Studies on the Translocation of Photosynthates in Satsuma Mandarin

II. Effect of Root Environmental Conditions on the Translocation of ^{14}C

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Summary

Effects of water stress and H-ion concentration on the rate of translocation of ^{14}C -labeled photosynthates in Satsuma mandarin trees were studied.

When the root growth was suppressed, translocation to the remaining plant parts (growing areas) was decreased and more ^{14}C was accumulated in the leaves.

In the plot of pH 3.0 a little decrease in the rate of translocation to fruits was observed, while in the plot of water stress the accumulation of ^{14}C in the juice was heavily decreased.

Water stress caused an increase in total sugar concentration of the juice. It seems likely that this was partly a result of the concentration effect arisen from water stress. However, in this case other factors such as polisaccharide metabolism may also play an important role in the process of sugar accumulation in the juice.

Introduction

In the previous paper, it was pointed out that during the early stage of shoot growth, a large amount of ^{14}C was translocated to the developing shoots and fruits. The distribution pattern of ^{14}C within a tree was strongly affected by such developing parts (2).

This paper deals with the effect of some root environmental conditions on the translocation of photosynthates in Satsuma mandarin trees.

H-ion concentration of culture solutions and the distribution of ^{14}C

Materials and methods

One-year-old Satsuma mandarin trees were grown in sand culture. As was described earlier, ^{14}C was used as a tracer. On August 26, 1969, $^{14}\text{CO}_2$ was generated in a feeding chamber and the leaves were exposed to the tracer gas for three hours, from 10:00 AM to 1:00 PM. The activity of ^{14}C used in this experiment was 70 μCi per tree. Immediately after $^{14}\text{CO}_2$ feeding, pH of the culture solution was adjusted to 3.0 and 6.8 with HCl or NaOH. The plot of pH 6.8 is referred to as the control. Samples were

collected 72 hours after $^{14}\text{CO}_2$ treatment. The procedures of ^{14}C analysis have been described in the previous paper (2).

Results

Table 1 shows the effect of H-ion concentration on the distribution of ^{14}C . Although the dry weight of summer cycle shoots was trivial to that of a whole tree, ^{14}C activity in those shoots was very high. This agreed with the data mentioned in the previous paper (2).

The percentage of ^{14}C translocated to the roots was 33.5 in the control plot while in the plot of pH 3.0, it was only 22.6. It seems reasonable to assume that the translocation of ^{14}C to the roots may have been affected by unfavorable conditions for root growth. This can be seen not only from the percentage of ^{14}C within a whole tree (Table 1) but also from the total amount of ^{14}C distributed to the underground parts (Table 2).

Effects of water stress and pH of culture solutions on the translocation of ^{14}C in Wase (Early ripening) satsuma mandarin trees.

Materials and methods

Four-year-old trees were used. The experiment consisted of the following treatments:

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Table 1. ^{14}C distribution in one-year-old Wase satsuma trees as affected by pH of nutrient solutions.

	pH of culture solution	Old leaves	Spring cycle leaves	Summer cycle leaves	Branches	Stem	Fibrous roots	Main root
Dry weight*	6.8	8.9	10.7	0.4	5.9	17.3	19.5	36.9
	3.0	8.1	10.8	1.0	4.2	16.9	17.7	40.8
$^{14}\text{C}^{**}$	6.8	16.1	23.7	11.8	6.5	8.1	21.6	11.9
	3.0	15.3	26.3	25.6	2.9	6.8	16.1	6.5

* Per cent of the entire tree.

** ^{14}C as shown in the percentage of total ^{14}C in the plant.Table 2. Total ^{14}C activity of plant parts in one-year-old Wase satsuma trees.

	pH of culture solution	Old leaves	Spring cycle leaves	Summer cycle leaves	Branches	Stem	Fibrous roots	Main root
Dry weight (g/tree)	6.8	6.66	8.00	0.31	4.44	12.87	14.56	27.48
	3.0	7.24	9.64	0.95	3.75	15.07	15.78	36.26
$^{14}\text{C}(\mu\text{Ci}/\text{tree})$	6.8	4.23	6.20	3.11	1.71	2.12	5.66	3.13
	3.0	3.88	6.66	6.48	0.75	1.74	4.07	1.66

Table 3. ^{14}C distribution in 4-year-old Wase satsuma trees as affected by pH and water stress.

	Treatment		Fruits	Leaves	Stem & braches	Roots
	pH of culture solution	Moisture				
Dry weight*	3.0	High	21.5	19.8	28.5	29.8
	6.8	Stressed**	26.8	19.3	24.3	29.0
	6.8	High	20.5	19.7	27.1	32.3
$^{14}\text{C}^{***}$	3.0	High	23.8	47.7	17.0	11.2
	6.8	Stressed	16.8	46.9	20.7	15.2
	6.8	High	23.8	37.0	15.7	23.1

* Per cent of the entire tree.

** Moisture was stressed during the first 24 hours after the $^{14}\text{CO}_2$ treatment.*** ^{14}C as shown in the percentage of total ^{14}C in plant.Table 4. ^{14}C activity of plant parts in 4-year-old Wase satsuma trees*.

