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Use of an *in situ* labeling technique for the determination of seasonal ^{14}C distribution in Ponderosa pine

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Abstract

A ^{14}C labeling apparatus was developed to permit the labeling of four-year-old Ponderosa pine with $^{14}CO_2$ in the field. The labeling system is a completely closed canopy system with $^{14}CO_2$ monitored by a GM tube ratemeter apparatus. The level of $^{14}CO_2$ corresponding to ambient levels is monitored by a micrologger-computer which controls a $^{14}CO_2$ generating system. The generated $^{14}CO_2$ is mixed in the canopy by circulating the atmosphere with 12 V diaphram pumps. The portable system requires little operator attention.

At approximately monthly intervals over a one-year period two four-year-old Ponderosa pine trees were labeled for three to five days using this labeling apparatus. After an assimilate distribution period, one tree was excavated and analyzed for ^{14}C distribution. During late spring and early summer most of the carbon assimilated (> 60%) was found in the active growing tips and new needles, with little being allocated to the roots (< 10%) or woody material (< 20%). During mid to late fall there was an increase in root labeling along with an increase in carbon going to woody material. Over the winter period, most of the fixed carbon (65%) resided in the older leaves. The early spring labeling period showed another pulse of root labeling along with some labeling of woody tissues.

Introduction

Some years ago an interest in carbon flow dynamics in forested ecosystems began to develop. This interest developed from a need to understand the carbon dynamics and total carbon balance of the biosphere, and determine the influence and changes man was having upon the world carbon budget. In examining the various carbon pools of the biosphere it was determined that 99 percent of the biosphere carbon was contained in terrestrial ecosystems, with forest systems accounting for 85–90 percent of this total (Rodin *et al.*, 1975; Whittaker and Likens, 1973). In addition, it was calculated that approximately 50 percent of the yearly primary production was produced by forested ecosystem. It is apparent that more accurate estimates of carbon pools and fluxes within forest ecosystems will improve overall global carbon estimations and balances.

The problems associated with estimating forest carbon pools are numerous. The major difficulty lies in quantitative determination of the belowground autotrophic carbon pool, which is the least accurately measured and least understood forest ecosystem pool (Harris *et al.*, 1975; Reichle *et al.*, 1973). Pool estimations of belowground autotrophic carbon are difficult to measure and are often based on indirect methods and broad assumptions. In addition to pool estimations there is very little known about the seasonal translocation and dynamics of carbon in forest systems (Reichle *et al.*, 1973).

Techniques for estimating the belowground

autotrophic carbon pool include: 1) calculating the root mass by dividing the above ground biomass by a reasonable shoot/root ratio, 2) periodical coring, which gives a root production value by diffeence along with an estimation of the standing pool, and 3) utilization of the mass balance of soil pools (Harris *et al.*, 1975; Persson, 1984). Most of the estimations use a 'by difference' method, which measures net increments over time rather than total carbon flow and turnover. All of the methods could be greatly improved by considering the age and size class of individual roots and by examining the seasonal dynamics of root growth (Coleman, 1976).

The application of tracers, and specifically ^{14}C, in ecosystem carbon flow and distribution studies would seem to be the most useful method, however these types of studies have been limited. Carbon flow experiments have been used successfully in grassland studies (Warembourg and Paul, 1977), in a shortgrass prairie ecosystem (Singh and Coleman, 1977), and in some woody perennial plant (Wallace *et al.*, 1977), however, there have been very few *in situ* studies on trees and forest systems.

