

Growth Performance of Apple Nursery Trees in Relation to Reserve Nitrogen and Carbohydrates

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As apple growers move to high density planting systems, the investment for orchard establishment is considerably increased. The key to achieving early economic return and profitability is to bring the orchard into early production and have sustained high yield of best quality fruit. Tree quality and performance during establishment play a very important role in determining the early productivity of the orchard. If tree establishment is poor, it is very difficult to achieve early productivity.

Currently nursery stock is graded on the basis of caliper size and the number of feathery leaves. From a physiological standpoint, it is the nutrient reserves that support the initial growth of apple nursery trees during establishment in the orchard. Therefore, a high quality tree needs to reach good size with appropriate root-to-shoot ratio but, more importantly, to have high levels of nutrient reserves. Among the reserves, carbohydrates and nitrogen are the most important as they provide energy and building blocks for the new growth before any photosynthesis and significant root uptake of nitrogen can take place. Carbohydrates, including both starch and soluble sugars, make up the bulk part of the total reserves in apple trees. In contrast, total nitrogen, including proteins and amino acids, accounts for less than 2% of the dry matter of an apple tree in the winter.

Although both nitrogen and carbohydrate reserves are essential, the limitations of reserve nitrogen and carbohydrates on the initial growth are not clear. Compared with bearing trees in the orchard, nursery trees have only vegetative growth and the assimilated carbon is partitioned only between growth and storage. Therefore, the requirement for reserve carbohydrates should be readily achievable unless the trees keep growing very late into the season.

... The growth potential of apple nursery plants is mainly determined by reserve nitrogen and is not limited by reserve carbohydrates.

Nursery trees, on the other hand, may be more dependent on reserve nitrogen for their regrowth during establishment because root uptake of nitrogen is delayed by damaged root system, lack of new roots or low soil temperatures in the spring.

Understanding the relationship between reserve nitrogen and carbohydrates and the role they play in tree performance has direct practical implications. If the growth potential of apple nursery trees is mainly determined by reserve carbohydrates, cultural practices in the nursery should be optimized to improve reserve carbohydrate status of the tree. In contrast, if the regrowth potential is mainly determined by reserve nitrogen, management strategies directed at optimizing nitrogen storage would improve the regrowth performance of apple nursery stock. In this article, I will describe how tree growth is dependent on reserve nitrogen and carbohydrates accumulated in the tree from the previous year and how to use foliar urea application in the fall to improve reserve nitrogen status and consequent tree growth the following spring.

SOURCES FOR RESERVE NITROGEN AND CARBOHYDRATES

Mature leaves are the only source for reserve carbohydrates. Growing shoot tips and young leaves are strong sinks for assimilated carbon. When an apple tree is actively growing, most of the assimilated carbon is being used for growth. Only when growth slows down will assimilated carbon accumulate for storage. Therefore, any cultural practices that keep plants growing late into the season, such as heavy N fertilization or over-irrigation, will result in low reserve carbohydrate levels.

For reserve N, there are two sources. One is the root uptake from the soil. The other is mobilization of N from leaves back to the storage tissues during leaf senescence. Mobilization of leaf nitrogen requires a normal senescence process during which proteins are broken down and the resulting amino acids are translocated back to the stem and root tissues. Approximately 50% of the total N in a tree is in the foliage before any significant nitrogen mobilization in the fall. Typically 50 to 60% of the leaf N can be mobilized back to the tree during leaf senescence (Oland, 1963; Cheng et al., 2002). However, if too much nitrogen is applied to the soil in the fall, leaf senescence will be delayed and nitrogen mobilization will be reduced. In addition to reducing carbon reserve, late N fertilization to the soil may also reduce nitrogen mobilization from the leaves.

In addition to the mobilization of existing nitrogen in leaves, leaves can readily absorb urea in the fall, and the nitrogen derived from foliar urea applications can be translocated back to the tree. Our data showed that apple leaves can translocate 80 to 90% of the nitrogen absorbed from urea sprays back to the storage tissues (Cheng et al., 2002). After urea is absorbed by leaves, its metabolism involves hydrolysis of urea to ammonium, followed by incorporation of ammonium into amino acids. Some amino acids derived from foliar urea may be directly translocated back to the tree (Shim et al., 1973). In contrast, the existing proteins in the leaves have to break down to amino acids before they are mobilized.

