How Does Nitrogen Supply Affect 'Gala' Fruit Size?

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To grow large size and good quality 'Gala' a sufficient nutrient supply must be provided to achieve a leaf N status (2.0 to 2.2%). This level of nitrogen results in a dark green leaf color with Gala. If foliage color is anything less than dark green, leaf nitrogen content may be below a sufficient level. This level of N supports high leaf and canopy photosynthesis and early fruit growth. If N is sufficient, cropload must not be too high so that sufficient leaf area (550 cm^2/fruit) is available to provide enough carbon to each fruit.

Gala trees tend to produce small size fruit due to a combination of several factors. First, Gala is a small-fruited cultivar. Second, Gala trees differentiate flowers readily, have heavy fruit set, and are difficult to thin when tree vigor is low; as a result trees often carry heavy cropload. Finally, heavy cropping reduces vegetative growth, which further decreases leaf area to fruit ratio. However, the market prefers large size fruit at a significant premium. This has prompted growers to strive for large size fruit. We have conducted field trials for three years to determine the optimal rate of nitrogen fertilization to improve Gala fruit size, but the results were inconsistent. We found that when cropload was maintained at a medium level, increasing the rate of nitrogen fertilization led to an increase in fruit size. However, under heavy cropload, we didn't find any significant effect. This raised the question of how nitrogen supply affects the source-sink relationship, leading to differences in final fruit size. In this experiment, we used fifth leaf Gala/M.26 trees grown in sand culture 1) to determine the effect of nitrogen supply on vegetative growth, fruiting and fruit size, and 2) to understand fruit sizing in terms of source-sink relationships.

Procedures

Fifth leaf 'Gala'/M.26 trees that were in sand culture and trained to a tall spindle were used in this study. They were spaced at 3.5 by 11 feet. These trees had regular crops for the two previous years. They received a total of 3.3, 10.0, 20 or 40g actual nitrogen per tree (equivalent to 8.3, 25, 50 or 100 lbs of actual nitrogen per acre) via fertigation using a complete nutrient solution (Hoagland's solution) from early May to three weeks before harvest. Each nitrogen treatment was replicated six times in a completely randomized design. The cropload of these trees was adjusted to 6.5 fruit per cm^2 trunk cross-sectional area by hand thinning at 10 mm king fruit, and this cropload was maintained to fruit harvest. Leaf samples were taken at 70 days after bloom for nitrogen analysis. Single leaf photosynthesis was measured on leaves at the mid-position of extension growth at the end of shoot growth and diurnal changes of whole canopy photosynthesis were monitored using an automatic system. Fruit number, fruit yield per tree, average fruit weight, fruit firmness and soluble solids were measured at fruit harvest in mid-September. Fruit samples were also taken at harvest to determine the number of cells per fruit and average cell size. Right after fruit harvesting, all the trees were destructively sampled to measure total leaf area, spur leaf area and shoot leaf area, total dry matter accumulation and partitioning. The net dry matter gain per tree from budbreak to fruit harvest was calculated as the difference between total tree dry weight at fruit harvest and at budbreak. A set of trees were destructively sampled at the beginning of the experiment (at budbreak) to determine their baseline total dry weight.

Results

As nitrogen supply increased, leaf N content increased from 1.2% to 2.2% (Figure 1A). Correspondingly, leaf photosynthesis increased from 12.5 µmol m^{-2} s^{-1} to 22.2 µmol CO_2 m^{-2} s^{-1} (Figure 1B). In response to nitrogen supply, total leaf area per tree increased from 2.2 m^2 in the lowest N supply to 4 m^2 in the highest N supply (Figure 2). The total leaf area of an apple tree consists of two types of leaf area: spur leaf area and shoot leaf area. It was apparent that increasing nitrogen supply did not significantly affect total spur leaf area, but increased total shoot leaf area (Figure 2). Due to increases in both leaf photosynthesis and total leaf area per tree, total dry weight per tree increased from 3.6 kg in the lowest nitrogen treatment to about 4.9 kg in the highest nitrogen treatment at fruit harvest and the net dry weight from budbreak to fruit harvest increased from 1.8 kg to 3.1 kg (Figure 3). This corresponds very well with whole canopy photosynthesis measurements (Data not shown).