These previous investigations have demonstrated the usefulness of ^{14}C in carbon flow studies, however the design and development of a portable field labeling apparatus to carry out such studies in forest systems is a major obstacle. Lister *et al.* (1961) described a closed-circuit labeling chamber which utilized a geiger tube to measure ^{14}C inside the chamber, and an infrared CO_2 analyzer to measure total CO_2 concentrations. This equipment was used to monitor CO_2 assimilation, but, it had no automatic CO_2 level controller which would be necessary for long term^{14}C labeling. Warembourg and Paul (1973) developed a more automated labeling apparatus which could be used for greenhouse or field studies. In their system, $^{14}CO_2$ in the labeling chamber was monitored by a GM tube-ratemeter combination with the output signaled to a chart reorder. When the concentration of $^{14}CO_2$ dropped below a preset level, a signal from the recorder activated a solenoid valve to open and release $^{14}CO_2$ into the labeling chamber. This system was successfully used in studying carbon transfers in grassland systems (Warembourg and Paul, 1977). Webb (1975) described a labeling apparatus which he used for labeling Douglas fir seedlings. This system used a solid state controller to regulate CO_2 levels in the chamber with the $^{14}CO_2$ or $^{12}CO_2$ added as a gas. Each of these labeling systems has its particular advantages, however, for a completely portable labeling system, to be used *in situ* in a forest ecosystem, substantial modification and update to current technology is needed.

The need to investigate field labeling for tree ecosystems is important based upon the amount of information a single labeling can produce. Carbon labeling can be used for detailed studies of rhizosphere systems and answer major questions concerning the soil-microbial-plant root system. The extent of carbon secretions and the effect these carbon exudates have on soil microorganisms has been studied for over 30 years (Rovira, 1969). However, aspects such as carbon exudates affecting rhizosphere nutrition and the effect on carbon flow and utilization by mycorrhizal associated roots, has had little experimental attention.

This paper desribes the utilization of a portable field labeling apparatus that can be used in forested systems. In addition, we present data showing carbon distribution and redistribution in four-year-old ponderosa pinesover a one-year period utilizing *in situ* labeling methodology.

Methods

Labeling chambers

Two ^{14}C labeling chamber systems were developed; one system was designed for greenhouse labeling of pine seedlings, and the other for field labeling of four-year-old pine trees. The greenhouse studies were to provide preliminary data concerning the rate of assimilate translocation and equilibration within young trees.

The field and greenhouse labeling chambers (Fig. 1) were compartmentalized systems. The field system consisted of a metal cylinder 90 cm in diameter and 23 cm in height placed around a pine tree and pushed down 8 cm into the soil. A PVC plate 90 cm in diameter was placed inside the cylinder and was supported 8 cm above the soil surface by four small blocks of wood. The PVC plate was sealed to the cylinder using an industrial caulking material. A PVC collar was placed around the base of the tree and sealed to the plate to form an 8 cm × 90 cm airtight chamber inside the cylinder above the soil surface. The metal cylinder had hose fittings both

above and below the plate for pumping air through either chamber. The PVC plate also formed the base of the aboveground labeling chamber. The canopy chamber was made from a high strength heat-sealable plastic material (propafilm "c") which showed low permeability to CO_2 but good light transmittance. the canopy chambers were made large enough to enclose the trees (300–500 l) and was attached to the metal cylinder with pliable caulking and rubber tubing to facilitate removal and reinstallation.

Computer controlled labeling equipment

The greenhouse labeling system and the field system are controlled by the same automated equipment which was designed for reliability and portability (Fig. 1). Initially, $^{14}CO_2$ is generated manually by opening a buret valve and adding 1.0 *M* $NaH^{14}CO_3$ to lactic acid in a reaction vessel. A 12 volt diaphram air-pump circulates the $^{14}CO_2$ throughout the closed system to bring the canopy to ambient CO_2 concentrations. The canopy atmosphere flows past a GM tube, through the $^{14}CO_2$ generating vessel and back to the aboveground canopy. The GM tube is connected to a 12 volt ratemeter system fitted with auxiliary high-low alarm and millivolt outputs. To monitor the ratemeter output, and thus the $^{14}CO_2$ activity within the canopy, we have used a datalogger computer