TABLE 1

Effects of foliar urea application in the fall on cold hardiness of Fuji/M.26 nursery trees.

Treatment	LT50* (December 27) (°C)	LT50* (February 25) (°C)
Control	-38.5	-30.0
1.5% Urea 2 times	-39.5	-28.6
3% Urea 2 times	-40.8	-30.8
4.5% Urea 2 times	-40.4	-30.0

*Stem tissues were tested. LT50 is the temperature at which 50% of the tissue is killed. Each number is the mean of 6 replications.

EFFECTS OF N FERTIGATION AND FOLIAR UREA ON RESERVE N AND CARBOHYDRATES

Compared with soil-applied nitrogen, foliar urea application after terminal budset has the advantage that it maintains the existing root to shoot ratio and cold tolerance of the trees because it does not stimulate new growth in the fall. As shown in Table 1, apple trees that received foliar urea application have the same level of cold hardiness as the control trees.

Both nitrogen fertilization during the growing season and foliar urea application after terminal budset in the fall were used in our study to alter reserve nitrogen and carbohydrate status of apple nursery trees (Cheng and Fuchigami, 2002). Briefly, bench-grafted Fuji/M.26 trees were fertigated with seven different N concentrations ranging from 0 to 280 ppm by using a balanced nutrient solution from June 30 to September 1. There were 30 trees at each N fertigation concentration. Half of the fertigated trees were sprayed with 3% (25 lbs urea/100 gal water) twice at weekly interval in mid-October, and the remainder were sprayed with water as controls. All the plants were dug in late November after natural leaf fall and stored at 2°C. One set of trees (five plants) from each treatment was destructively sampled before budbreak for N and carbohydrate content. The remaining plants were used in the regrowth test described below.

N content of the dormant trees increased almost linearly with increasing N fertigation concentration (Fig. 1A). Foliar urea application increased reserve N content to a similar level across all seven N fertigation concentrations. Carbohydrate concentration generally declined with increasing N fertigation concentration (Fig. 1B). Foliar urea application decreased carbohydrate concentration to a similar level across the N fertigation concentrations. On a whole tree basis, total amount of N increased linearly with increasing N fertigation concentration (Fig. 2A). Total reserve carbohydrates increased with increasing N fertigation concentration at first, then tended to decrease with further rise in N concentration (Fig. 2B). Foliar urea applications increased total N reserve and decreased total carbohydrate reserve at each given N fertigation concentration.

GROWTH IN RELATION TO RESERVE NITROGEN AND CARBOHYDRATES

For the regrowth test, trees from each treatment were grown under either no N supply or sufficient N supply (140 ppm) in a balanced nutrient solution for 2 months after budbreak (Cheng and Fuchigami, 2002). ¹⁵N-labeled ammonium nitrate was used as the sole nitrogen source for the regrowth in order to distinguish current uptake of nitrogen from reserve nitrogen. Regardless of N supply in the spring, total

leaf area at the end of the regrowth period increased curvilinearly with increasing N concentrations from the fertigation treatment the previous year (Fig. 3). Trees sprayed with fall foliar urea produced greater total leaf area at each given N fertigation concentration. Because the fall foliar urea application did not alter the tree size at each given N fertigation concentration, this means that when tree size was the same, trees with higher reserve N but lower reserve carbohydrates had more new leaf growth than those with lower N reserve but higher carbohydrate reserve.

In addition to the increased quantity of new leaf growth, the quality of the leaf growth was also related to the reserve N status. Regardless of current N supply, trees sprayed with foliar urea maintained a higher level of leaf N content and green color than the controls (data not shown). The effect of N supply in the spring on leaf N content and leaf color was observed mainly on trees fertigated with low N concentrations the previous growing season, and the effect was relatively small.

