**Project Title:**  Growth and Fruiting in Relation to Reserve Nitrogen and Carbohydrates

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**Objectives**

The overall objective is to determine if reserve carbon or nitrogen limits growth and fruiting of apple trees in growing regions with a short postharvest leaf retention period, and modify nutrient management practices accordingly to overcome the limitation to achieve the climate-allowable maximum productivity.

**Significant Findings**

- Manual defoliation after harvest reduced both reserve nitrogen and carbohydrates. 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. Thus, the growth and fruiting of apple trees in spring are primarily determined by reserve nitrogen, not by reserve carbohydrates.
- Concentrations of reserve nitrogen and reserve carbohydrates were not affected significantly by cropload. However, total amounts of reserve nitrogen and carbohydrates were decreased by overcropping as it reduced tree size (i.e. storage size). Therefore, optimizing cropload is critical for reserve nutrient management.
- 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.

**Methods**

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

**Experiment 1.**  Effects of manual defoliation and foliar urea applications in the fall on reserve nitrogen and carbohydrate status, and tree growth and fruiting the following year

This experiment was conducted at Cornell Experimental Orchards using 6 year-old Marshall Mac on M.9 at a spacing of 6×14 feet. Trees received one of the following 4 treatments after harvest: (1) manual defoliation on October 12, (2) 3% foliar urea sprayed twice in the fall (September 28 and October 5), (3) 3% foliar urea sprayed twice (September 28 and October 5), followed by manual defoliation on October 12, and (4) natural defoliation without foliar urea (control). There were 5 replications for each treatment with 4 trees in each plot in a completely randomized design.

Spur and extension shoots were sampled before budbreak for to measure reserve 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.** Carbon dioxide enrichment and nitrogen application in the fall on reserve nitrogen and carbohydrates and tree growth and fruiting the following year.

CO₂ enrichment and N applications were used to alter reserve nitrogen and carbohydrate status of Gala/M26 trees after harvest. There were two levels of CO₂ concentrations: ambient (360 ppm) and an elevated level (1000 ppm), and two levels of N supply: no N or 2 liters of 10 mM N applied to soil twice weekly for 5 weeks. So, there were a total of 4 treatment combinations with 3 replications each in a completely randomized design. Second leaf Gala/M.26 trees that are grown in sand culture were used in this experiment. The cropload of these trees were adjusted by hand thinning to 6 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 5 mM ammonium nitrate were provided to each tree twice weekly for 5 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 4 treatment combinations was destructively sampled to measure dry weight, reserve nitrogen and carbohydrates. The remaining trees were divided into two groups. One group did not receive any nitrogen supply while the other group received 10 mM 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 recorded.

**Experiment 3.** Cropload effects on tree growth and reserve nitrogen and carbohydrates

The effect of cropload on tree growth and reserve nitrogen and carbohydrates were evaluated using third leaf Honeycrisp/M.9, Jonagold/M.9 and Gala/M.26 trees. Cropload was adjusted at 10-mm king fruit by hand thinning to 0, 3, 6, 9, 12, and 15 fruit/cm²TCA. At harvest fruit number and total fresh weight were recorded. Before budbreak the following spring, spurs, extension growth, and roots were sampled for reserve nitrogen and carbohydrate analysis.

For all the experiments above, nitrogen was determined by the Kjeldahl method. Soluble sugars were extracted with 80% ethanol, then separated and quantified by using a Dionex High Performance Liquid Chromatograph (HPLC). Starch was converted to glucose, 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**

1. **Reserve nitrogen and carbohydrates**

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

2. **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. Foliar urea application did not affect spur leaf number, specific leaf weight, and leaf N content, but increased total spur leaf area. Foliar urea application followed by manual defoliation increased total spur leaf area, specific leaf weight, and leaf N content compared to manual defoliation alone (Data not shown).
Manual defoliation significantly decreased fruit number and yield per tree (Table 2). Foliar urea 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.

