

Management of Nitrogen and Carbohydrate Reserves to Improve Growth and Yield of Apple Trees

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Both reserve nitrogen and reserve carbohydrates are essential for the growth and development of apple trees in spring because they provide energy and building blocks for the new growth before photosynthesis and significant root uptake of nitrogen take place. In the fall, trees accumulate carbohydrate and nitrogen reserves. Some of the nitrogen reserves come from the leaves as the tree remobilizes nitrogen from the leaves back into the permanent parts of the tree before leaf fall. Compared with other apple growing regions, there is a very short leaf retention period in the fall after harvesting the crop in New York and the Northeast. This could limit tree performance the following season in our area for two reasons. First, because photosynthesis is often limited after harvest, apple trees may not have enough time to accumulate sufficient reserve carbohydrates. Secondly, the rapid drop of temperature after harvest may significantly reduce mobilization of nitrogen from leaves back to the plants during leaf senescence and decrease root activity for nitrogen uptake from the soil, leading to low reserve nitrogen status.

Understanding how growth and fruiting of apple trees are related to reserve nitrogen and reserve carbohydrates has important practical implications for managing nitrogen and carbohydrate reserves to improve growth and yield of apple trees. The conventional view has been that the initial growth and development of apple trees in the spring is largely determined

by reserve carbohydrate levels. By differentially altering reserve nitrogen and reserve carbohydrates using foliar urea application in the fall, we have shown that the initial growth of apple nursery trees is mainly determined by reserve nitrogen, not reserve carbohydrates. Conversion of a portion of the reserve carbohydrates to free amino acids and proteins by foliar urea application in the fall significantly improved tree growth. However, this may not be completely applicable to bearing trees in the orchard. Bearing trees not only have vegetative growth, but also have reproductive growth. As a result, the assimilated carbon in bearing trees is not only partitioned to vegetative growth and storage, but also to the fruit. In fact, producing a high quality, consistent crop is the ultimate goal of orchard management. The objective of this work was to determine how growth and fruiting of apple trees are related to reserve nitrogen and reserve carbohydrates and how to optimize the management of these nutrient reserves to improve the productivity of apple trees.

Experimental Procedures

Three experimental approaches have been used to alter the reserve nitrogen and reserve carbohydrate status of apple trees. The first is manual defoliation in combination with or without foliar urea applications in the fall; the second is carbon dioxide enrichment with or without nitrogen

In the fall, trees accumulate carbohydrate and nitrogen reserves. Some of the nitrogen reserves come from the leaves as the tree remobilizes nitrogen from the leaves back into the permanent parts of the tree before leaf fall. The relatively short period of good weather in the fall after harvesting the crop may limit reserve nitrogen and reserve carbohydrate levels of trees in New York. Results from this project show that nitrogen reserves are very important to tree growth and cropping the next year. Management strategies for improving tree nitrogen reserves include fall urea sprays or fall ground fertilization.

application after harvest in the fall; and the third is manipulation of cropland.

Experiment 1. We studied the effects of manual defoliation and foliar urea application in the fall on reserve nitrogen and reserve carbohydrate status, and tree growth and fruiting the following year. This experiment was conducted at a Cornell experimental farm using six-year-old 'Marshall McIntosh' / M.9 trees at a spacing of 6 x 14 feet. Trees received one of the following four treatments after harvest: (1) natural defoliation without foliar urea application (control), (2) manual defoliation on October 12, (3) 3 percent foliar urea sprayed twice in the fall (September 28 and October 5), and (4) 3 percent foliar urea sprayed twice (September 28 and October 5), followed by manual defoliation on October 12. There were five replications for each treatment with four trees in each plot in a completely randomized design. Spur

and extension growth were sampled before budbreak to measure nitrogen and carbohydrates. Test trees did not receive any nitrogen fertilizer during the second growing season. Spur leaf samples were taken on June 1 to determine total spur leaf area, leaf number, leaf nitrogen content. Fruit number, yield, and fruit quality were measured at harvest.