A single linear relationship was found between the total amount of N accumulated in the tree from the previous growing season and the amount of reserve N used for new shoot and leaf growth in the spring regardless of N supply in the spring (Fig. 4). This clearly indicates that reserve N utilization for new shoot and leaf growth was dependent on the total

FIGURE 1 A, B

Tree N content (A) and carbohydrate concentration (B) of dormant Fuji/M.26 trees in response to N fertigation during the growing season and to foliar urea applications in the fall. Trees were destructively harvested before budbreak. Each point is mean with SE of 5 replicates. Solid circles represent trees that were fertigated with only seven N concentrations during the growing season, while the open circles are those that also received fall applications of foliar urea.

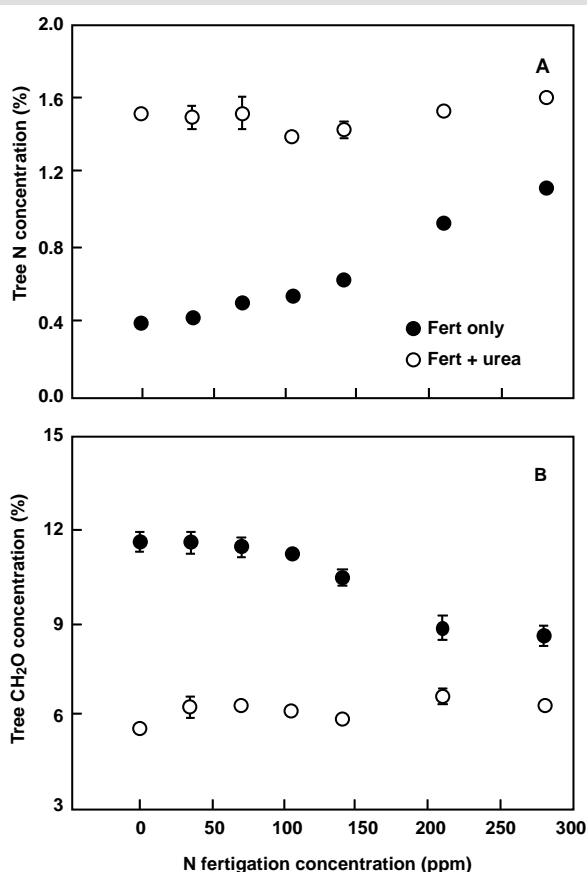
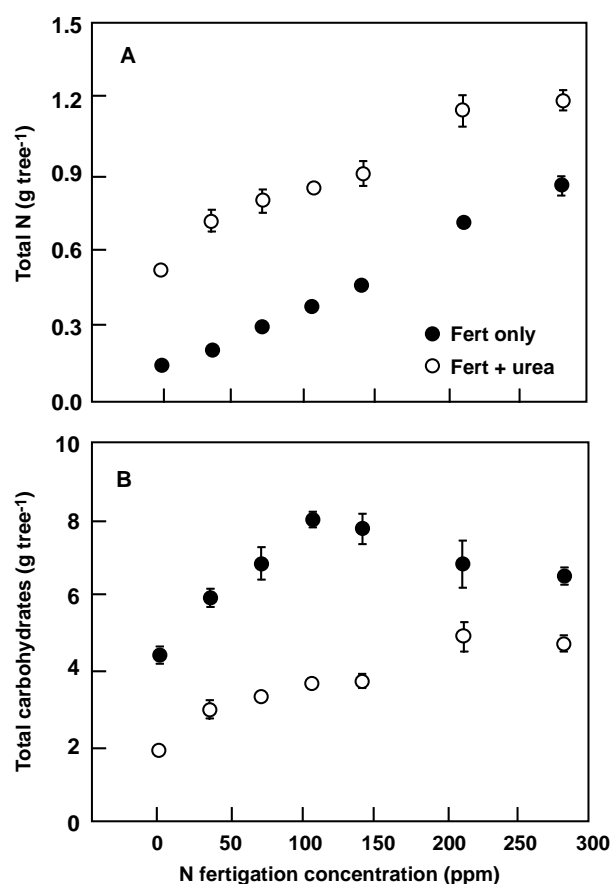


FIGURE 2 A, B

Total nitrogen (A) and carbohydrates (B) of dormant Fuji/M.26 trees as affected by nitrogen fertigation during the growing season and foliar urea applications in the fall. Trees were destructively harvested before budbreak. Solid circles represent trees that were fertigated with only seven N concentrations during the growing season, while the open circles are those that also received foliar urea applications.



reserve N available and was not affected by the current N supply in the spring.

