

Translocation and Distribution of ^{14}C -Photosynthates Assimilated in Different Seasons by Young Tea Plants

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Growth of new shoots for the first crop (spring crop, the most important one in tea farming) exceeds the amount of net production by photosynthesis in the season⁷⁾, resulting in a marked decrease of reserve carbohydrates in plants. It suggests that the growth of new shoots for the first crop depends on both accumulated carbohydrates produced by photosynthesis in the autumn and winter seasons, and photosynthates produced in the spring season⁶⁻¹¹⁾. These three seasons differ each other as to plant conditions such as maturity level of assimilative leaves, and presence or absence of developing new shoots, and environmental conditions after photosynthesis such as temperature, so that it seems that the role of photosynthates produced in the different seasons to be played for the growth of new shoots of the first crop might be different.

From this viewpoint, translocation and distribution patterns of photosynthates produced in each of the spring, summer, autumn,

and winter seasons were studied by using the ^{14}C -tracer²⁻⁵⁾.

Materials and methods

Two-year-old plants of cultivar Yabukita were planted in Wagner pots (1/5000 are), and fed ^{14}C by photosynthesis (Table 1). After that, the whole plants were sampled from time to time to examine translocation and distribution of photosynthates. Immediately after the plants were separated into different organs, they were chopped to less than 1 mm (leaves and rootlets were homogenated), and put into hot 80%-ethanol. The extraction was repeated until ^{14}C activity in the final extracts showed less than 2% of the total activity of each organ.

The ethanol insoluble residue was converted to $^{14}\text{CO}_2$ by an automatic sample combustion system, except a part of it was treated with 0.8N sulfuric acid to separate it into sulfuric acid soluble fraction (reserve carbo-

Table 1. Condition for ^{14}C assimilation of tea plants

Date of ^{14}C assimilation		Temperature	Light intensity	Assimilation time	$^{14}\text{CO}_2$ activity (CO ₂ conc.)
Spring	Mar. 24, 1977*	16.5°C	30 klx	4 hr.	700 μCi (0.1%)
Summer I	May 22, 1980**	23	30	2.5	1000 (0.1%)
Summer II	July 24, 1980***	27	30	2.5	1000 (0.1%)
Autumn	Oct. 25, 1978	19.5	30	4	1000 (0.1%)
Winter	Dec. 16, 1976	13.5	30	4	700 (0.1%)

* Bud opening time of the 1st crop.

** The first flush shoots were picked leaving lower two leaves on May 19, 1980.

*** The first and second flush shoots were picked leaving lower two leaves on May 19, and July 21, 1980, respectively.

Table 2. Distribution (%) of ^{14}C in each organ at various seasons

Date of ^{14}C assimilation	Sample No.	Days after ^{14}C -feeding	^{14}C activity*	New shoot**	Leaf***	Branch	Trunk	Thick & medium root	Rootlet	Total
Autumn Oct. 25, 1978	A1	1	196		56.6	8.3	11.1	13.6	10.4	100
	A2	34	107		40.1	9.6	5.1	19.2	26.0	100
	A4	98	76		38.6	7.7	5.1	32.4	18.2	100
	A5	131	98		26.5	8.5	5.7	25.4	33.9	100
	A7	191	63	10.9	16.1	15.1	7.6	21.0	29.3	100
	A9	265	51	0.4	25.8	13.1	13.3	21.5	28.9	100
Winter Dec. 16, 1976	W1	0	125		93.1	5.1	1.4	0.2	0.2	100
	W2	1	95		66.4	5.3	7.6	16.6	4.1	100
	W3	46	93		25.0	6.7	9.9	45.7	12.7	100
	W4	83	89		23.7	8.8	12.9	43.4	11.2	100
	W5	148	38	13.9	6.2	11.2	12.3	37.2	19.2	100
	W7	226	28	0.6	19.7	15.0	10.0	27.7	27.0	100
Spring Mar. 24, 1977	Sp 1	1	97	2.7	64.7	5.4	17.4	7.2	2.6	100
	Sp 2	28	48	37.6	12.1	8.9	5.0	6.3	30.1	100
	Sp 3	43	28	52.7	3.1	7.7	2.5	8.7	25.3	100
	Sp 6	124	21	1.6	40.2	26.2	4.5	7.3	20.2	100

* ^{14}C activity: dpm $\times 10^6$ /plant Fr. Wt.

