Europ.J.Hort.Sci., **68** (5). S. 227–233, 2003, ISSN 1611-4426. © Verlag Eugen Ulmer GmbH & Co. Stuttgart

Effects of Water Stress at Different Deficit Intensities on Transport and Distribution of ^{14}C-Assimilates in Micropropagated Apple Plants

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Summary

Micropropagated 'Fuji' apple plants in Hoagland nutrient solution were subjected to water stress at different deficit intensities by regulating the osmotic potential of the solution with PEG-6000. Transport and distribution of ^{14}C-assimilates among organs of previously water-stressed plants were compared with those under a normal water status by feeding leaves with $^{14}CO_2$. Most ^{14}C-assimilate was exported from the labelled leaves within 48 hours, and there were two peaks of export rate of ^{14}C-assimilate in plants under a normal water status. No matter what deficit intensity was applied to the plants, water stress significantly decreased the export rate of ^{14}C-assimilates from fed leaves, but did not modify the export patterns of ^{14}C-assimilates. About 90 % of the ^{14}C-assimilates exported from the labelled leaves within 48 hours were distributed in the above-ground parts of the plants under a normal water status while from one third to two thirds of the ^{14}C-assimilates were transported from labelled leaves into the roots of the micropropagated plants under water stress depending on the deficit intensity. Moreover, water stress decreased the distribution coefficient (*K*) of ^{14}C-assimilates in the shoot apex, and increased the *K*s of the roots and the phloem of the plants. A lower *K* of the shoot apex of water stressed trees than that of well-watered ones may result in a decreased growth of shoots. The higher *K* of the roots of the plants under water stress may signify a stronger sink and also a greater reservoir of carbon assimilates in the roots than those of the plants under normal water situation. It is suggested that the *K* of the phloem within a short time after feeding the leaves with $^{14}CO_2$ may only signify the quantity of ^{14}C-assimilates transport to the roots or a temporary reservoir of carbon assimilates in the phloem.

Zusammenfassung

Wirkung von Wasserstress unterschiedlicher Intensität auf Transport und Verteilung der ^{14}C-Assimilate bei mikrovermehrten Apfelpflanzen. Mikrovermehrte und in Hoagland-Nährlösung kultivierte Apfelpflanzen der Sorte 'Fuji' wurden unterschiedlichen Intensitäten von Wasserstress ausgesetzt, wobei der osmotische Druck der Lösung mittels PEG-6000 verändert wurde. Durch die Zuführung von $^{14}CO_2$ über die Blätter, konnte der Transport und die Verteilung der ^{14}C-Assimilate in die Pflanzenteile von Pflanzen unter Wasserstress und Normalbedingungen verglichen werden. Der Großteil der ^{14}C-Assimilate wurde innerhalb von 48 Stunden aus den markierten Blättern exportiert, dabei wies die Exportrate der normal versorgten Pflanzen zwei Peaks auf. Unabhängig vom Grad des Wasserdefizits, war die Exportrate aus den Blättern deutlich reduziert, ohne dabei das Exportmuster der ^{14}C-Assimilate zu verändern. Bei normal versorgten Pflanzen wurden mehr als 90 % der innerhalb von 48 Stunden exportierten ^{14}C-Assimilate in die oberidischen Pflanzenteile verbracht, wohingegen bei wassergestressten Pflanzen in Abhängigkeit vom Grad des Stresses zwischen einem und zwei Drittel der ^{14}C-Assimilate in die Wurzeln transportiert wurde. Außerdem verringert Wasserstress den ^{14}C-Assimilat-Verteilungskoeffizienten (*K*) in die Sprossspitze und erhöht die *K*s in die Wurzeln und das Phloem. Der geringere *K* in die Sprossspitzen bei wassergestressten Pflanzen könnte zu einem geringeren Sprosswachstum führen. Der größere *K* in die Wurzeln wiederum könnte bei wassergestressten Pflanzen ein größeres Sink und einen größeren Kohlenstoffassimilatspeicher in den Wurzeln bewirken. Es scheint naheliegend, dass der *K* des Phloems zeitnah zur Zuführung von $^{14}CO_2$ nur einen Hinweis auf die Höhe des ^{14}C-Assimilattransports in die Wurzeln oder einen zeitlich begrenzten Kohlenstoffassimilatspeicher im Phloem gibt.