Experiment 2. In this study we enriched the air with carbon dioxide or applied nitrogen in the fall to affect reserve nitrogen and reserve carbohydrates and evaluated tree growth and fruiting the following year. There were two levels of CO₂ concentrations: ambient (360 ppm) and an elevated level (1000 ppm), and two levels of nitrogen supply: no N or 2 liters of 140 ppm N applied to soil twice weekly for five weeks. So there were a total of four treatment combinations with three replications each in a completely randomized design. Second leaf Gala/M.26 trees that grow in sand culture were used in this experiment. The cropload of these trees was adjusted by hand thinning to six fruit per cm² TCA at 10 mm king fruit. They were supplied with 150 ppm Peter's 20-10-20 fertilizer with micronutrients every week during the growing season until mid August. A total of 36 uniform trees were selected and each was randomly assigned to one of the four treatments above. Six temperature-controlled plastic chambers were used in the field to provide CO₂ treatment. The CO₂ concentration inside the chamber was controlled by an injection system and monitored by an infrared analyzer. Soil N treatment began at the same time when the trees were moved into the CO₂ chambers. Two liters of 140 ppm N (from ammonium nitrate) were provided to each tree twice weekly for five weeks. After natural leaf fall, pots were covered with woodchips to protect the root system during the winter. Before budbreak the following year, one set of trees from each of the four treatment combinations was destructively sampled to measure dry weight, nitrogen and carbohydrates. The remaining trees were divided into two groups. One group did not receive any nitrogen supply at all while the other group received 140 ppm N supply starting from petal fall until mid August. Fruit was harvested in mid September. Total fruit number, fresh weight, and total leaf area were measured at harvest.

Experiment 3. We imposed different croploads to determine the effect of cropload on tree growth and reserve nitrogen and reserve carbohydrates. We used third leaf 'Honeycrisp'/M.9, 'Jonagold'/M.9 and 'Gala'/M.9 trees. Cropload was

Treatments	Spur N(%) (%)	Shoot N(%) (%)	Spur carbohydrates (mg/g)	Shoot carbohydrates(mg/g)
Control	1.37a	0.94a	91.7a	103.9a
Foliar urea (F)	1.47b	1.05b	79.0b	95.3b
Defoliation (D)	1.16c	0.73c	73.0b	94.4b
F + D	1.24c	0.80c	73.6b	93.6b

Different letters within the same column indicate significant level at 0.05%.

Treatments	Fruit number (#/tree)	Fruit Weight (g)	Yield (kg/tree)	Soluble solids (%)
Control	178.3ab	153.8a	27.30ab	12.46a
Foliar urea (F)	191.8a	159.6ab	30.64a	12.49a
Defoliation (D)	124.6c	171.1b	21.41c	12.09a
F + D	148.9bc	167.1b	24.72bc	12.40a

adjusted to 0, 3, 6, 9, 12, and 15 fruit/cm² trunk cross-sectional area (TCA) at 10-mm king fruit by hand thinning. At harvest, fruit number and yield per tree were recorded. Before budbreak the following spring, spurs, extension growth, and roots were sampled for nitrogen and carbohydrate analysis.

For all the experiments above, nitrogen was determined by the Kjeldahl method. Soluble sugars were extracted with 80% ethanol three times, then separated and quantified by using a Dionex High Performance Liquid Chromatograph (HPLC). Starch was converted to glucose, and then measured by the HPLC. Total non-structural carbohydrates are the sum of starch and soluble sugars. Soluble sugars include sorbitol, sucrose, glucose and fructose.

Results and Discussion

Experiment 1. Reserve nitrogen and carbohydrates. Manual defoliation significantly decreased both reserve nitrogen and reserve carbohydrates in spurs and extension growth (Table 1). Foliar urea application increased nitrogen content, but decreased reserve carbohydrates in both spurs and extension growth. Application of foliar urea followed by manual defoliation tended to increase reserve nitrogen content in both spurs and extension growth compared with manual defoliation alone although this is not statistically significant.