** A7, W5, Sp1-3: 1st crop, A9, W7, Sp6: 2nd crop.

*** A9, W7, Sp6: Mature leaves on residual 1st crop shoots.

hydrate) and sulfuric acid insoluble fraction (structural carbohydrate)¹¹.

^{14}C -activity of these samples was measured with a liquid scintillation counter.

Movement of ^{14}C assimilated at different seasons

1) Movement of ^{14}C assimilated in the autumn season³⁾

During a period of one month after the ^{14}C -feeding, about 45% of the ^{14}C activity in the plants was lost. This loss occurring in an early period after ^{14}C -feeding was commonly recognized at any season (Table 2), although the extent of the loss was considerably different with different seasons as shown later. During that period, leaf fall was hardly observed, and the loss occurred in free sugars of the ethanol soluble fraction⁴⁾. This loss, therefore, is inferred to be the consumption by respiration^{4,9)}.

Of the total ^{14}C assimilated in the autumn, except that consumed by respirations, 57%, 19% and 24% were distributed into leaves,

branches and trunks, and roots, respectively, one day after the ^{14}C -feeding. From 70 to 90% of the ^{14}C distributed into each organ was incorporated into the ethanol soluble fraction, mostly in the neutral fraction, while 60-90% of the ethanol insoluble fraction was contained in the sulfuric acid soluble fraction (reserve carbohydrate). Such a proportion of ^{14}C distribution one day after the ^{14}C feeding was almost similar for plants treated in winter²⁾, spring³⁾ or summer⁵⁾, hardly showing differences by presence or absence of growing new shoots, or different temperature conditions during the growth.

During one month period after that, the assimilated ^{14}C was translocated into roots, and in each organ the ethanol soluble fraction decreased while the ethanol insoluble fraction increased. As given in Fig. 1, it is considered that the ^{14}C remaining in plants was stored in the subterranean part in the ethanol insoluble form in the winter, and then retranslocated to the aerial part in the spring to contribute the development of new shoots for the first crop. Majority of the ethanol

