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Timing of urea application affects leaf and root N uptake in young Fuji/M.9 apple trees

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SUMMARY
Leaf and root nitrogen (N) uptake was compared at different times of the season in young apple trees. One-year-old potted Fuji/M.9 trees were supplied with 1% ^{15}N-labelled urea either by foliar or soil applications in May, July and September. Trees receiving only water served as controls. The trees were harvested 10 d after ^{15}N application, separated into shoots (leaves and current-year stems), stem (previous-year wood) and roots. Biomass, total N and ^{15}N contents of all tissues were determined. New shoot biomass and total tree biomass increased as the season advanced, while root biomass peaked in July. Leaf N uptake was higher than root uptake in May and September, while root N uptake was higher than leaf uptake in July. Leaf N uptake increased as the season advanced, while root N uptake was highest in July. The lowest ^{15}N recovery (11%) was obtained in May with soil N application, and the highest ^{15}N recovery (48%) was obtained in September with foliar N application. Our results suggest that foliar application of N early in the season, followed by soil N application in mid-season, then foliar application again late in the season is an efficient N management strategy for young trees.

The efficient use of fertilisers to increase crop yield is an important goal in all agricultural systems. However, matching nutrient application to crop requirements is not easy. It has been and will continue to be an ambitious pursuit for researchers and growers to maximise nutrient uptake by crops while minimising fertiliser application and leaching loss.

Plants usually absorb water and nutrients by their roots, therefore fertilisers are traditionally applied into soil (Mengel, 2002). While soil application can supply enough nutrients to improve plant production, it also causes world-wide concern about environmental contamination from nutrients leaching into ground water (Dinnes *et al*., 2002). Increasing public concern about excessive nutrient loss from agricultural land encourages the search for more efficient ways to apply fertilisers.

The ability of plant leaves to absorb nutrients has resulted in foliar application of nutrients becoming an alternative method for supplying nutrients to plants (Swietlik and Faust, 1984). Many researchers have shown that fruit trees receiving foliar nitrogen (N) applications use fertiliser N more efficiently than trees that receive soil N applications (Hill-Cottingham and Lloyd-Jones, 1975; Weinbaum, 1988). These results have encouraged fertiliser management approaches in orchards which completely depend on foliar N application (Embleton and Jones, 1974; Johnson *et al*., 2001). However, a dominant viewpoint of many researchers and growers is that foliar N fertilisation cannot completely substitute for soil nutrient applications.

Plant growth stage and timing of fertiliser application affect nutrient uptake (Faust, 1989). The effects of different growth stages on the efficiency of leaf and root N uptake and distribution in fruit trees is not well-documented. Understanding differences between leaf and root N uptake at different times of the season is important to achieve more efficient N management in fruit tree orchards.

The objectives of this study were to compare the effects of different timings of N application on leaf and root N uptake, and to determine the distribution of N absorbed by leaves and roots at different times in young Fuji/M.9 apple trees.

MATERIALS AND METHODS

Fifty uniform 1 year-old, Fuji/M.9 apple trees were selected based on height (80 ± 5.6 cm) and diameter (0.8 ± 0.2 cm), and planted in 8 l pots with a mix of peat moss (Primer Pro-mix, Quakertown, PA, USA) and sandy loam soil (1:1 by volume) on April 8, 2000. Trees were placed in a greenhouse and grown under a natural photoperiod and temperatures of 16°–26ºC in Corvallis, OR, USA (lat. 44°59'041" N, long. 123°27'217" W). Three groups of trees (5 per group) were selected at random on May 11, July 15 and September 3, respectively, and treated with either 1% ^{15}N-urea (^{15}N enriched to 5 atom %, ICON, Mt. Marion, NY, USA) as a foliar application (sprayed with a hand sprayer until runoff),