Key words. ^{14}C-assimilate – micropropagated apple plants – distribution – transport – water stress

Introduction

Transport and distribution of assimilates among organs may play an important role in vegetative growth and tree development, and also in production and fruit quality in fruit trees. It was shown that transport and distribution of carbohydrates in plants could be influenced by both the developing status of various organs and environmental conditions (ZENG 1992). Recently, radioactive labelling and tracing techniques by feeding $^{14}CO_2$ have been employed as an effective tool to study transport proportions, the fixed function locations of the carbohydrates among plant organs, to understand the regulatory mechanisms of carbohydrate partitioning during growth and development of plant organs under water stress (DENG et al.1990; STEINBERG et al. 1990; WAYRE et al. 1990; DAIE 1996; YAKUSHIJII et al. 1998).

Water stress results in both a low export ratio of carbohydrates and a reduced export rate of assimilates from leaves of apple, maize, or *Passiflora edulis/P. caerulea* (ZENG 1992; JURGENS et al. 1987; STAVELEY and WOLSTEAHOME 1990). In addition, distribution of the assimilates was reduced to either newly-growing organs of shoot and young leaves or reproductive organs, such as flowers and fruits, under water stress while it was much increased in storage organs of both trunk and roots (DAIE 1996; STAVELEY and WOLSTEAHOME 1990; STEINBERG et al. 1990; WESTGATE and BOYER 1985). However, no extensive study has yet been done on the transport rate of assimilates to different organs under water stress and the influence of water stress at different deficit intensities on the transport and distribution of assimilates on fruit trees.

Fruit trees have large plant sizes and there are great differences among studies due to the used experimental materials. Thus, experimental conditions are difficult to control in the field and even in pots when studying the transport and distribution of assimilates in fruit trees (XU 2000). Transport and distribution of ^{14}C-assimilates could be clearly demonstrated, however, if PEG-6000 was used to simulate water deficit on young micropropagated plants due to their uniformity. In this paper we report the results of transport and distribution of assimilates under water stress, regulated by using PEG 6000, obtained from micropropagated apple plants in order to determine the export rate of assimilates and the role of assimilates on organ growth in response to water stress at different deficit intensities.

Materials and Methods

Experimental site and materials

Micropropagated 'Fuji' apple plants with heights of 20 to 30 cm were pre-cultured in pots with 1/2 strength Hoagland nutrient solution for 10 days. The culturing conditions were of 24–28°C, 85 % relative humidity, and 400 μmol photons m^{-2} s^{-1} light intensity with a rotation of 16 hrs light/8 hrs dark in a day. Ten days after being transferred into the Hoagland solution, the plants with uniform vegetative growth were selected for the study. By methods of HSIAO (1973), treatments of three different water deficit intensities performed by regulating the osmotic potential of the solution using PEG-6000, at mild stress (MIS, solutions with osmotic potential of –0.75 MPa), moderate stress (MOS, solutions with osmotic potential of –1.5 MPa), and severe stress (SES, solutions with osmotic potential of –2.5 MPa), were compared with the control under a normal water condition (CK). A randomised complete block design was used with 3 replicates, and 10 plants in each block.

Measurement of leaf water potential and $^{14}CO_2$ fed

Leaf water potential was measured during the experiment from fully expanded leaves on the upper part of the plant. Leaf water potential was determined by Scholander pressure chamber (ZIZ-4, Lanzhou University). Leaf water potential was kept a high level (about –0.2 MPa) and was also stable on CK plants throughout the experiment while it decreased progressively on the water stressed plants during the first 13 hours after water stress was initiated and remained at low levels thereafter, –0.5 to –0.7 MPa for MIS, –1.0 to –1.2 MPa for MOS and –1.4 to –1.7 MPa for SES, respectively.