As nitrogen supply increased, average fruit size increased from about 129 g to about 180 g (Figure 4A). This was primarily caused by the increase in the number of cells per fruit at higher nitrogen supply levels whereas average cell size was not affected by nitrogen supply (Fig-

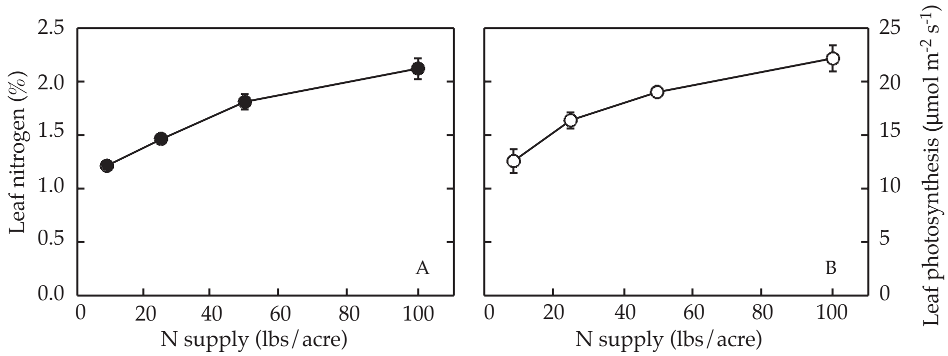

Figure 1. Leaf N content (A) and photosynthesis (B) in response to N supply

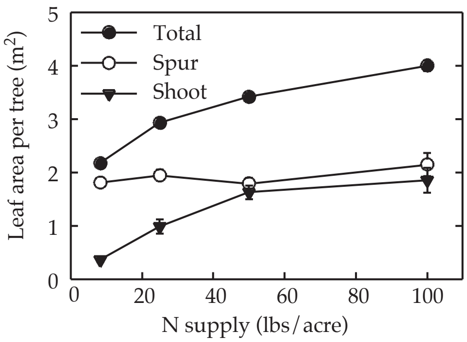

Figure 2. Total tree leaf area in response to nitrogen supply

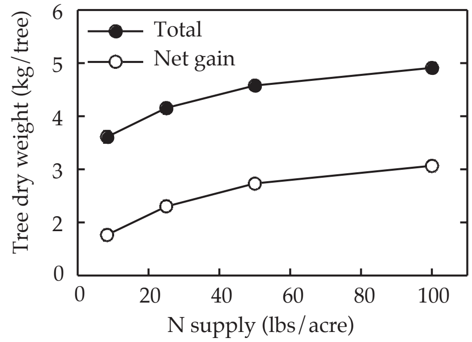

Figure 3. Total tree dry matter at fruit harvest and net dry matter gain per tree from budbreak to fruit harvest in response to nitrogen supply.

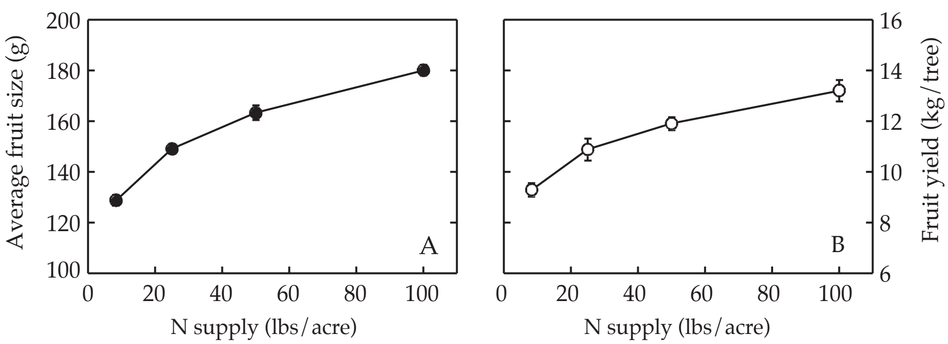

Figure 4. Average fruit size (A) and fruit yield per tree (B) in response to nitrogen supply.

