FINAL REPORT
WTFRC Project #: AH-01-65

Project Title: The relationship of foliar and soil N applications to nitrogen use efficiency, growth and production of apple trees

PI(s): Leslie H. Fuchigami, Department of Horticulture, Oregon State University, Corvallis, OR 97331
Denise Neilsen, Gerry H. Neilsen, Shufu Dong, PARC, Agriculture and Agri-Food Canada, Summerland, BC V0H 1Z0
Lailiang Cheng, Department of Horticulture, Cornell University, Ithaca, NY 14853

Cooperators: Pinghai Ding, Guihong Bi, Minggang Cui, Department of Horticulture, Oregon State University, Corvallis, OR 97331
Tye Fleming, Orondo, WA
Jim Johnson, Tonasket, WA

Objectives

1. Determine effects of foliar N application on tree nutrition and growth performance
    - Foliar N application in early season (spring)
    - Leaf N uptake after foliar urea application in autumn
    - Leaf surfaces and shoot bark effect on N uptake
    - Autumn foliar urea application effect on N reserves and fruiting
2. Compare effects of foliar and soil N applications on growth and fruiting of apple trees.
    - Determine effects of foliar and soil N application during the growing season (summer) on tree growth and N uptake in late season (autumn)
    - Determine effects of foliar and soil N application on soil and tree nutrient status, growth and fruiting

Significant Findings

1-1. Apple trees can absorb N from early season sprays, and the most effective spray time for N uptake was when the king bloom opened. There was no significant difference on N uptake between the two N sources tested: urea and $Ca(NO_3)_2$.

1-2. After foliar urea application in autumn, apple leaves rapidly absorbed urea-N and the average rate of absorption in the first two days was 290 µg/cm^2/day. The absorbed urea N was converted into amino acids in leaves and then translocated into bark and roots for storage. Leaves absorbed 35% of applied N and 63.6% of absorbed N was moved to bark and roots within 20 days following urea application.

1-3. Both surfaces of a leaf can absorb foliar-applied urea N, but the lower surface absorbed N four-times faster than the upper surface. The bark of the shoot can also absorb sprayed N and the uptake rate was similar to that of the upper surface of the leaf.

1-4. Fall foliar urea application after harvest increased the N reserve status of spurs and shoots of three classifications (vigorous, moderate and weak) of high-density Cameo/M9 apple trees, and improved fruit size and yield in the following year.

2-1. Soil urea application during the growing season (summer) promoted shoot growth and above-ground biomass while foliar urea application increased root biomass in young potted apple trees. Soil urea application promoted extension root initiation while foliar urea application promoted feeder root initiation. Trees receiving only soil N application during the summer promoted leaf N uptake in the autumn while trees receiving only foliar N application during the summer season promoted root N uptake in the autumn.

2-2. A field study of 6-year-old Gala/M9 bearing apple trees showed that both foliar and soil N applications increased leaf N status, improved leaf color, increased fruit size and yield. Soil N application significantly increased the length of shoots. Soil N application increased both NO_3^--N and NH_4^+-N contents in soil, and was less efficient since more N was lost below the root zone.

Experimental Procedures

1-1. Effects of foliar N applications early in the growing season

This experiment consisted of a field study (at Jim Johnson's orchard, Tonanasket, WA) and a pot study (at Oregon State University, Corvallis, OR). In the field study, uniform mature Fuji/M9 apple trees were selected and sprayed with 1% ^{15}N-labeled $Ca(NO_3)_2$ at floral bud break, king bloom (full pink), and petal fall stages, respectively. Trees received either regular $Ca(NO_3)_2$ or water sprays served as control. Leaf samples were taken one week after each spray, and one set of trees was sampled after three sprays. In the pot study, one-year-old Fuji/M26 apple trees with different N levels (fertigated with 0, 5, 10 and 15 mM N in previous year) were, respectively, painted with (1) 1% ^{15}N-urea, (2) ^{15}N-$Ca(NO_3)_2$ (with a N concentration equal to 1% urea), and (3) water for three times at weekly intervals beginning at bud break. The trees were sampled one week after the third painting. All samples from the two experiments were washed in 0.1mol.m^{-3} HCl and then in double distilled (DD) water to remove residue N from leaf surfaces, and freeze dried and ground for total N and ^{15}N analysis.