Treatment		Peel	Juice**	Leaves	Branches		Stem	Fibrous roots	Main root
pH of culture solution	Moisture				small	large			
3.0	High	0.123	0.019	0.314	0.116	0.077	0.059	0.075	0.026
6.8	Stressed	0.114	0.007	0.300	0.147	0.113	0.083	0.119	0.022
6.8	High	0.127	0.020	0.215	0.138	0.053	0.045	0.180	0.036

* $^{14}\text{C}\mu\text{Ci}$ per gram dry weight.** $^{14}\text{C}\mu\text{Ci}$ per ml juice.

1) Immediately after $^{14}\text{CO}_2$ feeding, pH of the culture solutions was adjusted to 3.0 and the solutions were supplied throughout the experiment; 2) During the first 24 hours, the trees were grown without any water supply. Thereafter, the culture solution having a pH of 6.8 was supplied; 3) The culture solution

adjusted to pH 6.8 was supplied from the beginning to the end of the experiment. In all the treatment plots, samples were collected 72 hours after $^{14}\text{CO}_2$ feeding and then ^{14}C analysis was performed.

Results

The distribution of ^{14}C was shown in Table

3. The translocation of ^{14}C to fruit was not inhibited by high acid conditions. These results may be confirmed further in Table 4. However, under the water stressed conditions, ^{14}C activity in the juice was about one third as compared with that of the control.

The distribution of ^{14}C to the roots was decreased in both pH 3.0 and water stressed plots (Table 3 and 4). In the leaves of the control plant the activity of ^{14}C was lowest. This shows that in the control plant the translocation of photosynthates out of leaves was very active.

Effect of water stress under field conditions on moisture and sugar contents in fruits.

Materials and methods

It has been reported that under water stressed conditions the sugar contents in the fruits were increased (6). However, the results mentioned above seems contradictory to the generally accepted experiences on the effect of water stress. Thus, it may be significant to clarify the effect of water stress on the sugar concentration of the juice from the viewpoint of the translocation of photosynthates.

For the field investigations, four commercial citrus groves were chosen. Two were located in Matsuyama area, and the other two were in Yawatahama area. In each citrus grove, two treatments were made. In the check plot, furrow irrigation was performed every 10 days from early September to early October. Twenty mm of water was supplied each time. In the water stressed treatment, however, no irrigation was supplied. Precipitation at Matsuyama and Yawatahama in the autumn of 1969 are shown in Table 6. Each plot consisted of 3 trees. Five fruits per tree were sampled. Varieties and sampling date were shown in Table 5. Immediately after the sampling, the fresh peel and pulp were weighed, oven dried at 100°C and reweighed. Moisture content was calculated from the data obtained. Total sugars in the juice was analyzed by a Somogy-Nelson procedure.

Results

Fruit growth was decreased with increasing water stress (Table 7). However, the dif-

Table 5. Four citrus groves where fruits were sampled for the analysis of moisture and sugar contents of fruits.

Citrus grove	Location	Age of tree (Yr.)	Variety	Sampling date
1	Matsuyama	48	Ikedo	Oct. 29, 1969
2	Matsuyama	15	Owari	Nov. 11, 1969
3	Yawatahama	8	Nankan No. 4	Nov. 20, 1969
4	Yawatahama	8	Miyagawa	Nov. 20, 1969

Table 6. Precipitations at Matsuyama and Yawatahama in the autumn of 1969.

Location	September	October	November
Matsuyama	16.5 mm	41 mm	65 mm
Yawatahama	17.0	74	78

ference in fruit weight was not always significant between the treatments. Moisture content in the pulp and peel was always high in the check plot. On the other hand, sugar contents were decreased with increasing water supply. As for the moisture and sugar contents in the pulp, it can be said that the rate of the increase in the latter is greater than that of the decrease in the former. In order to simplify the explanation about the 'concentration effect' of moisture, the following approximate estimation may conveniently be used. It is exemplified in fruits from the first grove shown in Table 7. In the control plot, moisture content of pulp per fruit is estimated as follows:

$$64.37 \times 88.68 \times \frac{1}{100} = 57.08\text{g}$$

Then if the juice content is assumed to be equal to the moisture content, an approximate estimate of sugar content of the juice per fruit may be

$$8.85 \times \frac{1}{100} \times 57.08 = 5.05\text{g}$$

Further, if it can be assumed here that in the water stressed plot a moisture loss occurred without any changes of sugar metabolism, water content in the pulp is

$$64.37 \times 85.04 \times \frac{1}{100} = 54.74\text{g}$$

where the value 85 indicates the water content in per cent of the pulp of water stressed fruit. Thus the total sugar content per 100 ml of juice can be estimated as follows:

Table 7. Effect of water stress on the sugar contents in Satsuma mandarin fruits.