Between two and three hours after initiating the treatments, a radioactive intensity of 20 μCi $^{14}CO_2$ was fed for 0.5 h to a single mature leaf on the upper middle part of each micropropagated plant. The plants were harvested at 1, 4, 12, 24, and 48 h after feeding $^{14}CO_2$. All plants were separated into seven parts consisting of shoot apex, labelled leaf, nonlabelled leaves, stem phloem, stem xylem, fine roots (<1.0 mm in diameter), and large roots (≥1.0 mm diameter) for radioactivity measurement on basis of fresh weight and dry weight of the tissue, respectively. Radioactivity from ^{14}C was measured with a BH216 Low-Background-α, β Instrument (Beijing Nuclear Instrument Factory, Beijing, China)

Equations for calculating transport and distribution of ^{14}C-assimilates

The following equations were used for calculating transport and distribution of ^{14}C-assimilates: (use colon instead of period)

- Total radioactivity (dpm_0) = (cpm–background radioactivity)/m_0×M_0
- where cpm represents radioactivity counts per minute; m_0, the sample weight being determined (≈50 mg herein); and M_0, total dry weight of the plant organ.
- Distribution percentage of ^{14}C-assimilates (^{14}C %) = (dpm_0/dpm_T)×100
- where dpm_0 represents radioactivity of the determined organ; dpm_T, radioactivity of the whole plant.
- Export amount of ^{14}C from the fed leaf = (dpm_2–dpm_1)×100
- where dpm_2 represents radioactivity of the determined organ at the later analysis time; dpm_1, radioactivity of the same organ at the former analysis time.
- Export rate of ^{14}C from the fed leaf = (dpm_2–dpm_1)/(duration between analysis time of dpm_2 and dpm_1)×100
- where dpm_2 and dpm_1 are same as described above.

Table 1. Export amount and export rate of ^{14}C-assimilates from labelled leaves of micropropagated apple plants in response to water stress at different deficit intensity: mild stress (MIS), moderate stress (MOS), and severe stress (SES). CK is the control under a normal water condition.

	Export amount (%)				Export rate (% h^{-1})			
	CK	MIS	MOS	SES	CK	MIS	MOS	SES
0–1h	7.53 a	2.33 b	0.31 c	0.22 c	7.53	2.33	0.31	0.22
1–4h	2.82 b	4.95 a	4.48 a	0.05 c	0.71	1.24	1.12	0.01
4–12h	22.74 a	19.04 a	5.71 b	0.73 c	2.84	2.38	0.71	0.09
12–24h	6.70 a	10.60 a	4.26 b	1.31 c	0.56	0.88	0.36	0.11
24–48h	13.74 a	0.84 b	0.95 b	1.26 b	0.57	0.04	0.04	0.05

Means followed by the different letters within the same column are significantly different at $P<0.05$ level.

– Distribution coefficient of ^{14}C $(K) = (dpm_0/M_0)/[(dpm_T–dpm_F)/(M–m_F)]$
– where dpm_0, dpm_T, and M_0 are as described above; dpm_F, radioactivity of the fed leaf; M, dry weight of the whole micropropagated plant; m_F, dry weight of the fed leaf.

Results

Export of ^{14}C-assimilates from the labelled leaves

Water stress influenced the export of ^{14}C-assimilates from the labelled leaves (Table 1). The quantity of exported assimilates from fed leaves was significantly reduced under water stress as compared with CK. The more severely water stress was applied, the more reduction in exported assimilates was observed from the leaves. The effect of water stress on export of assimilates was observed in the first hour after $^{14}CO_2$ was fed. There were 7.53 % of the assimilates exported from the labelled leaves under a normal water status while there were only 0.22 % to 2.33 % of the assimilates exported from the plants under water stress. The differences increased as water stress progressed between the CK and water stress treatments, and also among the water stress treatments at different deficit intensities. More about 50 % of the ^{14}C-assimilates were exported within 48 hours after feeding from the labelled leaves of CK plants. However, a much lower export of 37.76 % and 15.71 % ^{14}C-assimilates in the same period were observed in the MIS and MOS treatments, respectively. The water stress at severe deficit intensity limited the export of ^{14}C-assimilates from leaves even more. Almost all of the ^{14}C-assimilates was held up in the fed leaves under severe water stress. Only 3.57 % of ^{14}C-assimilates were exported within 48 hours from the labelled leaves on SES plants.