1-2. Nitrogen absorption, translocation and distribution of foliar urea application in autumn

One-year-old bench-grafted Fuji/M.26 apple trees were planted in one-gallon plastic pots containing a 1:1:1 (by volume) mix of peat moss, perlite and loam soil at Oregon State University in Corvallis, Oregon. The trees were grown under outdoor conditions. Each tree was trained into a single shoot and fertigated with 10 mM of nitrogen in a 20-10-20 (N:P:K) formula once every two weeks from May until mid-August. In early October, uniform trees were selected based on height and stem diameter for experimental treatments. The number of leaves on selected trees was adjusted to 22 from the top of the shoot in order to obtain consistent leaf status for each tree and extra leaves (about 5-10) were manually removed from the bottom. Trees were randomly divided into two groups with 28 trees in each group. On October 6, one group of trees was evenly painted with 3% urea on both surfaces of all leaves, and the other group painted with water as the control. Five additional trees were painted in the same way with 3% regular urea solution to determine the volume of the solution used for each tree. Complete painting of the upper and lower surfaces of all leaves used 18±1.5 cm^3 3% urea solution and this supplied 248±20.7 mg N (18*3%*46%*1000) for each tree in the experiment. During the leaf painting, no ^{15}N was allowed to contact the bark or soil in the pot. Prior to treatment application, four trees were harvested and the contents of nitrogen and amino acids were determined in tissues. After treatment, four trees from each treatment were harvested on October 8, 10, 13, 16, 21 and 26 (2, 4, 7, 10, 15 and 20 days after treatment), respectively. At each harvest, trees were separated into leaves, stem, shank (rootstock tissue between roots and grafting union), and roots. Leaves were washed in 0.1mol.m^{-3} HCl and then in double distilled (DD) water to remove urea residue from leaf surfaces. The stem, shank and root system were washed with DD water. Stem samples were carefully separated into bark and xylem with a surgical knife after washing. All samples were put into a –80°C freezer and then freeze dried, and ground with a Wiley mill (20 mesh) and reground with a cyclone mill (60 mesh) for analysis.

1-3. Effects of leaf surfaces and shoot bark on N uptake

One-year-old Fuji/M26 apple trees were selected, and leaves in the middle of the shoots were painted with 3% ^{15}N-urea on either the upper surface, lower surface or both surfaces, respectively. Another group of trees were manually defoliated and painted with 3% ^{15}N-urea on the bark of shoots. Leaves and stems were sampled two days after painting, and washed in $0.1 mol.m^{-3}$ HCl and then in double distilled (DD) water to remove urea residues. Stem samples were carefully separated into bark and xylem with a surgical knife after washing. All samples were freeze dried and ground for ^{15}N analysis.

1-4. Effects of foliar urea application in autumn on N reserves and fruiting

Three classifications (vigorous, moderate and weak) of high-density bearing Cameo/M9 apple trees were selected according to tree growth vigor at Fleming's orchard in Orondo, Washington, and each tree classification was further divided into four subgroups for treatments: Trees were, respectively, sprayed with 3% urea either 0, 1, 2, or 3 times beginning after harvest in late October at weekly intervals. During the dormant season, spur and shoot samples were collected and analyzed for total nitrogen by the Kjeldahl method. Growth performance was recorded in the following season, and fruit number, fruit size and yield were measured at harvest time.