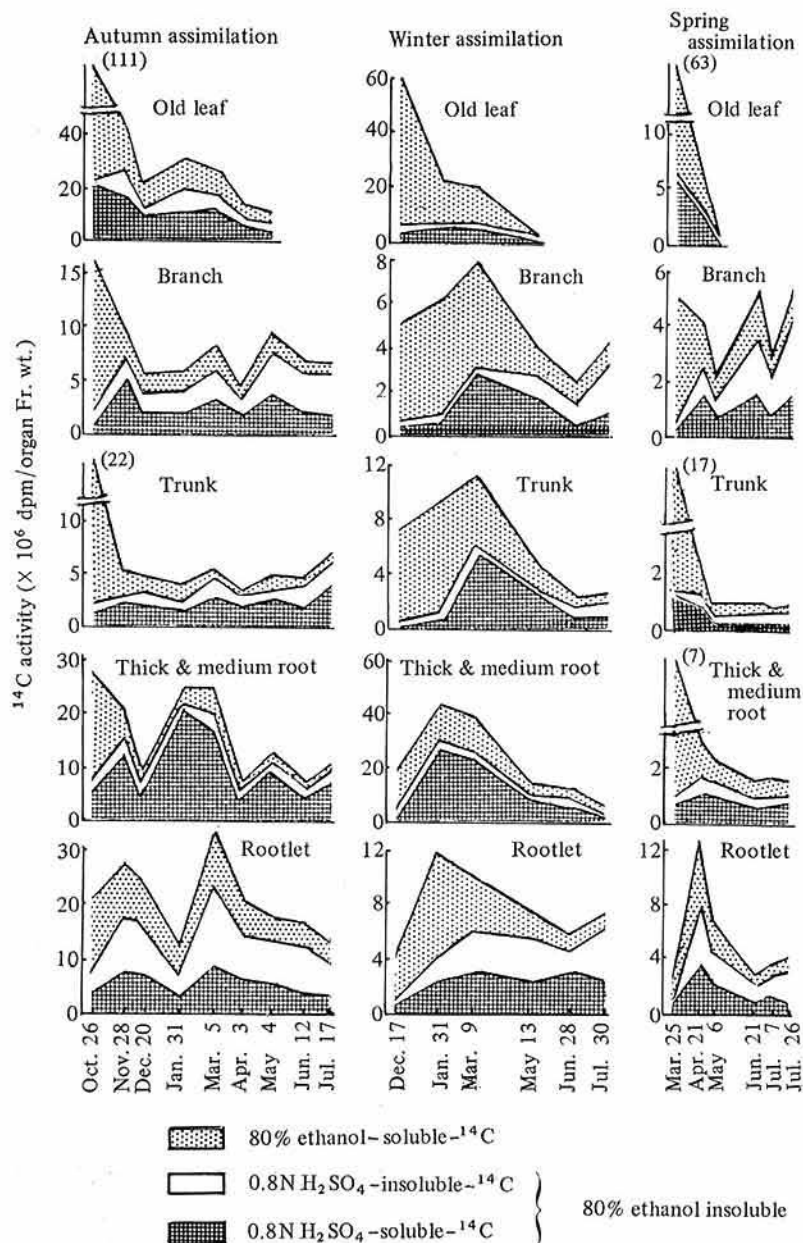


Fig. 1. Seasonal changes in radioactivities of ^{14}C -photosynthates of tea plants

insoluble form was reserve carbohydrates in old leaves, thick and medium roots, and trunks, and structural carbohydrates in branches and rootlets. This tendency is not necessarily consistent with a previous report⁹⁾ with some aspect, but this difference may be due to differences in treatment after ^{14}C -

feeding, climatic condition, and in storage capacity of trunks and thick and medium roots depending on plant age.

Rate of translocation to the new shoots at the plucking time of the first crop was 11% of the remaining ^{14}C in the plants (3.5% of ^{14}C activity found in the plants within 24 hr

after ^{14}C assimilation). However, at this time, a marked increase in ^{14}C per unit weight of old leaves and branches was recognized⁴⁾. It indicates that ^{14}C -photosynthate was fairly retranslocated from roots into aerial parts during the first crop season. It is inferred from these facts that the reserve carbohydrates are mainly utilized as an energy source for the growth of new shoots, as well as a component of old organs, while the newly produced photosynthate is mainly translocated into new shoots of the first crop.

2) *Movement of ^{14}C assimilated in the winter season²⁾*

The ^{14}C assimilated in the winter season was found to be translocated into stems and roots, because of absence of new leaves which serve as a sink, except 24% of it was consumed by respiration soon after the assimilation, and stored there in the form of ethanol soluble carbohydrates (mainly free sugars)²⁾ or reserve carbohydrates such as starch (ethanol insoluble and sulfuric acid soluble).

During this season, assimilated ^{14}C decreased only slightly (Table 2, $W_2 \sim W_4$), probably because of low rate of respiration due to low temperature in the coldest season and reduced growth, showing a difference^{4,5)} from the autumn season with relatively warm climate and hence active growth.

Afterwards, ^{14}C in thick and medium roots and rootlets was decreased, followed by the decrease of ^{14}C in branches and trunks, prior to the bud opening and development of the first crop shoots. Also, ^{14}C in old leaves decreased, too. These decreases occurred mostly with starch in thick and medium roots, with the ethanol soluble fraction in branches and rootlets, and with starch and ethanol soluble fraction in trunks and leaves (Fig. 1).

However, the amount of translocation into the first crop shoots was only 14% of the total ^{14}C remaining in plant. Furthermore, the total decrease of ^{14}C in these organs far exceeded the loss by defoliation which occurred during this season. These facts suggest that a considerable amount of ^{14}C was lost by re-

spiration. Namely, it seems that the assimilation products in the winter season without a major sink, i.e. growing shoots, were translocated, except those consumed as a respiratory substrate soon after the assimilation, into stems and roots and stored temporarily as reserve substances. At the time of growth of the first crop shoots, they were translocated into aerial parts¹⁰⁾ and utilized for new shoot formation and as an energy source for it.