The export rate of ^{14}C-assimilates from the labelled leaves varied over time after feeding the leaves and over the deficit intensity of water stress (Table 1). Under a normal water status, two peaks in export rate of ^{14}C-assimilates from the labelled leaves could be found. The first peak that had the highest export rate (7.53 % of total assimilates per h) happened during the first hour after feeding leaves. The second one was observed during 4 to 12 hours after feeding leaves. The export rate became lower thereafter, only about fifth during 12 to 24 hours, and 13.74 % during 24 to 48 hours as compared with that during 4 to 12 hours after feeding leaves. Mild stress did not modify the pattern of assimilate export from the fed leaves although the rates of export during the first hour and during 24 to 48 hours on CK plants were much higher than those on the plants of MIS. As to the treatments MOS and SES, the pattern of export of ^{14}C-assimilates from the labelled leaves changed. Only one peak of export rate could be found on the fed leaves on MOS plants and the peak was delayed by 8 hours when compared with the first peak on CK plants. The second peak was also delayed

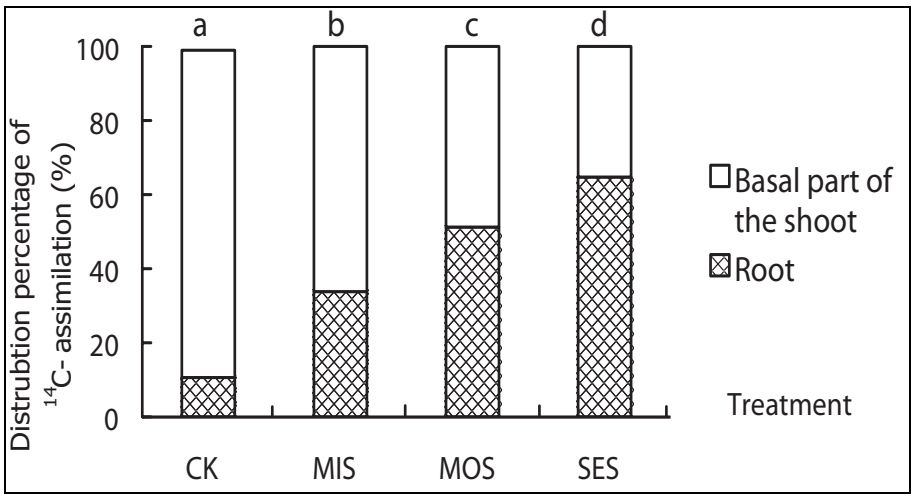


Fig. 1. Distribution of ^{14}C-assimilates between the basal part of the shoot and root of the micropropagated apple plants in response to water stress at different deficit intensity: mild stress (MIS), moderate stress (MOS), and severe stress (SES) 48 hours after feeding. CK is the control under a normal water condition and the different letters above the column in the Fig. are significantly different at $P<0.05$ level within the basal part of the shoot or root of the plant between the treatments.

by 8 hours on SES plants when compared with the second peak on CK plants.