2-1. Effects of soil and foliar N application during the growing season (summer) on tree growth and late-season N uptake (autumn)

One-year-old Fuji/M26 potted apple trees were used in this experiment. 90 uniform trees were selected and randomly divided into three groups. There were three treatments during the growing season:

1) Control (trees were regularly watered and received no nitrogen);
2) 0.5% urea soil application weekly from June to August
3) 0.5% urea foliar application weekly from June to August

With the foliar application, urea solution was sprayed to leaves until runoff and pots were covered with plastic film to prevent urea solution from contacting the soil surface. Both root and shoot growth, leaf color, leaf area, shoot length, new root type and number were recorded. In the autumn (mid October), each group of trees were divided into three subgroups and treated with (a) water, (b) 3% ^{15}N-urea foliar application, and (c) 3% ^{15}N-urea soil application, respectively. After leaf defoliation, trees were harvested, and total N and ^{15}N were analyzed.

2-2. Compare effects of foliar and soil N applications on growth, fruiting and nutrient use efficiency

The experiment was carried out in a research block at the Pacific Agri-Food Research Center in Summerland, British Columbia for two years. The orchard soil was a sandy loam, a typical fruit growing soil found throughout the Pacific Northwest. Six-year-old Gala/M9 apple trees were used in this study. Uniform trees were selected and baseline data were collected before bud break. The number of flower clusters were adjusted according to the trunk cross-sectional area (TCA) at the king bloom stage. The same amount of urea nitrogen was applied to each tree by either foliar or soil treatment from the middle of May to the middle of August at two-week intervals, and trees receiving no N served as a control. Leaf color was measured with a SPAD meter throughout the growing season. Leaf and root zone soil samples were collected in June, July, late August and middle October for analysis of N status. Nitrate-absorption PRS-probes (Western Ag Innovations, INC, Saskatoon, SK, Canada) were placed below the root zone (about 60 cm deep) to monitor soil nitrate loss from the root zone from June to October. Yield and fruit quality were measured at harvest. The effects of foliar and soil N application were compared.

Results and discussion

Study 1-1

Apple trees had the ability to absorb N from early spring sprays, and N status in new leaves was higher after these spray. All three times tested were able to improve tree N status, but the most effective spray time for N uptake in the spring was at the King Bloom stage (Fig.1). Absorbed N from the early spray was able to translocate within the canopy as needed (data not showed). There was no significant difference in ^{15}N uptake between early urea and $Ca(NO_3)_2$ spray (Fig. 2). The tree with low background nitrogen showed more efficient in taking up foliar applied N.

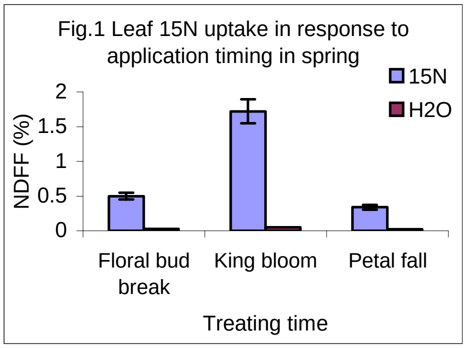


Fig.1 Leaf 15N uptake in response to application timing in spring

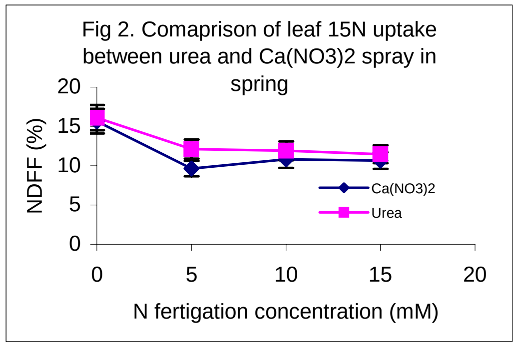


Fig 2. Comaprison of leaf 15N uptake between urea and Ca(NO3)2 spray in spring

Note: NDFF (%) indicating a percentage of N derived (absorbed) from applied fertilizer (urea).