In conclusion, regrowth of apple nursery trees in the spring is mainly determined by nitrogen reserves and is not limited by carbohydrate reserves. Although there are high concentrations of reserve carbohydrates

accumulated in the trees with low reserve nitrogen, these trees cannot make the best use of these reserve carbohydrates for new growth unless foliar urea is applied to increase the reserve nitrogen level. So, nitrogen plays a pivotal role in the utilization of carbohydrate resources (Cheng et al., 2001; Cheng and Fuchigami, 2002). Our results also indicate that reserve nitrogen utilization for new shoot and leaf growth is dependent on the total amount of reserve and is not affected by the current N supply in the spring.

FIGURE 3

Total leaf area of Fuji/M.26 trees at the end of the regrowth period, in relation to previous N fertigation and foliar urea treatments under no N supply (A) or 140 ppm N supply (B) during the spring regrowth period. Solid circles represent trees that were fertigated with only seven N concentrations during the previous season, while the open circles are those that also received foliar urea applications in the previous fall.

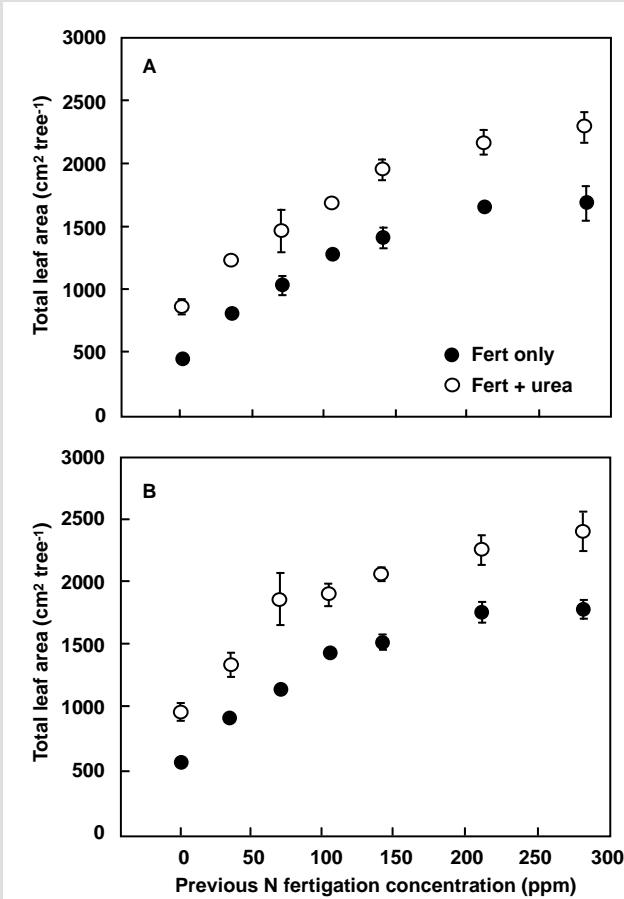
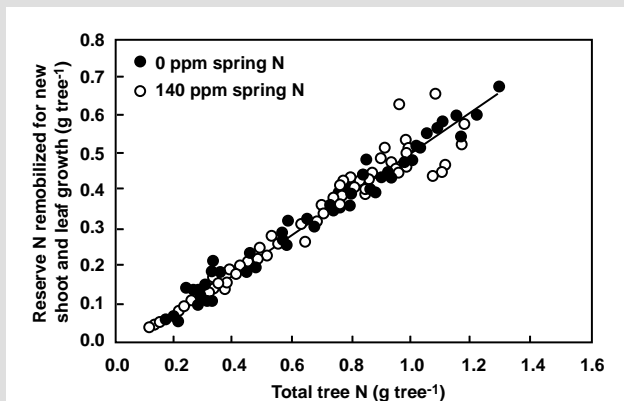


FIGURE 4

Reserve nitrogen remobilized for new shoot and leaf growth at the end of the regrowth period in relation to total amount of nitrogen accumulated in the tree from the previous growing season. Solid circles represent trees that did not receive any nitrogen, while open circles are those that received 140 ppm N supply during the spring regrowth period.