Distribution of ^{14}C-assimilates

As shown in Fig. 1, about 90 % of labelled ^{14}C-assimilates exported from the leaves within 48 hours after feeding leaves were distributed in the basal part of the shoot of the micropropagated plants under a normal water status. The most remarkable influence of water stress on the distribution of ^{14}C-assimilates exported from fed leaves was a reduction in distribution of ^{14}C-assimilates in basal part of the shoot of the plants. The more severely plants were subjected to water stress, the greater the proportion of ^{14}C-assimilates distributed in the roots. At the end of the experiment, there were significant differences among water stress treatments in the proportion of ^{14}C-assimilates distributed in the basal part of the shoot or the roots of the plants. About 64.8 % of ^{14}C-assimilates exported from fed leaves were found in the roots on the SES treatment. However, only 33.8 % and 51.3 % of the ^{14}C-assimilates were distributed in the roots of MIS and MOS plants, respectively.

Water stress modified the distribution of ^{14}C-assimilates among the organs and this modification depended on the stress intensity (Table 2). Water stress reduced the percentage of ^{14}C-assimilate distributed in the shoot apex. The CK plants had higher ^{14}C -assimilate distribution in the shoot apex than those subjected to water stress for each the sampling time. Generally, the more severe the water stress on the plants, the greater the reduction in ^{14}C-assimilates distributed to the shoot apex. Moreover, the differences increased between CK and all water stress treatments as the length of the 12 to 48 hours stress progressed.

There was transport of assimilates to the mature leaves, as 6.71 %, 13.72 %, 4.90 % and 6.16 % of total assimilates exported from labelled leaves during 48 hours were distributed to nonlabelled mature leaves on CK, MIS, MOS and SES plants, respectively. The amount of assimilates exported from the labelled leaf to the other mature leaves on the plants of all water stress treatments significantly decreased in the first 4 hours after feeding $^{14}CO_2$ when compared with CK plants. However, the nonlabelled mature leaves of MIS plants got significantly more ^{14}C-assimilates from the labelled leaves from 4 hours after feeding $^{14}CO_2$ to the end of the experiment than CK ones, even though the assimilate export from labelled leaves was limited for MIS. In regard to the MOS and SES treatments, stress decreased transport of assimilates from the labelled leaves to the other mature leaves until the end of the experiment.

Table 2. Distribution of ^{14}C-assimilates in various organs of micropropagated apple plants in response to water stress at different deficit intensity: mild stress (MIS), moderate stress (MOS), and severe stress (SES). CK is the control under a normal water condition.

Organs	Treatment	Distribution of ^{14}C-assimilates at time after feeding leaves (%)				
		1 hr	4 hr	12 hr	24 hr	48 hr
Shoot apexes	CK	1.51 a	2.30 a	21.60 a	24.65 a	36.26 a
	MIS	0.88 b	1.91 a	10.32 b	14.24 b	7.56 b
	MOS	0.03 c	0.52 b	1.59 c	2.57 c	1.91 c
	SES	0.02 c	0.04 c	0.08 c	0.49 c	0.29 c
Other mature	CK	1.97 a	1.80 a	3.07 b	3.66 b	3.59 b
leaves except	MIS	0.48 b	1.16 b	4.63 a	6.66 a	5.18 a
labelled leaves	MOS	0.08 b	0.58 c	0.76 c	0.79 c	0.77 c
	SES	0.04 b	0.04 d	0.07 c	0.24 c	0.22 c
Phloem	CK	0.61 a	2.81 a	2.56 b	4.62 a	4.49 b
	MIS	0.45 b	1.23 b	3.71 a	3.11 b	5.85 a
	MOS	0.04 c	1.19 b	2.43 b	2.80 b	2.83 c
	SES	0.02 c	0.04 c	0.21 c	0.29 c	0.44 d
Xylem	CK	1.31 a	1.16 a	1.57 b	2.40 b	3.53 b
	MIS	0.17 b	1.15 a	3.71 a	4.08 a	6.40 a
	MOS	0.09 b	0.89 a	1.93 b	2.98 ab	2.14 b
	SES	0.02 b	0.03 b	0.26 c	0.32 c	0.31 c
Fine roots	CK	0.49 a	0.59 a	2.08 a	1.14 b	3.05 b
	MIS	0.18 b	0.40 ab	1.76 a	3.37 a	5.34 a
	MOS	0.03 c	0.22 bc	1.23 a	2.21 c	3.84 b
	SES	0.05 c	0.05 c	0.20 b	0.43 c	1.22 c
Large roots	CK	1.64 a	1.69 a	2.21 a	0.32 b	2.61 bc
	MIS	0.17 b	1.43 a	2.19 a	5.46 a	7.43 a
	MOS	0.04 b	1.39 a	1.39 a	3.41 b	4.22 b
	SES	0.07 b	0.07 b	0.18 b	0.54 c	1.09 c

Means followed by the different letters within the same column for the same tissue are significantly different at $P < 0.05$ level.