3) *Movement of ^{14}C assimilated in the spring season³⁾*

About 70% of ^{14}C assimilated in the spring (bud opening time of the first crop) was lost by respiration of each organ and by defoliation during the development of new shoots of the first crop. During this period, 53% of the remaining ^{14}C was translocated into the new shoots, and ratio of ^{14}C distribution to rootlets was also increased. From these results, it was inferred that ^{14}C assimilated in the spring was translocated actively into rapidly growing organs (Table 2). Transformation into ethanol insoluble fraction occurred actively: incorporation into sulfuric acid insoluble fraction in branches and rootlets, and into sulfuric acid soluble fraction in trunks and thick and medium roots (Fig. 1).

Translocation of ^{14}C assimilated in the spring into new shoots of the second crop was only 1.6% of the remaining ^{14}C . However, relatively high rates of ^{14}C distribution were observed in mature leaves and branches (Table 2, Sp6). This finding seems to suggest that the photosynthate newly produced in the second crop season is translocated into new shoots of the second crop, while ^{14}C assimilated in the spring is utilized as an energy source for the growth of the second crop new shoots and as a component of mature leaves. Namely, the development of new shoots is supported by photosynthate obtained during the period of the development and reserve carbohydrates derived from photosynthate produced in the preceding period, but the former constitutes a major translocation into new shoots.

Table 3. Distribution (%) of ^{14}C in each organ

Date of ^{14}C assimilation	Sample No.	Days after ^{14}C -feeding	^{14}C activity*	Fraction***	New shoot**	Leaf	Branch	Trunk	Thick & medium root	Rootlet	Total
Summer I May 22, 1980	S11	0	217	ES EIS		68.8 19.8	7.3 0.6	3.2 0.1	0.1 tr.	0.1 tr.	79.5 20.5
	S12	1	72	ES EIS		37.0 24.7	8.3 4.4	5.4 0.4	5.8 1.2	10.7 2.1	67.2 32.8
	S14	62	83	ES EIS	0.9 0.8	32.4 32.5	2.6 15.1	0.7 3.5	1.0 3.0	3.0 4.5	40.6 59.4
	S15	113	87	ES EIS	0.2 0.1	30.9 38.1	2.4 13.5	1.2 3.3	1.2 2.1	2.2 4.8	38.1 61.9
	S21	1	126	ES EIS		55.4 11.2	4.0 0.8	9.0 0.9	5.4 0.2	10.4 2.7	84.2 15.8
Summer II July 24, 1980	S23	42	42	ES EIS	1.3 1.4	11.7 14.6	2.7 23.5	2.7 14.0	3.1 7.4	6.4 11.2	27.9 72.1

* ^{14}C activity: dpm $\times 10^6$ /plant Fr. Wt.

** S14: 2nd crop, S15, S23: 3rd crop.

*** E E: 80% ethanol-soluble ^{14}C , E I S: 80% ethanol-insoluble ^{14}C .4) Movement of ^{14}C assimilated in the summer season⁵⁾

Majority of leaves left after plucking the first crop were immature leaves grown during the first crop season, and buds of the second crop were recognized still undeveloped by the naked eye. It took 25 days from the ^{14}C feeding to the bud opening. Therefore, the sink for the ^{14}C assimilated at this time is maturing leaves on residual shoots of the first crop, as well as growing stems and roots. As the result, most of the assimilated ^{14}C was lost by respiration at an early stage after the ^{14}C -feeding, and the rest was distributed into each plant part (especially in leaves) in the form of ethanol insoluble fraction (Table 3). It hardly translocated into new shoots of the second crop.

After the plucking of the second crop, buds of the third crop are still undeveloped when observed by the naked eye, and it took 25 days from the ^{14}C -feeding to the bud opening. However, the assimilating leaves are composed of 65% of mature leaves on the residual first crop shoots and 35% of maturing leaves on the residual second crop shoots, showing an increased source activity. On the other hand, stems and roots have exhausted their

nutrients by the first and second pluckings. Accordingly, it was inferred that ^{14}C assimilated after the second plucking hardly translocated into new shoots of the third crop, but was mostly translocated into stems and roots to enrich plant body, except those lost by respiration.