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1% ^{15}N urea as a soil application (the same amount as for foliar application), or control (receiving the same amount of water in soil). The volumes of solutions used were 98.5 ± 2.3 ml, 102.7 ± 2 .6 ml and 103.1 ± 3.0 ml in May, July and September, respectively, as determined by the foliar application. During foliar applications, pots were covered with paper towels to prevent ^{15}N entering the soil. During soil applications, care was taken to prevent ^{15}N from contaminating the above-ground portion of the trees. Water was supplied manually according to the trees' requirements during the experiment and care was taken to prevent ^{15}N being washed off leaves once ^{15}N was applied. Trees (5 per treatment) were harvested on May 21, July 25 and September 13, (10 d after each treatment), and separated into new growth (new leaves and shoots), stem (previous stem wood) and roots. Leaf area was measured immediately with a leaf area meter (LI-3000A, LI-COR, Lincoln, NE, USA) after sampling. Leaves and stems from the foliar ^{15}N-urea treatment were washed in 0.1 mM HCl and double-distilled water (dH_2O) to remove urea residues from the surfaces. All other samples were washed in tap water and dH_2O. Samples were oven dried at 65°C for 3 d, then weighed and

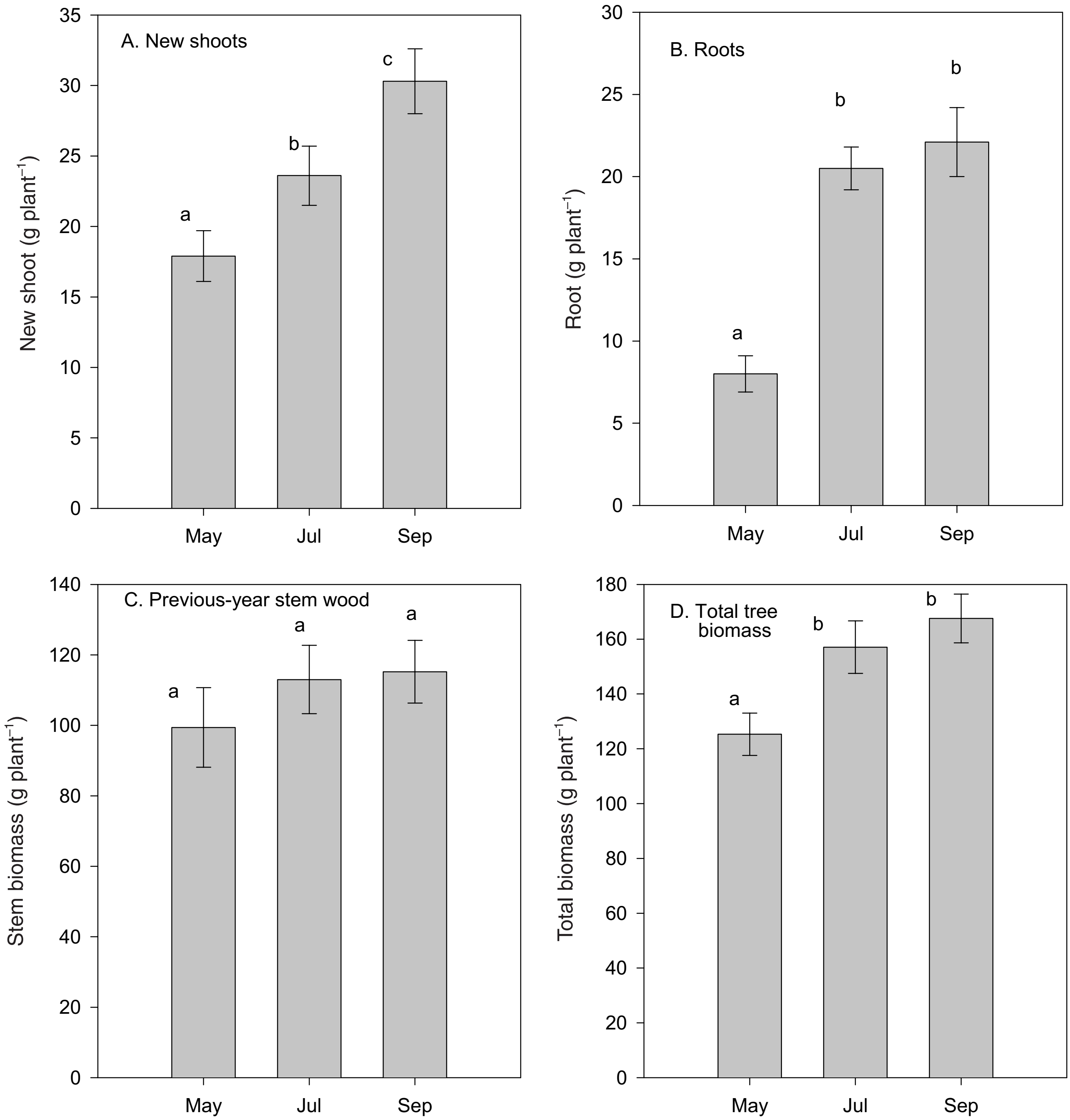

FIG. 1
Components (A–C) and total tree biomass (D) of young Fuji/M.9 apple trees at different times of the season. Bars on each column represent standard errors of the mean of 15 trees. Columns with the same letter above them are not significantly different (LSD, $P \leq 0.05$).

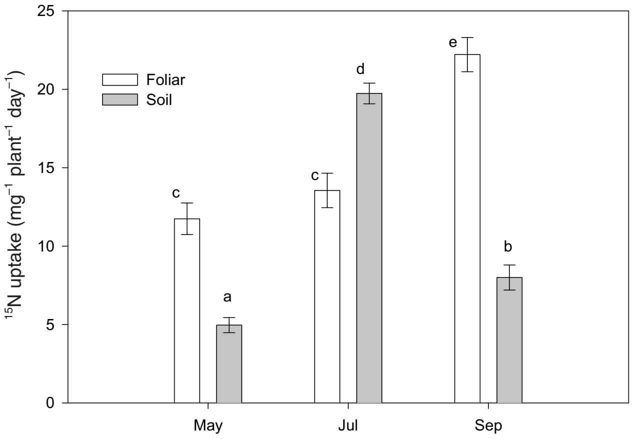

FIG. 2