Study 1-2

Autumn foliar urea application promoted the build-up of tree N reserves. Apple leaves were able to rapidly absorb foliar applied urea N, and the average absorption rate was 290µg/cm^2/day in the first two days after application (Fig. 3). The absorbed urea-N was converted into amino acids in leaves, and then translocated back to bark and further to roots for storage (Fig. 4). 15N absorbed by leaves was quickly exported out of leaves in autumn, and export rate declined with time (Fig. 5). Very little 15N from autumn foliar urea application was distributed in xylem and shank tissues, whereas 15N exported from leaves was mainly distributed in bark and roots (Fig. 6), indicating that bark and roots were the main organs for N reserves. Amino acids in bark and roots was partially converted into other forms of N compounds such as proteins for storage (data not showed).

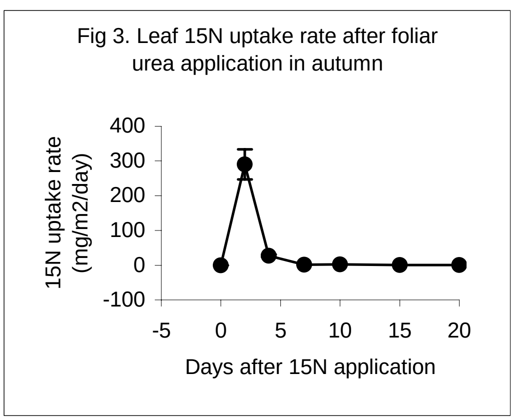


Fig 3. Leaf 15N uptake rate after foliar urea application in autumn

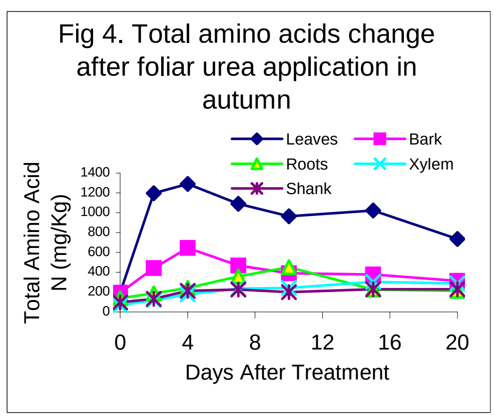


Fig 4. Total amino acids change after foliar urea application in autumn

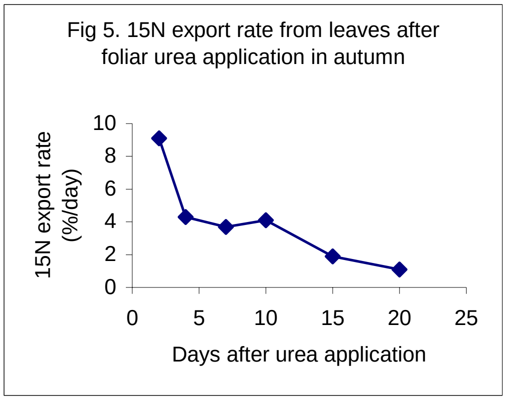


Fig 5. 15N export rate from leaves after foliar urea application in autumn

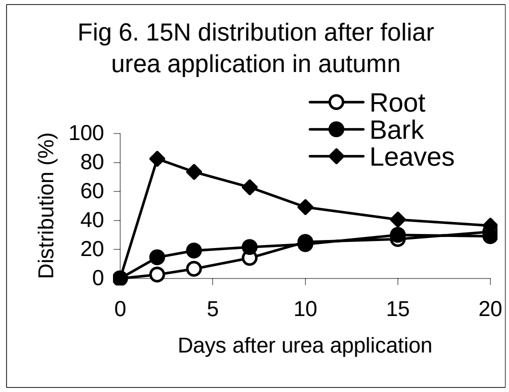


Fig 6. 15N distribution after foliar urea application in autumn

Study 1-3

Both surfaces of leaves were able to absorb foliar applied nitrogen, but the lower surface absorbed N much faster than the upper surface (Fig. 7). Application of N to both surfaces resulted in an additive effect on N uptake. The bark of one-year-old stems was also able to absorb sprayed on N, and its absorption ability was similar to the upper surface of the leaf (Fig. 7).