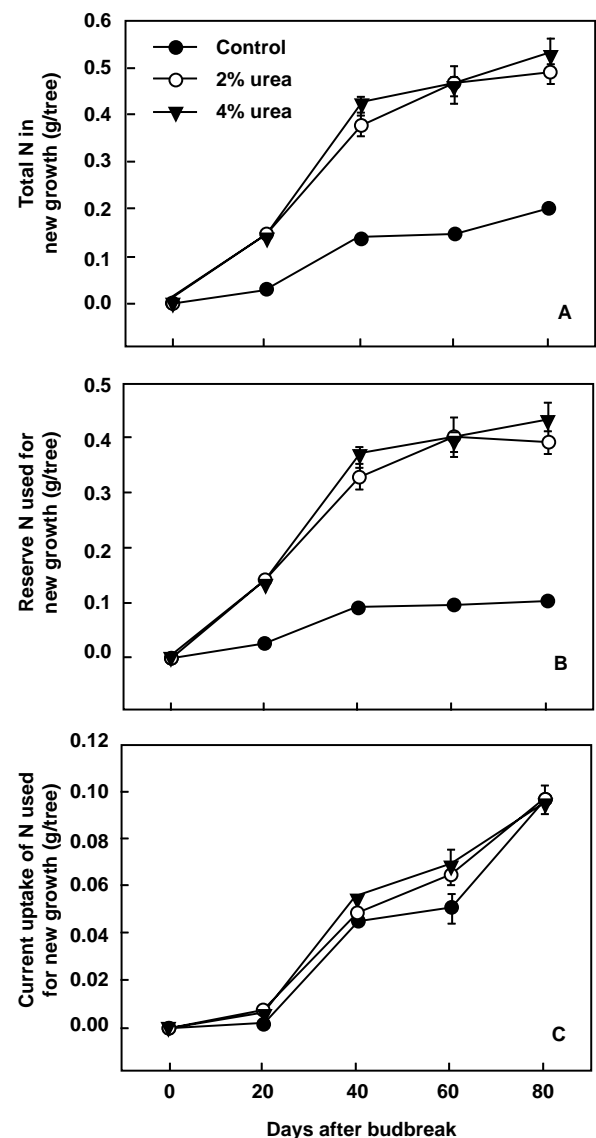


CONTRIBUTION OF CURRENT UPTAKE OF NITROGEN TO NEW GROWTH

Estimating the contribution of reserve nitrogen and current uptake of nitrogen to the new growth in the spring is important for developing a suitable fertilization program for newly planted trees. We altered the reserve nitrogen levels of Gala/M.26 trees by using foliar urea applications at concentrations of 0, 2 or 4% at weekly intervals for a total of four times in the fall. These foliar urea sprays increased total tree nitrogen from 0.267 g (control) to 0.781 g (2% urea treatment) and 0.844 g (4% urea treatment). The following spring, we supplied the trees with 140 ppm N in a balanced solution for 80 days. During this regrowth period, we destructively harvested trees every 20 days from budbreak to determine the contribution of reserve nitrogen and current uptake of nitrogen to the new growth.

FIGURE 5 A, B, C

The total amount of nitrogen present in the new shoots and leaves (A), the contribution from nitrogen reserves (B) and that from current uptake of nitrogen in the spring (C) over the course of the spring regrowth period as affected by foliar urea sprays in the previous fall.