The effect of water stress on the distribution of assimilates in phloem had a similar trend as that on the distribution of assimilates in xylem. The amount of ^{14}C-assimilates distributed in phloem and in xylem increased until 24 hours after feeding CO_2, then decreased thereafter in plants under a normal water status. Water stress reduced the ^{14}C-assimilate distribution in the above-ground organs at one hour after feeding $^{14}CO_2$ as compared with CK. However, there were no significant differences of ^{14}C-assimilates in xylem at 4 hours after feeding $^{14}CO_2$ between CK and MIS or MOS. A higher percentage of ^{14}C-assimilates in phloem and in xylem was observed at 12 hours after feeding $^{14}CO_2$ on MIS plants than that on CK plants. Thereafter this higher percentage of ^{14}C-assimilates in MIS plants was kept until the end of the experiment. However, reduced percentage of ^{14}C-assimilates in phloem and xylem was observed on MOS and SES as compared with CK.

Water stress increased the distribution of ^{14}C-assimilates to roots. At 24 hours after feeding $^{14}CO_2$, MIS plants had a significantly higher proportion of ^{14}C-assimilates than CK seedlings in both fine roots and large roots, and this difference between CK and MIS increased during the following 24 hours. In regard to the two other water stress treatments, significant differences were observed at the end of experiment only on the distribution of ^{14}C-assimilates in the fine roots between SES and CK. Because most of the ^{14}C-assimilates were detained in the labelled leaves, the distribution percentage in roots was much lower for SES than CK and the other two stress treatments. However, the proportion of ^{14}C-assimilates was much higher in the fine roots and large roots (more than 30 % for each type of roots) on SES plants than that on CK plants (only about 5 %) when the proportion of total exported ^{14}C-assimilates from labelled leaves was compared between the treatments.

Distribution coefficient of ^{14}C-assimilates (K)

Water stress modified *K* among organs in micropropagated apple plants as shown in Fig. 2. Shoot apexes of plants under normal water status (CK) had the highest *K* among the organs during the experimental period and It's *K* rapidly increased as soon as leaves were fed $^{14}CO_2$, reached a maximum at 13 hours after feeding, and fell thereafter till the end of the experiment (Fig. 2A). However, all the water stress treatments had a significantly reduced *K* for the shoot apex throughout the experiment as compared with CK. Moreover, the *K* of the all stress treatments was very stable during the experimental period, and there were no significant differences for *K* between the treatments at different stress intensities.

Although MOS and SES resulted in a significant increase of *K* of leaves other than labelled leaves compared to CK after the middle experiment period (Fig. 2B), but there were no significant differences of *K*