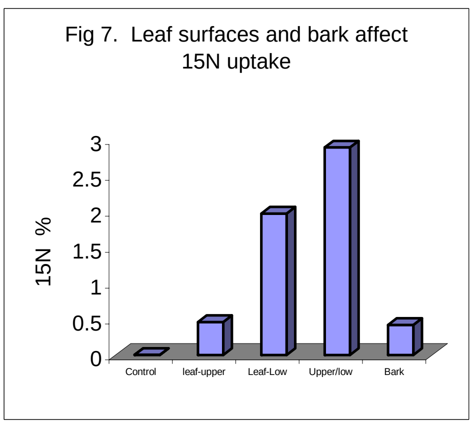


Fig 7. Leaf surfaces and bark affect 15N uptake

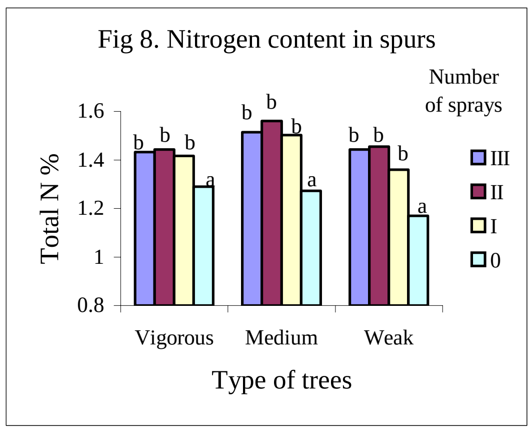
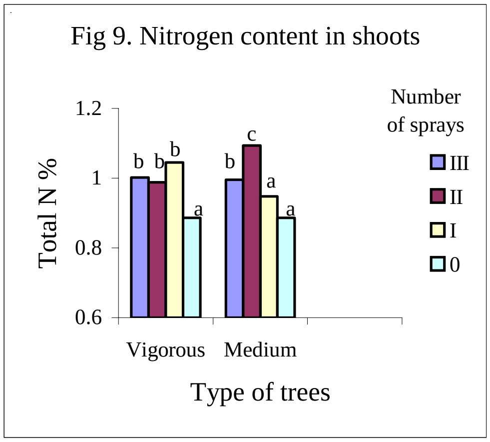
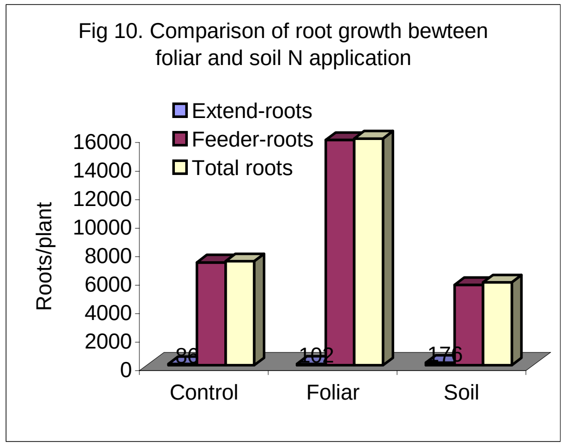


Fig 8. Nitrogen content in spurs

Study 1-4

The autumn foliar urea applications significantly increased spur N concentration in all three classifications of Cameo/M9 trees (vigorous, moderate and weak), but there were no significant differences in response to the number of applications, which suggests that the N reserve of the spurs were saturated by all the urea treatments (Fig.8). The weak trees used in this experiment had no long shoots, and therefore shoot N status was measured only in the vigorous and moderate trees. The fall foliar urea applications also increased shoot N concentration in both classifications of trees. In the vigorous trees one application appeared to be sufficient to saturate the N reserve status of the branches while in the moderate trees at least two urea applications appeared to be necessary to maximize the N reserve status of the branches (Fig. 9).