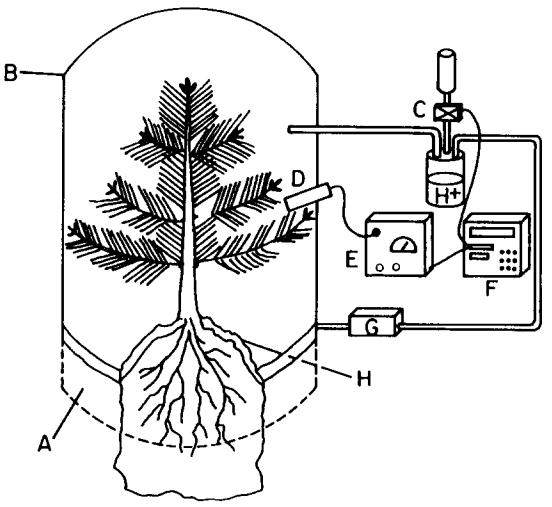

Fig. 1. Field ^{14}C labeling system: **A.** metal cylinder, **B.** canopy, **C.** ^{14}C generator, **D.** GM tube, **E.** ratemeter, **F.** computer, **G.** 12 V pump, **H.** PVC plate.

(CR21X, Campbell Scientific) programmed to monitor the millivolt output from the ratemeter at 1-second intervals. Since the disintegrations per second (Bq) from radioactive isotopes are random, and the efficiency of thin window GM tubes for ^{14}C is approximately 10 percent, the number of measurements taken becomes important. After 60 measurements (1 minute) an average value is calculated and compared to a preset value which was experimentally determined to represent 350 ppm $^{14}CO_2$ within a specified volume. If the average value is below this predetermined setpoint the computer executes a program to open a solenoid valve which meters 1.0 *M* $NaH^{14}CO_3$ into the closed vessel containing lactic acid. Within the program it is possible to vary the time interval in which the solenoid valve is open, thereby varying the volume of $NaH^{14}CO_3$ put into the system.

The automatically generated $^{14}CO_2$ is then pumped into the canopy by a diaphram pump which continuously circulates air through the canopy, monitoring apparatus, and the $^{14}CO_2$ generation system.

The field labeling system is completely portable and automated. The only maintenance required is to refill the $NaH^{14}CO_3$ reservoir and replace the 12 V battery.

Labeling experiments

Several labeling experiments were conducted in the greenhouse for the purpose of calibrating the chamber aparatus. A trial labeling of seedlings was conducted to determine the length of time it took for assimilate pools to reach steady state within the seedling.

In each of the greenhouse experiments we utilized 1-year-old Ponderosa pine seedlings. These seedlings were labeled for periods of 5–10 days with CO_2 at ambient levels (350 ppm), and specific activity of CO_2 of 7.7 MBq/g-C.

Our field experiments were conducted on 4-year-old Ponderosa pine trees within a newly planted mixed conifer system. Two trees were simultaneously labeled each month during the growing season of 1984 with ambient levels of $^{14}CO_2$ having a radioactivity of 7.7 MBq/g-C. The trees were labeled for approximately 4–6 days to allow for the assimilation of 22 MBq per tree. One tree was ex-

cavated during the same month of labeling and the other in May of 1985, thus providing a range of time for redistribution; both trees were excavated and analyzed using the same methods.

Upon the cessation of labeling in the field, the canopy was removed and the trees remained intact for 10 days to allow for assimilate translocation. When the canopy was removed, leaf and soil core samples were taken from and around each tree for ^{14}C analysis. After the 10 day period, the above ground portion of one tree was removed by sawing through the base of the tree. The root system was excavated by hand, following the roots out from the underground base of the tree. Soil that was closely associated with fine roots was also collected. Needles were classed by age and branch, branch and stem wood by year of formation, and roots were classed by size. Each class of material was placed in paper bags and dried at 60°C.

The dried plant samples were weighed and a subsample of each class was ground in a Wiley mill for use in total carbon and ^{14}C analysis. Total carbon analysis was done by oxidizing 15 mg of plant material with a chromic acid digestion mixture in a tightly closed vessel (Amato, 1983; Snyder and Trofyman, 1984); the carbon evolved was trapped in NaOH and the hydroxide trap was subsequently titrated with acid for total carbon determination.