Average ^{15}N uptake rate of young Fuji/M.9 apple trees 10 d after ^{15}N-urea was applied either to the foliage (white) or through the soil (gray) at different times of the season. Bars on each column represent standard errors of the mean of five replicates. Columns with the same letter above them are not significantly different (LSD, $P \leq 0.05$).

ground prior to determinations of total N and ^{15}N concentrations in each tissue.

Total N in samples was determined by Kjedahl analysis (Schuman *et al*., 1973) at the Central Analysis Laboratory, Oregon State University. The amount of ^{15}N in samples was determined from the gas evolved from combustion of powdered tissue in an elemental analyzer coupled to a mass spectrometer by the laboratory of Isotope Services Inc. (Los Alamos, NM, USA). The average ^{15}N content in control samples (0.37%) was very similar to the natural abundance; therefore, natural abundance was used to calculate the percentage of N derived from fertiliser (% NDFF) in each tissue:

$$\%NDFF=\frac{(atom\%^{15}N)_{tissue}-(atom\%^{15}N)_{natural.abundance}}{(atom\%^{15}N)_{fertiliser}-(atom\%^{15}N)_{natural.abundance}}\times 100$$

The content of ^{15}N in each tissue was calculated from the %NDFF and total N. The amount of ^{15}N was calculated by multiplying ^{15}N content by the dry weight. Rate of ^{15}N uptake was calculated by pooling ^{15}N amounts in different tissues divided by the time of uptake (10 d).

The experiment was a randomised design with five single-tree replicates per treatment, per treatment date. All data were subjected to a two-way ANOVA analysis to test treatment effects over time. Differences between means were assessed by Fisher's LSD test at $P \leq 0.05$. All statistical analyses were performed with NCSS Statistical System Software (NCSS Statistical Analysis Software, Kaysville, UT, USA).