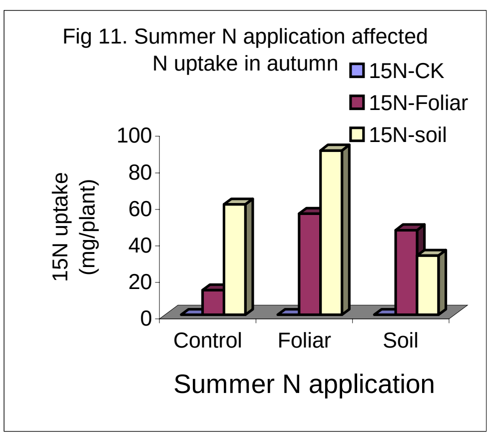


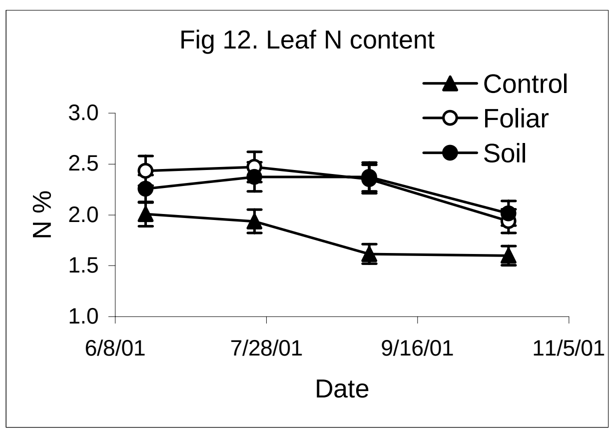


The fall foliar urea applications increased fruit size with increasing number of sprays for the vigorous trees, but did not affect fruit size in weak trees (Data not shown). For moderately vigorous trees two and three sprays increased fruit size but one spray had no effect on fruit size (Data not shown). Fruit number and yield showed very similar trends. The fall foliar urea applications increased both fruit number and yield in general (Data not shown).

Study 2-1

In the pot study, we found that soil N application during summer promoted shoot growth while foliar N application promoted root growth especially initiation of feeder roots (Fig. 10) in young Fuji/M26 apple trees. Soil N application in summer also promoted extension root initiation compared with foliar N application. Trees which received soil N application during the summer had greater leaf N uptake in autumn, while trees which received no N (control) or foliar N during summer had greater root N uptake in autumn (Fig.11).





Study 2-2

In a field study, both foliar and soil N applications during the growing season increased leaf N concentration (Fig. 12) and improved leaf color (Fig. 13), but there was no significant difference between these two treatments. Soil N application increased shoot length (Fig. 14), increased the level of both NO_3^- (Fig. 16) and NH_4^+ (Fig. 17) in the soil, and increased losses of nitrate beneath the root zone (Fig. 18). In contrast, foliar N application slightly increased in soil NO_3^- and no effect on nitrate losses beneath the root zone (Fig. 16 & 18).

Both foliar and soil N application increased N reserves in stem and roots especially in roots (Fig. 15). Trees received foliar N application tended to have more reserve N in roots. This may indicate that N from foliar application is easier to withdraw during the process of leaf senescence.

Fig 13. Leaf color (SPAD readings)