Carbon-14 was analyzed using both total carbon oxidtion and a tissue solubilization method (Fuch and DeVries 1972; Snyder and Trofyman, 1984). In the solubilization procedure 5 mg of finely ground plant material was placed in a scintillation vial, 1.0 ml of hyamine hydroxide was added, the vials were then incubated 24 h at 60°C in the dark. After the incubation, 0.5 ml of 1:1 (V/V) glacial acetic acid:water mixture was added to the vial to reduce quenching. Ten ml of scintillation fluid was added to the vials before placing them in the scintillation spectrometer.

Results

Greenhouse studies

In labeling dynamic systems, such as trees, it is important that the system is labeled long enough that mixing and utilization of ^{14}C and ^{12}C occur. In addition, the newly assimilated carbon must have time to equilibrate throughout the plant before harvest. To estimate these time periods we labeled three pine seedlings in the greenhouse labeling chambers, continuously monitoring $^{14}CO_2$ and total CO_2 being respired from the belowground system of each tree. The specific activity of the belowground CO_2 increased in a linear fashion and plateaued on the 10th day of labeling (Fig. 2). Labeling was continued for one more day, the canopy removed and monitoring of belowground respiration and specific activity continued for 22 days. The decrease in specific activity was quite rapid after labeling (Fig. 2) and did not level out until day 20; thus indicating that translocation and redistribution of assimilates to final destinations takes a number of days, even in small seedlings.

During the spring six 1-year-old ponderosa pine trees were labeled simultaneously in the greenhouse chamber for a five-day period. At the end of the labeling period half of the trees were harvested and analyzed for ^{14}C distribution and the other half were harvested and analyzed 10 days later. Both the specific activity of trees components and the percent of total activity they contained are shown in Table 1. Considerable movement of photosynthates occurred in the 10 days after labeling. A good deal of the newly assimilated ^{14}C was lost as respiration during this time. Decreases in total activity occurred in the tip and buds with substantial increases in the stem, new root, and needles. According to this analysis the growing tips and buds were the largest source of recently assimilated material,

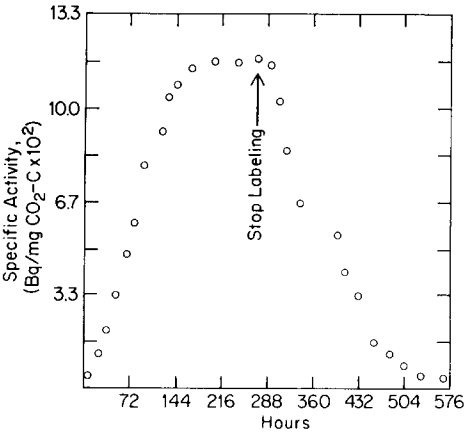

Fig. 2. Specific activity of belowground respired CO_2 during a greenhouse labeling of pine seedlings.

Table 1. Carbon distribution in pine seedlings harvested at 0 and 10 days after a 5-day labeling period

	Days after ^{14}C labeling			
	0	10	0	10
Tree component	Specific Activity[a] (Bq/mg-C × 10)		% of total activity	
Growing tip	48 (4)	8 (0.5)	34	10
Buds	42 (5)	13 (1)	37	10
Needles	42 (10)	9 (0.4)	15	25
Stem	12 (1)	8 (0.3)	8	22
Tap root	23 (2)	7 (1)	3	5
Lateral root	8 (1)	3 (0.4)	2	7
New root	13 (2)	10 (2)	2	20

[a] means and standard deviation of three replicate trees.

with the needles, stem and new roots being the largest sink for carbon at this stage in the growing season.

Field experiments

The field labeling experiments were begun in May 1984, to coincide with the start of bud break. At approximately monthly intervals throughout a 1-year period 2 new trees were labeled for 5 days and one tree harvested 10–14 days after labeling. The distribution of fixed carbon during the year by 4-year-old Ponderosa pine is shown in Table 2. At bud break in May, most of the carbon resided in the leaves and the new growing tip. By the July labeling harvested in late July, new needle elongation had ceased and carbon had begun accumulating in the branch leaves with twice as much carbon being allocated to roots and woody material than in May. The October and November labelings had similar carbon distribution patterns. Much of the carbon being assimilated during this fall period went to roots and woody material, however a buildup of carbon in the branch leaf material occurred as it did in the trees labeled in July. The early spring labeling in March 1985, two months before bud break, showed a substantial amount of carbon being allocated to the root system and woody material. This allocation is similar to the October and November period when the carbon shifted from the branches to the roots.