RESULTS

Plant growth

Biomass was used as a parameter to evaluate tree growth at each time of fertilisation during the experiment. Neither foliar nor soil N application had a significant effect on tree biomass 10 d after application compared to control (data not shown). New shoot biomass (including leaves and current-year stems) increased as the season advanced from May to September (Figure 1A). Root growth increased significantly between May and July, but no significant increase was found in root biomass between July and September (Figure 1B). The increase of stem wood biomass from the previous year was not significant between May and September (Figure 1C). Total tree biomass increased significantly between May and July, due to new shoot and root growth, but did not increase significantly between July and September (Figure 1D). Average leaf area increased from about 2400 cm^2 per plant in May, to about 3000 cm^2 per plant in July, and then trees retained similar leaf areas to September.

^{15}N uptake

Leaves absorbed more ^{15}N than roots in the early (May) and late season (September), and roots absorbed more ^{15}N than leaves in mid-season (July) (Figure 2). The rate of N uptake by leaves was similar in May and July, and increased by approximately 60% in September. The rate of root uptake was highest in July and lowest in May. The recovery of ^{15}N showed a similar trend. Trees recovered about 26, 29 and 48% of foliarly applied N, and 11, 37 and 17% of soil applied N, respectively, in May, July and September.

^{15}N distribution

More than 70% of ^{15}N absorbed from foliar applications was distributed to new shoot tissues at all three treatment times (Figure 3A). For trees receiving foliar applications of urea, the percentage of ^{15}N in roots increased and the percentage of ^{15}N in stem wood decreased as the season advanced from May to September (Figure 3B,C). When trees received soil applications of ^{15}N-urea, approximately 45% of the absorbed ^{15}N was found in new shoot tissues in May and July, and only 14% in September (Figure 3A). The percentage of ^{15}N in roots, after soil application of ^{15}N-urea, increased from approximately 13% in May to 60% in September (Figure 3C). Stem wood of trees receiving soil applications of ^{15}N-urea had the lowest percentage of ^{15}N in July (Figure 3B). Foliar N applications distributed significantly more ^{15}N to new shoot tissues than soil N applications (Figure 3A). In contrast, soil N applications distributed significantly more ^{15}N to roots and stem wood than foliar applications at all three treatment times (Figure 3C).

DISCUSSION

For newly-planted young apple trees in Spring, new leaf and shoot growth usually starts earlier than root growth. Leaves and shoots grow rapidly after bud break, while rapid root growth does not occur until shoot growth has slowed, which is usually in late June or July (Atkinson, 1980; Neilsen *et al*., 2001). Our experiments showed that the biomass of new shoots (including new stems and leaves) increased steadily from May to September for newly-established young Fuji/M.9 apple trees, while the root biomass increased rapidly only from May to July. This indicates that a peak in root growth occurs in June and July. Similar results have been reported by others (Atkinson, 1980; Neilsen *et al*., 2001).

Root N uptake changes during the growing season, with the highest uptake rates found early in the summer in tree fruit crops (Dong *et al*., 2003; Faust, 1989; Neilsen