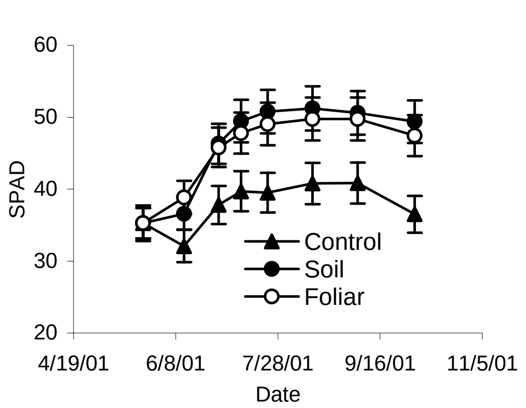


Fig 14. Shoot growth

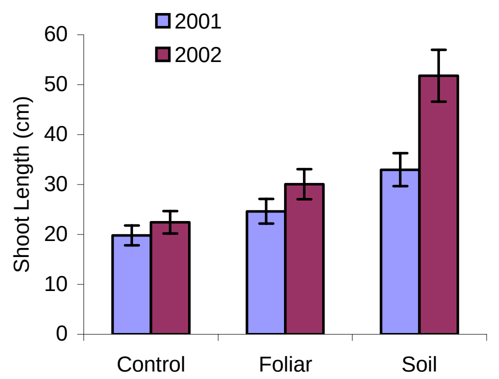


Fig 15. Nitrogen reserves in stem and roots

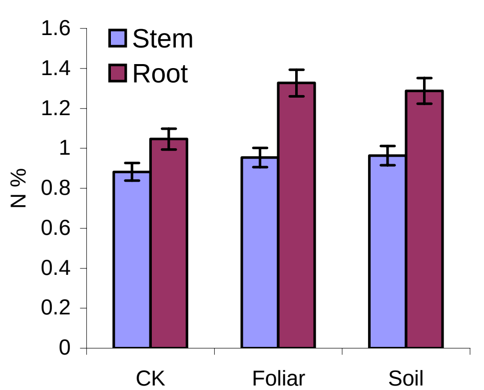
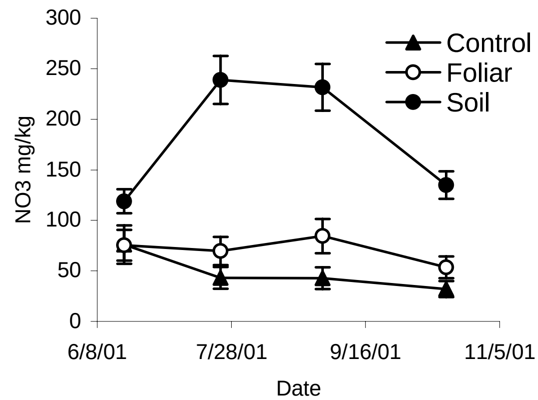
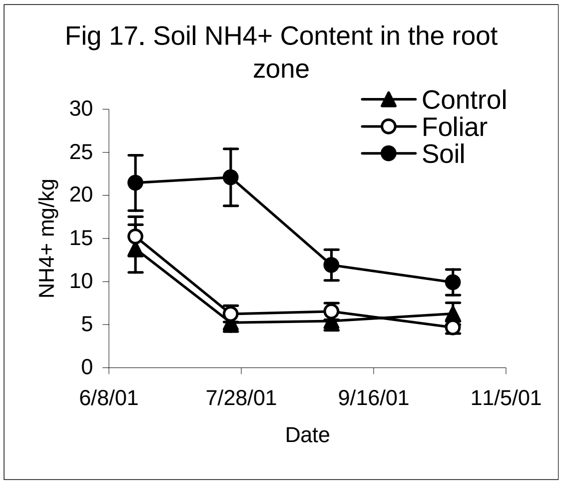


Fig 16. Soil Nitrate Content in the root zone



Yield and fruit size increased with N application in both years of the experiment, but there were no significant difference between foliar and soil N application (Table 1). Increased fruit number per tree in 2002 resulted in smaller fruits in both foliar and soil N application treatments, but total yield did not change. The control treatment had smaller fruit and lower yield in 2002 than in 2001 mainly due to lack of N supply. There was no significant difference in fruit color at harvest, but a delay in fruit coloring was observed with either foliar or soil N application in both years. The firmness of fruit flesh was reduced in both foliar and soil N application treatments in 2001 (the first year), but not in the second year (2002), which may be related to bigger fruit size. There were no differences in soluble solid and titratable acid contents among the three treatments for two years (Table 1).



