15}N uptake by apple trees was lessened in the plots where the growth of grass was more vigorous.

Nitrogen circulation in orchard

In orchards, fruit production and field managements continue every year for many years. Fertilizer nitrogen and absorbed nitrogen move around in the orchard in the form of nutritional circulation. Suzuki and Sato pursued reutilization of nitrogen in fallen parts of trees on the orchard of young dwarf apple trees, using ^{15}N[16]. Out of the fertilizer nitrogen, 16% was absorbed by apple trees during the 15-month period of April to June in the following year. About 50% of the absorbed nitrogen was distributed in leaves, and fruits and pruned shoots in the first year, which were parts fallen on soil surface and removed from the orchard, respectively. The estimated reutilization of the nitrogen fallen on orchard was that 5–8% of the nitrogen contained in thinned young fruits and 7% of the nitrogen in fallen leaves were absorbed again by apple trees and orchardgrass. Another half of the absorbed nitrogen was stored in trees. Out of the stored nitrogen, 63% was translocated to newly produced parts in the following year.

In the above experiment, the concentration of ^{15}N in labelled fertilizer was 10 atom % excess. However, the excess % of ^{15}N contained in the fallen leaves and the thinned fruits was 1.24 and 1.08, respectively. These concentrations were too low for the following analysis in the secondary trace. As shown in Table 1, concentrations of ^{15}N in labelled fertilizers are quite often less than 10 atom % excess. It is likely that in a short-term experiment using grass and young trees planted in pots, the labelled fertilizer even with 3 atom % excess could be traced effectively.

Nitrogen tracing in organic matters in orchard

Since many of the orchards in Japan are located on a slope land, due attention has to be paid to improvement and conservation of soils. Toward that end, effectiveness of soil surface management and application of organic matters should be carefully examined.

Ishitsuka et al. undertook a study on translocation of nitrogen, using ^{15}N, in barley-straw mulch and inorganic fertilizer in a Japanese pear orchard[2]. Within a year after application of these materials on soil surface, 9.6% of the nitrogen contained in the straw mulch remained in straw, 15.6% were translocated to the soil and the rest was denitrified or leached away. In regard to the nitrogen from fertilizer, 4% of the applied nitrogen was translocated to mulch straw and 25.5% was to soils, while 51.7% of the nitrogen fertilized remained in the soils without straw mulching, as shown in Table 3. It is presumed that the barley-straw mulch increased unsoluble organic nitrogen in the soils, but a greater amount of nitrogen was lost by denitrification under the straw mulch than the case under clean culture under an acidic soil condition (pH 5.1 in H_2O).

Sawada et al. carried out a study on the improvement of reclaimed vineyard soil through application

Table 3. Nitrogen movement in barley-straw mulch in pear orchard

Treatment[a)]	Rate of remained ^{15}N (%)		Rate of translocated ^{15}N (%)		Rate of denitrification (%)	Rate of denitr. & leaching (%)
	BSM	Soil	F→BSM	BSM→Soil		
BSM-^{15}N + F-^{14}N	9.6	–	–	15.6	–	74.9
BSM-^{14}N + F-^{15}N	–	25.5	4.0	–	–	70.5
BSM-^{14}N + F-^{15}N[b)]	–	42.8	13.9	–	43.3	–
F-^{15}N	–	51.7	–	–	–	48.3

a): BSM; Barley-straw mulch, F; Fertilizer $(NH_4)_2SO_4$.
b): Tested under the condition preventing rain-water leaching.
Source: Ishitsuka et al. (1976)[2].

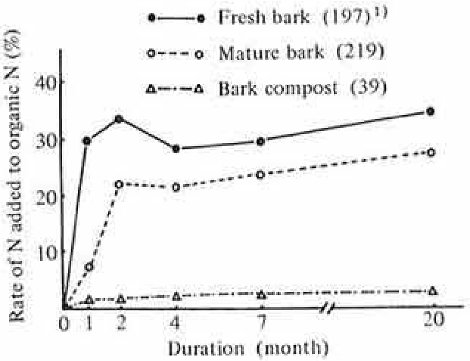

Fig. 7. Changes in rates of nitrogen added to organic nitrogen in pot incubation
1): C/N ratio at start.
Source: Sawada et al. (1988)[14].

of organic matters[14]. They identified some characteristics of decomposition of woody bark and its compost incubated for 20 months with 10 atom % $^{15}NH_4$ under a pot experiment condition. The rate of immobilization of nitrogen in the first month after ^{15}N addition was 30% in fresh bark and 8% in mature bark, while in bark compost, no immobilization was observed, as shown in Fig. 7. Based on this result, it was estimated that to avoid nitrogen starvation, the amount of nitrogen to be added was more than 1.5 and 1.0 kg/t dry matter of fresh bark and mature bark, respectively.

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