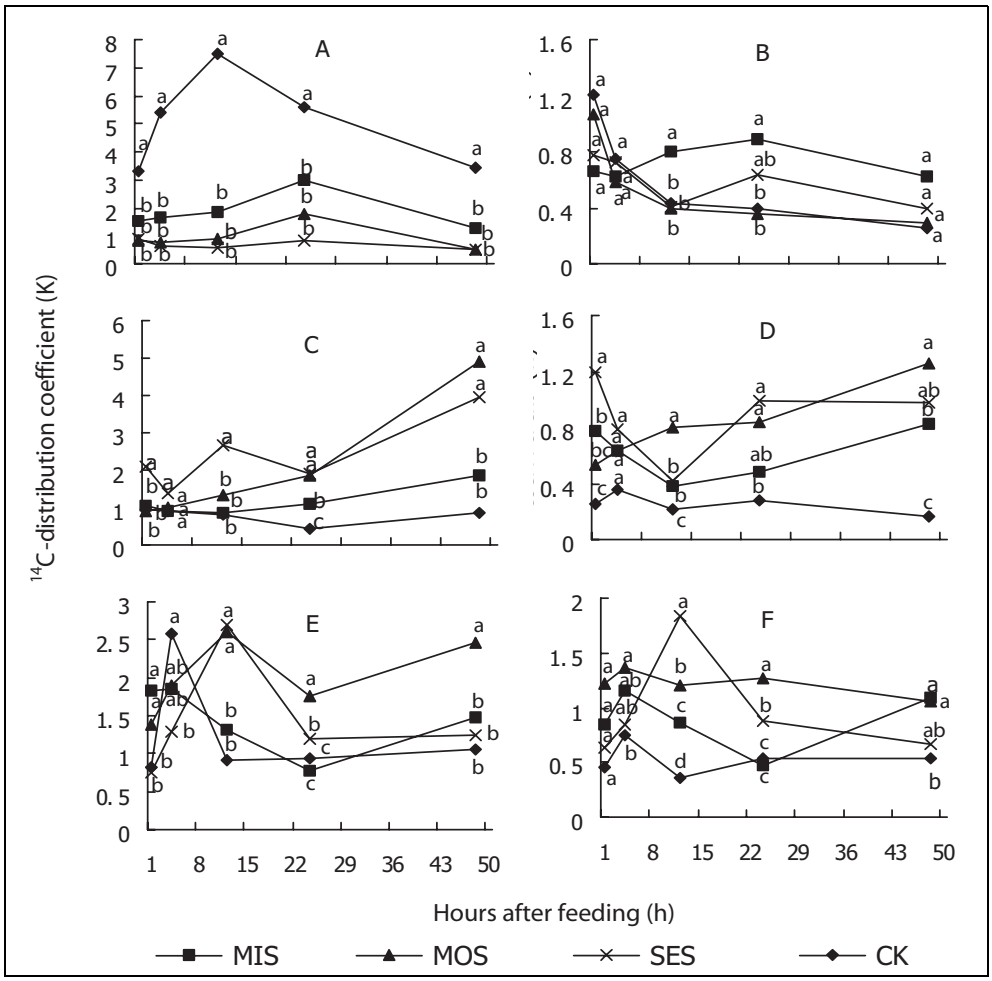


Fig. 2. ^{14}C-distribution coefficient (*K*) of shoot apex (A), nonlabelled mature leaves (B), fine roots (C), large roots (D), phloem (E) and xylem (F) of micropropagated apple plants in response to water stress at different deficit intensity: mild stress (MIS), moderate stress (MOS), and severe stress (SES). CK is the control under a normal water condition and the different letters in the Fig. at the same sampling time are significantly different at $P<0.05$ level between the treatments.

in mature leaves between CK and water stress treatments at all. There might be little exchange of assimilates between mature leaves (DONG et al. 1994), so the ability to compete for the assimilate may be less affected by the treatments at different stress intensities.

The *K* of both fine and large roots of CK plants was very small and very stable during experimental period, while water stress treatments resulted in an increased *K* with different slopes according to the stress intensity as the stress period was prolonged (Fig. 2C and 2D). As opposed to the response of the apex, water stress increased the *K* of fine roots of plants in general although the effect of water stress varied over the stress intensities and the time after leaves were fed. Significant differences of *K* of fine roots were found between SES and CK at the first sampling time, *i.e.*, at one hour after feeding the leaves with $^{14}CO_2$, and between MOS or MIS and CK at 25 hours after feeding the leaves. At the end of the experiment, significantly higher *K* of fine roots was obtained in all stress treatments than in CK, and in MOS or SES than in MIS. The large roots under severe water stress had a significantly lower *K* during the whole experiment period than did the large roots of CK. But MIS resulted in an increased *K* at 25 hours after feeding leaves as compared with that of CK. At the end of the experiment, the highest *K* in large roots was observed on MIS followed by that of MOS among the treatments.