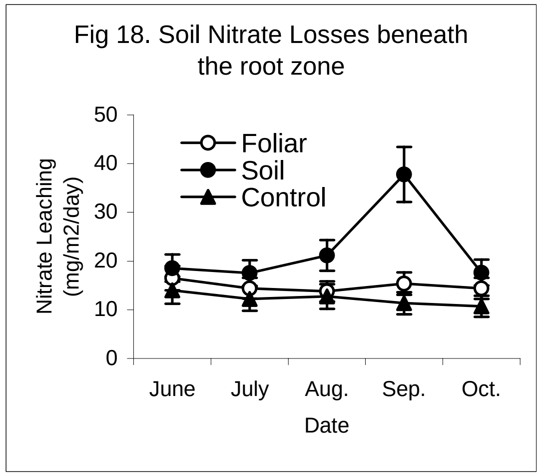


Table 1. Effects of foliar and soil N application on yield and fruit quality

Year	Treatment	Fruit Size (g/fruit)	Yield (lbs/tree)	Color (% of red)	Firmness (lbs)	Soluble solids (%)	Titratable acid (malic acid g/100ml)
	Control	137.5 a[z]	42.9 a	88.9 a	19.2 b	12.1 a	0.355 a
2001	Foliar	173.9 b	58.2 b	84.5 a	17.4 a	12.6 a	0.332 a
	Soil	172.3 b	57.2 b	82.7 a	17.3 a	12.5 a	0.343 a
	Control	109.5 a	36.7 a	84.4 a	20.9 a	13.1 a	0.360 a
2002	Foliar	158.1 b	63.5 b	82.3 a	19.0 a	13.6 a	0.353 a
	Soil	160.8 b	64.3 b	80.4 a	18.8 a	13.5 a	0.353 a

[z] Different letters in the column indicated significant differences (p=0.05)

Overall Budget

Project Title: The relationship of foliar and soil N applications to nitrogen use efficiency, growth and production of apple trees

PI(s): Leslie H. Fuchigami,

Project duration: 2001-2002

Project total: $50,000

Year	2001	2002	Total
Total	25,000	25,000	50,000

Publications

1. Shufu Dong, Denise Neilsen, Gerry H. Neilsen, Lailiang Cheng, and Leslie H. Fuchigami. 2002. Comparison of effects of foliar and soil N applications on soil N and growth of young Gala/M9 apple trees. *Acta Horticulturae*. (In press).
2. Shufu Dong, Lailiang Cheng, Carolyn F. Scagel and Leslie H. Fuchigami. 2002. Nitrogen absorption, translocation and distribution from autumn foliar applied urea in young potted apple (*Malus domestica*) trees. *Tree Physiology*. 22:1305-1310.

3. Shufu Dong, Lailiang Cheng and Leslies H. Fuchigami. 2002. Effects of urea and defoliant-CuEDTA in a single and a mixed application in the fall on N reserves and regrowth performance of young Fuji/M26 apple trees. *Acta Horticulturae*. (In press).
4. Lailiang Cheng, Shufu Dong, and Leslie H. Fuchigami. 2002. Urea uptake and nitrogen mobilization by apple leaves in relation to tree nitrogen status in autumn. *Journal of Horticultural Science & Biotechnology*. 77(1):13-18.
5. Shufu Dong, Lailiang Cheng, Pinghai Ding, and Leslie H. Fuchigami. 2001. Effects of foliar urea application in the fall on N reserves and cold hardiness of young Fuji/M26 apple trees. *HortScience*. 36(3):600.
6. Lailaing Cheng, Shufu Dong, and Leslie H. Fuchigami. 2001. Effects of copper chelate in combination with foliar urea on defoliation and reserve N levels of apple nursery trees with different background nitrogen status. *HortScience*. 36(3):464.

Acknowledgement

We gratefully thank Washington Tree Fruit Research Commission and Agriculture and Agri-Food Canada MII program for providing research funds.