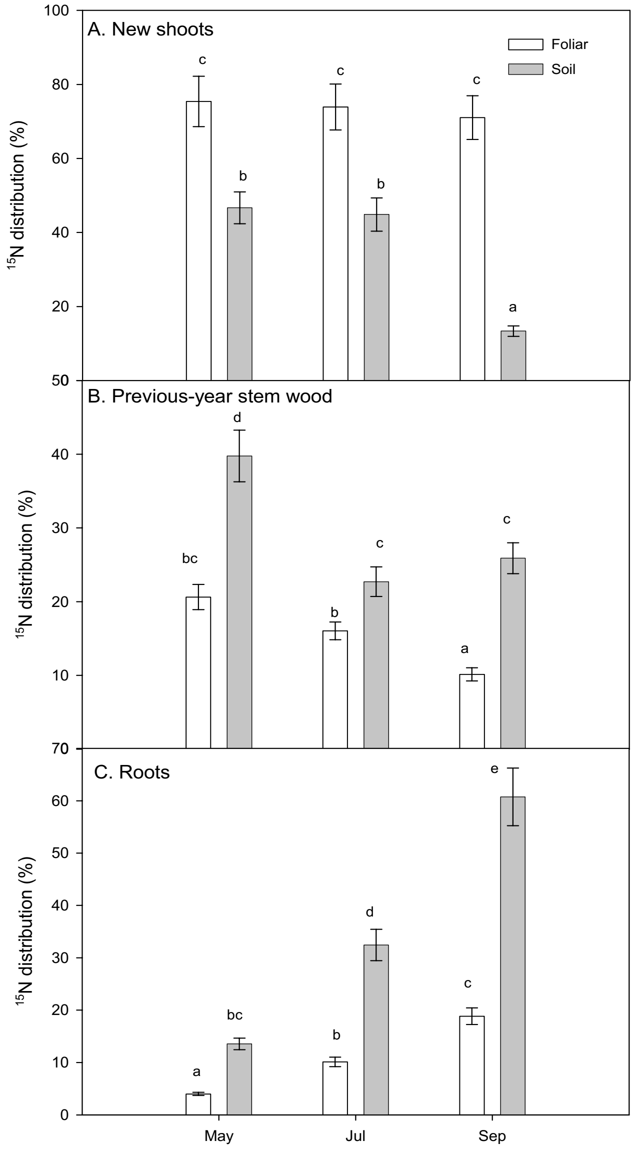

FIG. 3
The percentage of ^{15}N in major organs (A–C) of Fuji/M.9 apple trees 10 d after ^{15}N-urea was applied either to the foliage (white) or through the soil (gray) at different times of the season. Bars on each column represent standard errors of the mean of five replicates. Columns with the same letter above them are not significantly different (LSD, $P \leq 0.05$).

and Neilsen, 2002; Weinbaum *et al.*, 1978). In our experiments, the highest rate of root N uptake was observed in July, during the time when root biomass increased rapidly, and root N uptake was reduced in May and September. In Spring, the new growth is supported mainly by remobilisation of reserve N (Millard, 1996), and root N uptake may be inhibited during the period of remobilisation (Neilsen and Neilsen, 2002). Later in the season when active growth ceased, the N-demand of trees is low, which may account for the reduction in root N uptake in September.

Our results show that the uptake of N by leaves varied with the timing of urea application, and leaf N uptake increased as the season advanced, with the highest rate of leaf N uptake in September. Numerous reports have shown that leaves can effectively absorb late-season foliar-applied N (Cheng *et al.*, 2002; Dong *et al.*, 2002; Johnson *et al.*, 2001; Rosecrance *et al.*, 1998; Tagliavini *et al.*, 1998), and Autumn foliar N application is a useful practice to build-up N reserves for initial growth in the following season.

We found that the distribution of absorbed N was affected both by the timing and method of N application. N absorbed from foliar applications remained mainly in leaves during our experiments (May through September). N taken up by roots was distributed almost equally to new shoots and previous-year stems early in the season. By July, most N from root uptake went to new shoots and roots, while, in September, most N from root uptake remained in roots. An increasing proportion of N was distributed to roots as the growing season progressed regardless of the N application method, but a significantly higher percentage of absorbed N was distributed to roots in trees receiving soil N applications than in trees receiving foliar N applications, especially in September.

There is little information in the literature comparing leaf and root N uptake at different times of the growing season. Our experiments showed that leaf N uptake was higher than root N uptake both early and late in the season, but root N uptake was higher in mid-season. Therefore, it may be a good N management strategy, for young trees, to apply N by foliar spray in early and late season and by soil fertilisation in mid-season in order to increase the efficiency of N fertiliser uptake. It should be emphasised that this experiment was carried out using young potted apple trees, grown under greenhouse conditions, and the results may not reflect field conditions in orchards. However, some growers in Washington State, USA, have used foliar urea sprays on Fuji apple trees early in the season and reported good responses (Jim Johnson, personal communication).

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