Growth and yield. Manual defoliation in the fall significantly decreased spur leaf number, total leaf area, specific leaf

weight, and leaf N content per unit leaf area the following spring. Foliar urea application did not affect spur leaf number, specific leaf weight, and leaf N content, but increased total spur leaf area the following spring. Foliar urea application followed by manual defoliation the following spring increased total spur leaf area, specific leaf weight, and leaf N content compared with

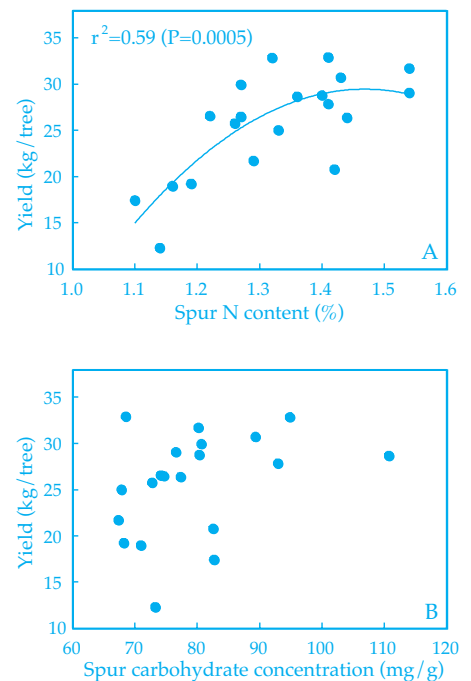


Figure 1. Fruit yield of 6 year-old 'Marshall McIntosh'/M.9 trees in relation to reserve nitrogen content (A) and reserve carbohydrate concentration (B) in spurs.

TABLE 3

Effects of elevated CO₂ and N application in the fall on dry weight and reserve N and reserve carbohydrate status of potted 'Gala'/M.26 apple trees.

Fall Treatments	N	DW(g/tree)	N content	Total N	CHO Conc	Total CHO
CO ₂		(g/tree)	%	(g/tree)	(mg/g)	(g/tree)
360	0	1031.0	0.62	6.39	153.3	158.1
	Soil N	1024.9	0.98	9.99	134.8	138.2
1000	0	1107.2	0.59	6.54	162.1	179.7
	Soil N	1104.8	0.86	9.51	140.4	155.2
Significance						
Fall CO ₂		ns	ns	ns	Ns	P<0.05
Fall N		ns	P<0.0001	P<0.0001	P<0.05	P<0.05

P values indicate the significance level. ns: non significant.