Table 2. Seasonal (1984–1985) distribution of fixed carbon (%)

Component	May	July	Oct.	Nov.	Jan.	March
Growing tip	26.0	3.8	2.4	0.9	–	3.3
Stem leaves	22.3	5.4	10.2	8.0	18.8	6.5
Branch leaves	36.6	61.7	32.6	39.8	64.6	45.3
Large roots	3.7	8.7	21.0	23.8	3.7	10.9
Fine roots	0.2	0.2	0.2	0.1	0.1	0.3
Wood	11.2	20.2	33.6	27.4	12.8	33.7

To view the seasonal carbon alloation in more detail, each harvested tree was divided into at least 20 separate components which were analyzed for total carbon and radiolabeled carbon content. The specific activity of the more detailed component analysis is shown in Table 3. These values represent the sink strength of various components and can be used to separate differences in carbon allocation with age class.

In the July labeled tree, the 4th year components constituted the strongest sink. This is reasonable since the tree was harvested at the cessation of needle elongation. The specific activity increased in the stem wood from 2nd to 3rd and from 3rd to 4th year growth as it did in the 2nd and 3rd year branches. Specific activity decreased from large to fine (< 1 mm) roots.

Table 3. Seasonal (1984–1985) changes in specific activity (Bq mgC^{-1}) of tree components

Tree component	July	November	March
Stem leaves			
3rd year	—	6.2	7.4
4th year	35.7	10.0	13.6
Stem wood			
2nd year	6.7	4.3	4.2
3rd year	12.5	2.4	2.8
4th year	24.2	6.7	3.6
2nd year branch			
2nd year leaves	8.9	7.7	—
3rd year leaves	43.3	11.2	10.3
4th year leaves	55.0	11.2	10.5
3rd year branch			
3rd year leaves	21.4	8.0	9.7
4th year leaves	36.0	10.0	10.8
4th year branch			
4th year leaves	118.8	9.2	9.0
Roots (mm diameter)			
> 5	20.6	8.3	6.5
2–5	3.9	8.9	6.0
1–2	1.2	4.3	5.0
< 1	1.2	3.6	6.8

The November labeled tree showed a constant specific activity throughout all components. Leaf age class had little effect on carbon allocation when the assimilation occurred in late fall. The roots are a larger sink at this time than in July, and show a constant specific activity of 8.3 Bq/mg-C for the medium to large roots, which is twice as much as the fine roots (4.2 Bq/mg-C).

The March labeling again showed a relatively constant specific activity over all components (Table 3). The branch leaves and wood increased in labeled carbon allocation (Table 2) but showed no age class effect on distribution. The labeled carbon distribution to the roots decreased by 13 percent (November, 24% to March, 11%), however, the sink strength of each class of roots was similar in March at 6.7 Bq/mg-C.

The sink strength of individual components seems to vary during the height of the growing season (May to July) and remain fairly constant thereafter. When comparing July to the November and March tree labelings it seems anomalous that the specific activity of the stemwood is greater than the fall and spring labelings. Also the specific activity of large roots is substantially higher in July (20.6 Bq/mg-C) than in November (8.3 Bq/mg-C) and March (6.5 Bq/mg-C). The time necessary for redistribution and the type of tissue being formed (*i.e.* phloem, xylem) may be responsible for these apparent anomalies.

Since carbon movement to roots is an integral part of the overall carbon balance of a system, it is desirable to determine the time frame of this movement, along with separating carbon allocation based on root size and morphological function. As evidenced by Table 1, carbon allocation to roots systems peaks in late fall and spring, coinciding with new root growth. A more detailed separation of the root system and analysis of changes in specific activity is shown in Table 4.