	Treatment	Citrus grove*			
		1	2	3	4
Pulp weight (gram)	Control	64.37	91.91	93.21	100.87
	Stressed	60.63	77.83	59.93	91.79
	Significance	NS	NS	10.55	8.81
Pulp moisture content (per cent)	Control	88.68	87.62	87.42	88.70
	Stressed	85.04	84.99	84.26	83.80
	Significance	0.35	0.59	0.79	0.86
Peel moisture content (per cent)	Control	73.77	73.00	73.17	74.75
	Stressed	69.95	70.80	67.43	68.02
	Significance	1.29	1.75	3.14	1.04
Total** sugar content (as glucose)	Control	8.85	9.19	10.34	9.44
	Stressed	9.54	11.93	12.12	13.42
	Significance	0.65	0.90	0.91	0.57

* Same as in Table 5.

** Grams per 100 ml juice.

$$\frac{5.05}{54.74} \times 100 = 9.22g$$

An increase from 8.85 to 9.22 may imply a concentration effect of moisture. It is important, however, that in the water stressed plot the sugar content was 9.54 which is somewhat higher than the calculated value 9.22. Similar results were obtained in the fruit from the other groves shown in Table 7.

Discussion

In the previous paper, it was pointed out that normally developing fruits and shoots had the capacity as strong sinks and affected the distribution pattern of ^{14}C within the tree.

The purposes of the present investigation were to clarify the effect of root environmental conditions on the distribution of photosynthates among plant parts. As was mentioned previously, an application of culture solutions with high acidity caused a decrease of ^{14}C translocation to the roots. This may be intimately related to the suppressing effect of the solution on the root growth. When a developing plant part was suppressed or injured, it may become weak as a sink. As for the translocation to the shoots and fruits, a considerable amount of ^{14}C was translocated even in the plot of pH 3.0. In the water stressed plot, however, the translocation was

heavily depressed.

When the sugar concentration of the juice increases, the two possibilities can be expected as follows;

1) As the water supply decreases, the juice is concentrated so that the sugar concentration increases even in the case where no change in the total amount of sugars of the juice results.

2) The absolute increase in the translocation of photosynthates to fruit occurs.

As shown in Table 7, it is true that moisture content was low in the water stressed plot. Considering the fact that the rate of the increase in sugar concentration is greater than that of the concentration effect of moisture in the juice, the first assumption is not enough to explain the mechanism of sugar accumulation in the juice. Thus, the second factor mentioned above must be considered as a possible mechanism. However, the data obtained in this experiment was not the case. The result agrees with that of POSSINGAM et al.(5). They noticed that a water stress of the type in which no visual symptoms were displayed completely inhibited the translocation of photosynthates. THOMPSON et al.(8) pointed out that the rate of photosynthesis was decreased with decreasing soil moisture or relative humidity and watering the plant

caused an immediate increase in photosynthetic rate. SUZUKI et al. also noticed that a reduction in soil moisture resulted in a decrease in the rate of apparent photosynthesis (7). KRIEDEMANN et al. (3) stated that above 20°C of leaf temperature the rate of photosynthesis increased with increasing relative humidity. From these results, it may be safe to say that there is no room to support the second factor.

PLAUT et al. (4) reported that the amount of ^{14}C which moved out of the leaf was much reduced by water stress, but the concentration of ethanol-soluble ^{14}C in the lower parts of stressed plants eventually surpassed that of the control plants. They postulated that this, at least, was due partly to the superior rate of synthesis of ^{14}C -sucrose into ethanol-insoluble compounds in the controls.

HILLER et al. (1) noticed that using a unicellular alga, *Chlorella pyrenoidosa*, water deficit reduced the incorporation of ^{14}C -glucose into methanol insoluble compounds, whereas it increased the incorporation of ^{14}C into sucrose. URSINO et al. (9) also pointed out that a more rapid conversion of translocated materials into the ethanol-insoluble form occurred in plants grown under higher soil moisture conditions. These reports show consistently that under water deficient conditions the translocation of photosynthates into sinks become inactive and at the same time the transformation to polysaccharides is also depressed so that the ratio of alcohol-soluble fraction to the total translocated sugars increases.

Turning now to the fruits which have been grown under water stressed conditions, it seems reasonable to assume that not only a concentration effect of moisture but also a suppression of polysaccharide synthesis resulted in an increase of sugar content in the pulp.

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温州ミカンの光合成産物の転流および分配に関する研究 (第2報)

根の生育環境の相違が ^{14}C の転流に及ぼす影響

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摘 要

1. 砂耕栽培の1年生温州を供試し、水素イオン濃度および断水処理により、根の生育環境を変えて、光合成産物の転流のようすを ^{14}C を使つて、追跡した。

2. 根の生長を抑制すると、光合成産物は、葉にとどまる量が多くなり、果実や新しうおよび根に対する転流が悪くなつた。pH 3.0 区で、水分供給が十分にある状態では、果実や新しうへの転流が、少し押えられた

にすぎなかつたが、24時間の断水処理をした場合には、果実への転流が著しく押えられた。

3. 乾燥下で生長した果実の糖度は高いが、その原因を、水分の物理的濃縮のみに帰するには無理があり、上記の結果とも合わせて、果実内での糖の代謝が乾燥下では変わつてくる可能性が指摘された。