Based on these results, it was made clear that the rate of translocation of ^{14}C assimilated in different seasons into new shoots of the first crop is highest for the spring assimilation, followed by the winter assimilation, and autumn assimilation. In other words, the nearer the time of assimilation to the time of new shoot development for the first crop, the more assimilate is used for the new shoots. At the same time, ^{14}C assimilated in the season prior to the new shoot development is not only used to enrich plant body, but also accumulated as reserve carbohydrates to be utilized as an energy source for the new shoot development. This fact suggests that reserve carbohydrates play an important role for the development of new shoot.

From the results of the present study, it was clarified that in the tea plant, a perennial evergreen tree, from which leaves, an assimilating organ, are removed repeatedly, accu-

mulation and translocation of these reserve carbohydrates are largely influenced by plant conditions (degree of maturity and quantity of leaves as a photosynthetic organ, extent of exhaustion in storage organs, and with or without growing new shoots and their stage), environmental conditions after the photosynthesis, and with or without leaf fall. Further studies on details of the relationship between these conditions and accumulation of reserve carbohydrates have to be done in future, in order to know how to increase the amount of reserve carbohydrate accumulation.

References

- 1) Akao, S. et al.: Studies on the translocation of photosynthates in alfalfa. II. The effects of phosphorus and adenosine-5'-triphosphate (ATP) on the translocation and distribution of photosynthates. *Bull. Shikoku Agr. Exp. Sta.*, No. 31, 133-146 (1978) [In Japanese with English summary].
- 2) Hakamata, K. & Sakai, S.: Translocation and redistribution of $^{14}\text{CO}_2$ -photosynthates assimilated in winter leaves in the young tea plant. *Study of Tea*, No. 58, 11-20 (1980) [In Japanese with English summary].
- 3) Hakamata, K. & Sakai, S.: Translocation and redistribution of $^{14}\text{CO}_2$ -photosynthates assimilated in spring leaves in the young tea plant. *Study of Tea*, No. 58, 21-28 (1980) [In Japanese with English summary].
- 4) Hakamata, K. & Sakai, S.: Translocation and redistribution of $^{14}\text{CO}_2$ -photosynthates assimilated in autumn leaves in the young tea plant. *Study of Tea*, No. 61, 11-21 (1980) [In Japanese with English summary].
- 5) Hakamata, K. & Sakai, S.: Translocation and redistribution of $^{14}\text{CO}_2$ -photosynthates assimilated in the tea plant after plucking of the 1st and 2nd crop shoot respectively. Abst., 1982 meeting, Soc. Sci. Soil & Manure, Jpn., 98 (1982) [In Japanese].
- 6) Harada, S. et al.: Studies on the cold resistance of the tea plant. I. The relation between the cold resistance and some physiological factors of the tea plant. *Bull. Tea Division, Tokai-kinki Agr. Exp. Sta.*, No. 7, 3-24 (1960) [In Japanese with English summary].
- 7) Harada, S., Kano, T. & Sakai, S.: Studies on the assimilation of carbon in tea plant. V. On the assimilation of carbon in mature tea garden. *Study of Tea*, No. 25, 1-10 (1961) [In Japanese with English summary].
- 8) Sanai, H. et al.: Studies on the changes of internal constituents with the growth in young tea plant. *Bull. National Research Institute of Tea*, No. 4, 1-33 (1967) [In Japanese with English summary].
- 9) Konishi, S. & Kasai, Z.: The metabolism and regulation of theanine and its related compounds in the tea plant. III. Translocation and metabolic changes of the $^{14}\text{CO}_2$ assimilated products in tea plants during autumn. *J. Sci. Soil Manure Jpn.*, 39, 444-446 (1967) [In Japanese].
- 10) Manivel, L.: Role of maintenance foliage. *Two and A Bud*, 27(2), 52-55 (1980).
- 11) Manivel, L., Hussain, S. & Sarma, A.K.: Seasonal changes in distribution of photosynthates in tea. *Two and A Bud*, 28(10), 15-18 (1981).

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