The July tree showed no new root growth, but specific activity of the primary roots (20.6 Bq/mg-C) was up to 4 times greater than at other times of year. The specific activity of the mycorrhizal roots was the same as the uninfected roots (3.9 Bq/mg-C).

Table 4. Seasonal (1984–1985) specific activity (Bq mgC^{-1}) of root components

Root type	July	Oct.	Nov.	Jan.	March
Primary (> 5 mm)	20.6	14.5	8.3	4.5	6.5
Lateral (< 5 mm)	3.9	8.3	4.3	2.3	5.0
New	—	25.0	3.6	1.9	6.8
Mycorrhizal	3.9	143.3	2.1	1.1	16.1

The October labeled trees allocated substantial amounts of carbon to new roots with a high specific activity (25 Bq/mg-C), 3 times that of older lateral roots of the same size. The mycorrhizal roots became a large sink for carbon at this time with a sink strength 6–17 times greater than other roots. It is evident from Table 4 that root sink strength for carbon is maximized in October.

The November labeling produced approximately the same total carbon allocation belowground (Table 2) as the October labeling, however, substantial decreases in component specific activity occurred. The specific activity of both the new and mycorrhizal roots decreased by over an order of magnitude, however, their total mass is small and has little impact on overall allocation.

Little carbon was allocated for the synthesis of root mass in January (3.8% of total) and the specific activity of each root class decreased further from the November labeling.

In early spring labeling (March), before bud break, carbon was again being allocated for root mass (11.2%, Table 2). New root production increased substantially during this period, with new roots having the same specific activity as the primary roots (6.7 Bq/mg-C). Mycorrhizal associated roots began showing a large sink strength (16.1 Bq/mg-C) during this time of new root proliferation. The magnitude of root sink strengths in March are lower than, but show a similar trend to, the October roots.

In May of 1985 the second tree of each labeled pair was excavated from the site. This provided data on the redistribution of assimilated labeled carbon over various time periods. Table 5 gives the

Table 5. Percent (%) distribution of ^{14}C labeled carbon in trees harvested 2 to 10 months after labeling

Component	Month labeled and months after labeling			
	July 10	Oct. 8	Jan. 5	March 2
Growing tip	2.1	3.2	3.4	4.9
Stem leaves	4.0	14.7	7.6	6.5
Branch leaves	64.1	27.6	52.7	36.2
Large roots	2.5	16.6	11.6	12.8
Fine roots	—	0.3	—	0.1
Wood	27.3	37.4	24.7	39.5

percent distribution of this carbon 2, 5, 8 and 10 months after initial labeling.

In the July labeled tree, harvested 10 months later, the percentage of labeled carbon increased in the branch leaves and wood components at the apparent expense of the roots. In the October labeled tree 8 months later the labeled carbon had increased in the stem leves and wood materials and had decreased in the branch leave and roots. After 5 months of redistribution the January labeled tree showed decreased label in the stem leaves and branch leaves with increases in roots and wood material. The March tree, labeled during a root growth period, showed an increase in root and wood carbon two months later and a decrease in branch leaf carbon.

Discussion

Previous studies of carbon allocation in pine trees have been limited to potted seedlings and short term pulse labeling of one or two tree components. For ecosystem carbon flux and nutrient cycling studies, it is necessary to label the entire tree to detect carbon flow into soil. In this study we have labeled entire four-year-old Ponderosa pine trees *in situ* to examine the periods of maximum carbon flux to roots. These studies were not conducted to determine the variability of carbon distribution in pine trees. The data presented represents the total analysis of one tree per time period. The extrapolation of this data would be unwise, however, it is apparent that this method could be expanded and used for ecosystem level analysis.

This labeling technique when used for pine trees is limited by the size of the canopy and thus ultimately by the size of the trees. The size of the canopy has two effects on the labeling system. Firstly, the pumps that circulate the air through the labeling chambers have a finite capacity. Slower circulation of air will cause slower response to decreased CO_2 and incomplete CO_2 mixing in the canopy. Secondly, larger canopies increase the risk of temperature problems inside the canopy. There are several solutions to these lmitations, such as air conditioning systems and larger air pumps. However these alternatives obviously decrease the portability of the entire system.