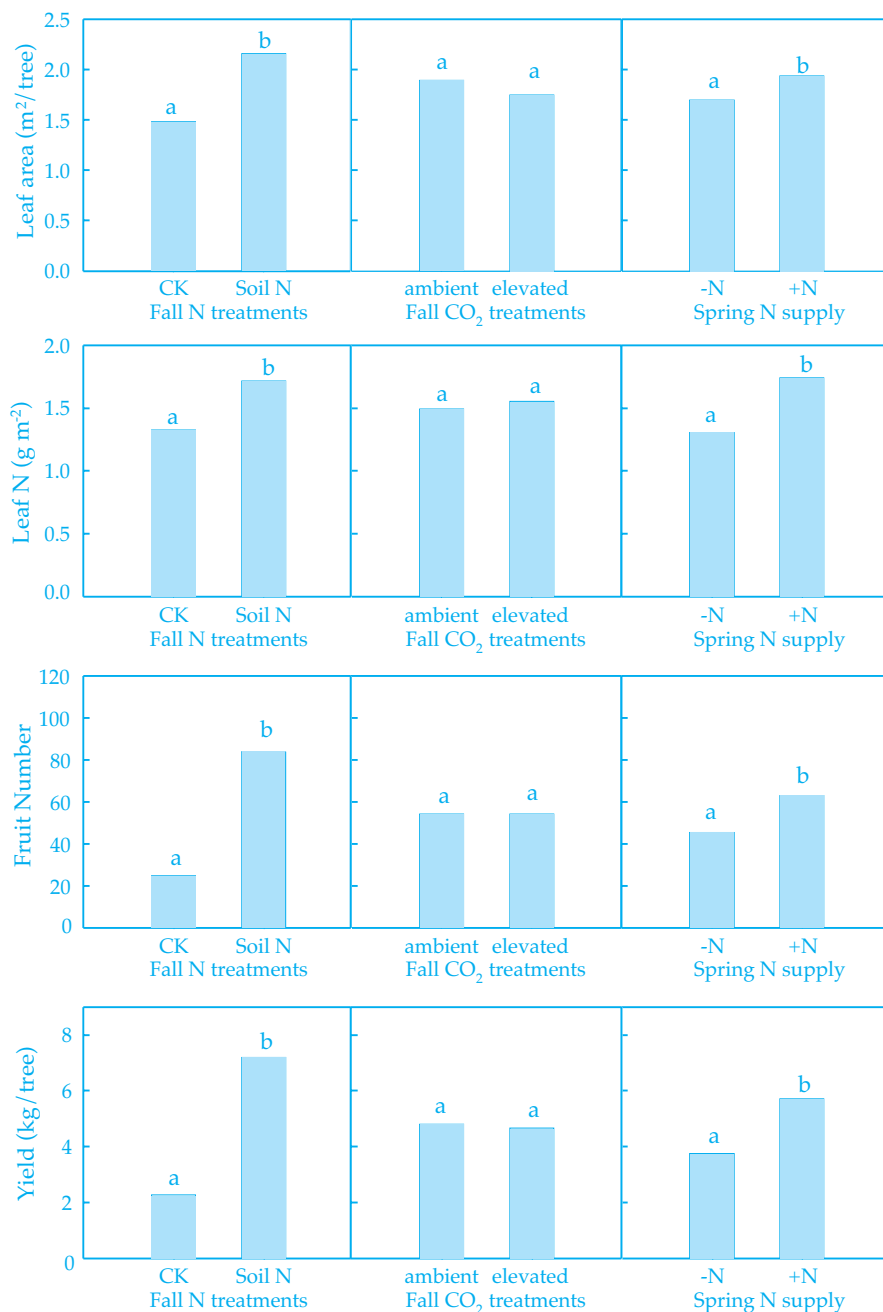


Figure 2. Leaf area, leaf nitrogen content, fruit number and yield of potted 'Gala'/M.26 apple trees in relation to fall CO₂ and N treatments and spring N supply. Different letters indicate significant difference at 5% level.

manual defoliation alone (data not shown). Manual defoliation significantly decreased fruit number and yield per tree the next year (Table 2). Foliar urea application tended to increase fruit number and yield per tree although not statistically significant. Foliar urea application followed by manual defoliation tended to increase fruit number and yield compared to manual defoliation alone. There was no difference in fruit quality except that fruit size was slightly larger in trees with lower fruit number. When regression analysis was used to examine fruit number and yield in relation to reserve nitrogen and reserve carbohydrates, it was found that fruit number and yield were significantly related to reserve nitrogen content in spurs, but not reserve carbohydrates (Figure 1).

Experiment 2. Reserve nitrogen and carbohydrates. Fall CO₂ enrichment slightly increased both carbohydrate concentration and total dry matter of the tree, resulting in a significant increase in the total amount of reserve carbohydrates (Table 3). Nitrogen application in the fall significantly increased N content and total amount of N accumulated in the tree, but reduced carbohydrate concentrations.

Growth and yield. Fall CO₂ enrichment increased total amount of reserve carbohydrates, but it did not affect total leaf area, fruit number, or fruit yield the following year (Figure 2). Regardless of spring N supply, trees with high N reserves but low carbohydrate reserves had a larger total leaf area, higher fruit number and total yield than those with low N reserves but high carbohydrate reserves. Spring N supply also significantly increased total leaf area, leaf N content, fruit number, and total yield.