The total amount of nitrogen (including both reserve and current uptake) present in the new shoots and leaves was greater in trees sprayed with 2 or 4% urea than the control trees (Fig. 5A). The amount of nitrogen from reserves used for new shoot and leaf growth was dependent on the N reserve levels. Trees sprayed with 2 or 4% urea remobilized more nitrogen for new shoot and leaf growth than the control trees (Fig. 5B). There was no significant difference in the amount of nitrogen from current uptake used for new shoot and leaf growth between low and high N reserve trees (Fig. 5C). At 20 days after budbreak, over 95% of the nitrogen used for new shoot and leaf growth was from reserves in both low and high N reserve trees whereas current uptake contributed less than 5% of the total amount of N present in new shoots and leaves. Thereafter, the contribution from current uptake increased.

SUMMARY

Although both reserve nitrogen and carbohydrates are essential for the initial growth of apple trees in the spring, the growth potential of apple nursery plants is mainly determined by reserve nitrogen and is not limited by reserve carbohydrates. Therefore, combining optimum nitrogen fertilization during the growing season with foliar urea application after terminal budset in the fall is an effective way to improve reserve nitrogen status yet still maintain enough reserve carbohydrates for the regrowth of nursery trees. Foliar urea application in the fall also may make earlier defoliation of nursery stock possible without reducing the growth potential in areas where early winter freezing injury is a concern for nursery trees. Because the tree growth during the first couple weeks after budbreak is almost completely dependent on reserve nitrogen, there is no need to apply nitrogen fertilizer until 2 to 3 weeks after budbreak for newly planted trees.

ACKNOWLEDGEMENTS

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CONVERSION FACTORS ENGLISH VS. METRIC

To convert Column 1 into Column 2, multiply by:	Column 1	Column 2	To convert Column 2 into Column 1 multiply by:
Length			
.621	kilometer, km	mile	1.609
1.094	meter, m	yard	.914
3.281	meter, m	foot, ft	.3048
39.4	meter, m	inch	.0254
.03281	centimeter, cm	foot, ft	30.47
.394	centimeter, cm	inch	2.54
.0394	millimeters, mm	inches	25.40

metric:	1 km = 1000 m; 1 meter = 100 cm; 1 meter = 1000 mm		
English:	1 mile = 5280 ft; 1 mile = 1760 yards; 1 yard = 3 ft; 1 ft = 12 inches		
Area			
247.1	kilometers ² , km ²	acre	.004047
2.471	hectare, ha	acre	.4047
.4047	trees/hectare	trees/acre	2.471

metric:	1 ha = 10,000 m ² = .01 km ²		
English:	1 acre = 43,560 ft ²		
Volume			
1.057	liter	quart (US)	.946

English:	1 US gallon = 4 quarts		
Mass—Weight			
1.102	ton (metric), MT	ton (English)	.9072
2.205	kilogram (kg)	pound, lb	.454
52.5	ton (metric) of apples	apple packed box, *carton	.01905

metric:	1 metric ton = 1000 kg		
English:	1 ton = 2000 lb; 1 packed box or carton* of apples = 42 lb		
Yield or Rate			
0.446	ton (metric)/hectare, MT/ha	ton (English)/acre	2.242
.892	kilogram/hectare, kg/ha	pound/acre	1.121
.991	ton (metric) of apples/hectare, MT/ha	bins* of apples/acre	1.009
.4047	trees/hectare	trees/acre	2.471
0.107	liter/hectare	gallon (US)/acre	9.354

metric:	1 metric ton = 1000 kg; 1 hectare = 10,000 m ²		
English:	1 ton = 2000 lb; apple bin* = 900 lb; 1 acre = 43,560 ft ²		
Temperature			
1.8 C + 32	Celsius, C	Fahrenheit, F	.555 (F-32)

*Commercial cartons (packed boxes) of fruit and field/storage bins of fruit do not have universal weights. The weight of fruit in a packed box or carton varies around the world and with the type of fruit, but is here taken for apples as 42 lbs (19.05 kg); the weight of fruit in a bin also varies but is here taken for apples as 900 lbs (408.2 kg).