In pine seedling studies it has been assumed that recent assimilates would reach their final destination sometime between three days and one week (Balatinecz *et al.*, 1966; Dickman and Kozlowski, 1970; Gordon and Larson, 1968). Our greenhouse studies have shown that translocation of recent assimilates can last between seven and fourteen days and varies seasonally. This is an important concept when trying to determine yearly carbon fluxes through forest systems.

In our field studies the annual distribution of fixed carbon conforms to a pattern that we would expect (Table 2). At bud break and immediately thereafter much of the carbon is utilized for new leader and needle growth. At no other time during the year did the growing tip show an appreiable sink strength. The stem leaves show a varying pattern of carbon accumulation throughout the year. However, during this particular year the older stem leaves were beginning to senesce. When the branch leaves of all ages are totaled we find an interesting pattern of carbon accumulation or storage. Throughout the year the branch leaves accumulate similar percentages of newly fixed carbon (33–45%) except for the summer and winter periods. In both the July and January labelings the branch leaves accounted for over 60% of the total fixed carbon. At each of these times the allocation to woody tissue decreased relative to the other months, excluding the May rapid growth period. This accumulation of carbon in branch leaves precedes periods of root carbon accumulation.

These field studies indicate that the major below-ground input of carbon into roots occurs in a bimodal pattern, with peaks in the late fall and early spring (Table 2). Recent data (not presented) indicates that the maximum input to roots can vary by over a month depending on climatic conditions and the time of bud break. Other component distributions can also vary from year to year and seem to respond rapidly to climatic changes.

Carbon redistribution patterns in these trees suggest that components that are strong sinks for carbon during labeling lose the most carbon upon redistribution and/or respiration. In most of the labeling periods, labeled carbon decreased in the branch leaves and increased in the root and wood material. In all redistribution periods from 2 to 10 months the woody tissue gained from 4–12% over time. Redistribution of carbon reserves was more pronounced in trees labeled in October and

November since a larger proportion of the label is fixed into reserves (Schier, 1970). Other seasonal and redistribution studies concerning carbon in tree seedlings have shown that ^{14}C translocation to root systems follows a bimodal pattern and was correlated with root respiration (Shiroya *et al.*, 1966; Ursino *et al.*, 1968; Webb, 1977a). In addition it was found that carbon transport to various vegetative components was based upon the intensity of development and phenological activity during particular periods of the growing season (Gordon and Larson, 1968; Schier, 1970; Webb, 1977b).

Seasonal dynamics of root carbon alloation can be followed with this labeling technique. However yearly actual root weight production and turnover are difficult to estimate due to the varibility among trees and the destructive analysis necessary to determine component carbon allocation. In studying the seasonal dynamics of roots it is important not only to determine increased mass of the system but also the total carbon flow dynamics which includes root respiration. This type of information cannot be obtained quantitatively from percent distribution, however estimates can be made from component sink strength using specific activity data. In our studies 30 to 40% of the total carbon assimilated remained in the trees, with the remainder being respired. By comparing the specific activity of the roots with other components (Tables 3 and 4) we can estimate total carbon fluxes through the tree. This analysis utilizing specific activity is necessary since the total carbon fixed in the roots may be similar for two given months but the sink strength and thus the total carbon flux may be different. From Table 2 it is evident that the carbon distributed to the roots in July is similar to the March period just as the October and November periods are similar. Examination of these similar months in Table 4 show substantial differences in root specific activity between July and March and October and November. The similar carbon distributions but dissimilar specific activities may indicate difference in respiration rates at particular time periods.

Using an *in situ* labeling technique, it is possible to study yearly carbon alloation in small trees. This type of information along with sink strength of tree components can be a valuable tool in estimating forest ecosystem carbon flow. This type of data will be helpful in investigating carbon input from trees into the soil, the effect of carbon on rhizosphere organisms and the effect of photoassimilated carbon on nutrient cycling in soils. The use of radioactive carbon provides a mechanism to separate these cyclic processes.

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