Experiment 3. Over a wide range of cropload (0 to 14 fruit per cm² TCA), spur N content or carbohydrate concentration did not change significantly (Fig. 3A, B). However, tree vegetative growth, as measured by the increase of TCA, decreased as cropload increased (Figure 3C). This indicates that apple trees are able to maintain their reserve nitrogen and reserve carbohydrate concentrations in response to increasing cropload by reducing vegetative growth. However, this will inevitably lead to a decrease in the total amount of reserves, which may in turn negatively affect growth and fruiting the following season.

Summary

The key findings of this project are:

- Manual defoliation after harvest reduced both reserve nitrogen and carbo-

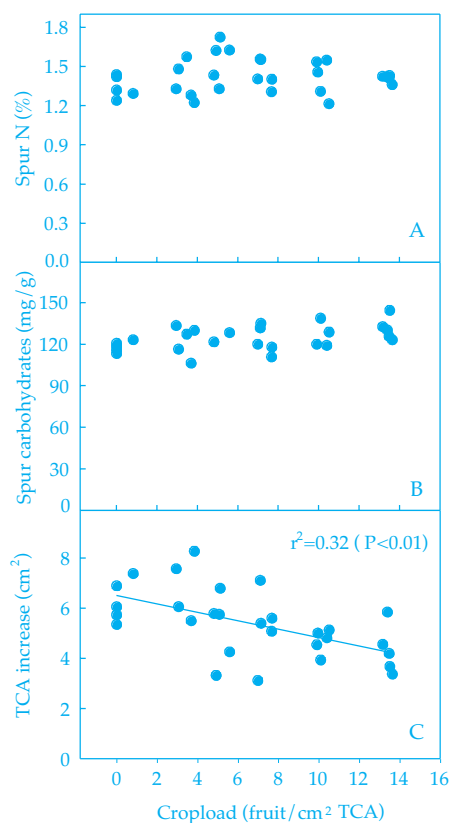


Figure 3. Effects of cropload on spur nitrogen (A), carbohydrates (B) and increase of trunk cross-sectional area (C) of 3rd leaf 'Honeycrisp'/M.9 trees.

hydrates. Foliar urea applications in the fall increased reserve nitrogen, but decreased reserve carbohydrates. Apple yield the following year was more related to reserve nitrogen than reserve carbohydrates.

- CO₂ enrichment of bearing trees after harvest increased the total amount of reserve carbohydrates. Fall nitrogen application increased tree total reserve nitrogen, but decreased total reserve carbohydrates. Trees with high nitrogen reserves but low carbohydrate reserves had better vegetative growth and higher fruit set and yield the following season than those with low nitrogen reserves but high carbohydrate reserves.
- Concentrations of reserve nitrogen and reserve carbohydrates were not affected significantly by cropload, but tree growth was decreased by increasing cropload.
- Both foliar urea application and soil N application in the fall enhanced tree nitrogen reserves, and consequently improved tree growth and fruiting the following season.

These findings clearly showed that both vegetative growth and fruiting of bearing apple trees are mainly determined

by nitrogen reserves, not carbohydrate reserves. Therefore, how to improve tree reserve nitrogen status should be an important part of orchard management. Cropload must be optimized as it affects tree growth (as well as fruit quality and flower bud initiation) and consequently the total amount of nitrogen and carbon reserves available for the following year. Maintaining healthy foliage in the fall is critical for building up both carbohydrate and nitrogen reserves. Both foliar urea application and soil N application can be used in the fall to enhance tree nitrogen reserves, and consequently improve tree growth and fruiting the following season.

In addition, our nitrogen timing study using ¹⁵N-ammonium nitrate showed that mature apple trees took up significant amounts of fertilizer nitrogen between budbreak and the end of spur leaf growth, which contributed about 30 percent to the spur leaf N. So, applying nitrogen between budbreak and bloom provides another route for satisfying early tree N demand for canopy development and fruit growth.

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