The *K* of phloem and xylem on CK was low and stable as shown in Fig. 2E and 2F. Moderate water stress and severe stress generally increased the *K* of phloem and xylem as compared with CK. Regarding mild stress, the effect was not obvious in the *K* of phloem, but it resulted in significantly higher *K* of xylem than CK in most cases.

Discussion

Export of ^{14}C-assimilates from the labelled leaves of micropropagated apple plants was significantly decreased under water stress, which agrees with results obtained on coconut (DENG et al. 1990), apple (DONG et al. 1994; XU 2000) and peach (XU 2000). However, the results in this study demonstrate the importance of intensity of water stress applied to the plant on assimilate export and distribution. The more severe the water stress, the more assimilates remained in fed leaves. Activities of the enzymes related to carbohydrate metabolism were increased, and the total sugar, reducing sugar and sorbitol accumulated in the leaves in apple and peach trees, under water stress (XU et al. 2001; CHAI et al. 2001). An increased distribution of assimilates to an organ signifies an increase of total sugar in this organ. Soluble sugar accumulation in the organ contributes to osmotic adjustment of cells which maintains cell turgor and keeps cell division normal under water stress. So the amount of assimilates distributed to an organ plays an important role in its growth under, and tolerance to, water stress.

When the growth of a sink organ is sensitive to water stress, assimilates are generally distributed into other organs with stronger sink abilities (WARDLAW 1969). The distribution coefficient of ^{14}C-assimilates, *K*, of an organ represents its sink strength. Water stress modified the *K* among the organs. The *K* of the shoot apex decreased under water stress at all deficit intensities, which could explain why the growth of shoots is sensitive to water stress in fruit trees (LI 1993). In contrast to the response of the apex, water stress increased the *K* of roots, particularly in the case of mild and moderate stress intensities. The *K* of roots rapidly increased as the stress period was prolonged. Although roots in fruit trees are very sensitive to water stress, for example, stopping root growth of citrus trees at a water potential of –0.05 MPa in the soil (BEVINGTON 1983), a recovery of root growth could be found as soon as water stress was removed. The higher distribution coefficient may signify a stronger sink and also a greater reservoir of assimilates in roots under water stress. This high sink strength, especially for fine roots, may result in a greater growth rate of roots under water stress at mild deficit levels than in well-irrigated soil, allowing fine roots to be in a better water status of soil. The greater reservoir of assimilates may also serve as an energy store for a relatively larger roots under severe water stress. The two previous functions may explain why greater numbers of roots and deeper root distribution can be obtained in fruit trees under water stress than with well-irrigated trees in the field (BEUKES 1984; JONES et al. 1983; LI and HUGUET 1989) and also in pots (LI et al. 1990).

The growth of the trunk is most sensitive to water stress as compared with the growth of the other organs (LI et al. 1989; LI et al. 1990). The higher *K* of phloem in the plants under water stress than that of CK plants obtained in this experiment may not signify that water stress increases sink ability of phloem. Assimilates are transported through phloem in trees. A higher distribution rate of ^{14}C-assimilates in phloem at certain times under water stress may be caused by a stronger sink ability of roots to obtain the assimilates. Because the *K* of phloem fell for all plants by 10 hours after feeding $^{14}CO_2$, the *K* of phloem a short time after feeding the leaves with $^{14}CO_2$ may mainly signify the quantity of ^{14}C-assimilates transport to roots or a temporary reservoir of assimilates, as an adaptable reaction, in phloem. It may be necessary to wait for a longer time, at least more than 50 hours after feeding the leaves, to obtain the *K* of phloem as its sink ability.

Acknowledgment

This study was performed thanks to funding by the Natural Science Foundation of China and of Beijing. We thank Dr. D.D. Archbold (University of Kentucky, USA) for his critical review of the manuscript.

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Received March 21, 2003 / Accepted July 14, 2003

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