Table 1. Reserve nitrogen and carbohydrates as affected by defoliation and foliar urea

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

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

Table 2. Effects of defoliation and foliar urea applications on fruit yield and quality

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Fruit number (#/tree)</th>
<th>Fruit Weight (g)</th>
<th>Yield (kg/tree)</th>
<th>Soluble solids (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>178.3ab</td>
<td>153.8a</td>
<td>27.30ab</td>
<td>12.46a</td>
</tr>
<tr>
<td>Foliar urea</td>
<td>191.8a</td>
<td>159.6ab</td>
<td>30.64a</td>
<td>12.49a</td>
</tr>
<tr>
<td>Defoliation</td>
<td>124.6c</td>
<td>171.1b</td>
<td>21.41c</td>
<td>12.09a</td>
</tr>
<tr>
<td>F + D</td>
<td>148.9bc</td>
<td>167.1b</td>
<td>24.72bc</td>
<td>12.40a</td>
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When regression analysis was used to examine fruit number and yield in relation to reserve nitrogen and carbohydrates, it was found that fruit number and yield were significantly related to reserve nitrogen content in spurs, but not reserve carbohydrates (Fig. 1).
Fig. 1. Fruit yield in relation to reserve nitrogen (A) and carbohydrates (B) in spurs
Experiment 2

1. Reserve nitrogen and carbohydrates

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

2. Growth and yield

Figure 2 shows the main effects of fall CO₂, fall N applications, and spring N supply on tree performance. Although fall CO₂ enrichment increased total amount of reserve carbohydrates, it did not affect total leaf area, fruit number, and fruit yield the following year. Regardless of current nitrogen supply the following season, 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.

Table 3. Effects of fall elevated CO₂ and N application on dry weight and reserve N and carbohydrate status of Gala/M.26 trees

<table>
<thead>
<tr>
<th>Fall Treatments</th>
<th>DW (g/tree)</th>
<th>N content (%)</th>
<th>Total N (g/tree)</th>
<th>CHO Conc (mg/g)</th>
<th>Total CHO (g/tree)</th>
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<tbody>
<tr>
<td>360</td>
<td>1031.0</td>
<td>0.62</td>
<td>6.39</td>
<td>153.3</td>
<td>158.1</td>
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<tr>
<td>Soil N</td>
<td>1024.9</td>
<td>0.98</td>
<td>9.99</td>
<td>134.8</td>
<td>138.2</td>
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<tr>
<td>1000</td>
<td>1107.2</td>
<td>0.59</td>
<td>6.54</td>
<td>162.1</td>
<td>179.7</td>
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<tr>
<td>Soil N</td>
<td>1104.8</td>
<td>0.86</td>
<td>9.51</td>
<td>140.4</td>
<td>155.2</td>
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Significance

<table>
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<tr>
<th></th>
<th>Fall CO₂</th>
<th>Fall N</th>
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<tbody>
<tr>
<td>N content (%)</td>
<td>ns</td>
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</tr>
<tr>
<td>Total N (g/tree)</td>
<td>ns</td>
<td>P&lt;0.0001</td>
</tr>
<tr>
<td>CHO Conc (mg/g)</td>
<td>ns</td>
<td>P&lt;0.05</td>
</tr>
<tr>
<td>Total CHO (g/tree)</td>
<td>ns</td>
<td>P&lt;0.05</td>
</tr>
</tbody>
</table>

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

Experiment 3:

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

Our data showed that both vegetative growth and fruiting of bearing apple trees are mainly determined by nitrogen reserves, not by 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 a healthy foliage in the fall is important 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, we found that spring application of nitrogen increased total leaf area, fruit number, and total fruit yield (Experiment 2). Based on our nitrogen timing study in New York, mature apple trees took up significant amount of fertilizer nitrogen between budbreak and the end of spur leaf growth, which contributed about 30% to the spur leaf N. So, applying nitrogen between budbreak and bloom may provide another route for satisfying early tree N demand for canopy development and fruit growth.

Project Title: Growth and Fruiting in Relation to Reserve Nitrogen and Carbohydrates
Principal Investigator: L. Cheng
Total Budget: $67,838
Project duration: 2000-2002
Budget breakdown

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<tr>
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