ure 5). Leaf area to fruit ratio showed a curvilinear response to nitrogen supply (Figure 6A). When average fruit size was plotted against leaf area to fruit ratio, a linear relationship was found (Figure 6B), i.e. fruit size is proportional to the leaf area that supports each fruit. Good size 'Gala' (180g/fruit) corresponds to a leaf area to fruit ratio of 550 cm^2/fruit. Since cropload was adjusted to the same level at 6.5 fruit per cm^2 TCA, the increase in fruit yield per tree in response to nitrogen supply (Figure 4B) was entirely due to the increase in fruit size. Fruit soluble solids also increased from 13.7% in the lowest nitrogen treatment to 15.5% in the highest nitrogen treatment (Figure 7A). Fruit firmness decreased slightly from the lowest N supply to the highest N supply, but fruit firmness was still 19 lbs even at the highest N supply (Figure 7B).

Discussion and Conclusions

The results of this experiment clearly indicate that 1) within the range of N supply used, increasing N supply improves leaf N status and leaf area to fruit ratio, leading to larger fruit and higher soluble solids; and 2) good size 'Gala' (180g/fruit) corresponds to a leaf N of 2.0 to 2.2% and a leaf area to fruit ratio of 550 cm^2/fruit. Based on these results, we think the following aspects need to be considered when managing Gala for large fruit size.

1. An optimal nitrogen status is essential for leaf function and fruit cell division.

Fruit growth and development depends on carbon supply from leaves. As shown in Figure 1, leaf photosynthesis is closely related to its nitrogen status. If leaves don't have good nitrogen (and other nutrient) status, they just don't have the machinery (proteins and enzymes) to perform photosynthesis at a high level. It should be noted that leaf nitrogen content at 2.0 to 2.2% corresponds to dark green foliage color for Gala. If foliage color is anything less than dark green, leaf nitrogen content may be below the sufficient level. Although this study was focused on nitrogen with all the other nutrients kept at optimal leaves, insufficient levels of any of the other mineral nutrients may lower leaf photosynthesis as well. So, to achieve high leaf and canopy photosynthesis, not only nitrogen but other mineral nutrients must also be maintained at sufficient levels.

Having sufficient levels of nitrogen and other nutrients in leaves is essential, but high rates of photosynthesis is not guaranteed as many other factors affect leaf and canopy photosynthesis. These include water supply, light availability, disease and insect damage, etc. In many cases, although leaf nutrient status is good, drought stress or poor disease and insect control can prevent leaves from reaching their photosynthetic potential, leading to small fruit size. In addition, many environmental stresses (such as drought) also directly reduce fruit cell division and expansion. Therefore, not only leaf nutrient status, but also all the other cultural practices need to be optimized to achieve high canopy photosynthesis.

The results of this study also clearly showed that the increase in average fruit size in response to nitrogen supply was primarily caused by the increase in the number of cells per fruit at higher nitrogen supply levels whereas average cell size was not affected by nitrogen supply (Figure 5). Fruit cell division lasts only for about four to five weeks after petal fall. During this period, the young fruitlets require high N concentrations in the tissue for protein (enzyme) synthesis to support the active metabolism associated with rapid cell division. Our measurements indicate that young fruitlets contain 3 to 4% nitrogen on a dry weight basis at this time. If nitrogen supply is low, the fruitlet will not be able to maintain rapid cell division, leading to lower number of cells in the fruit. This is one of the reasons why a good nitrogen status is so important in determining the potential fruit size.

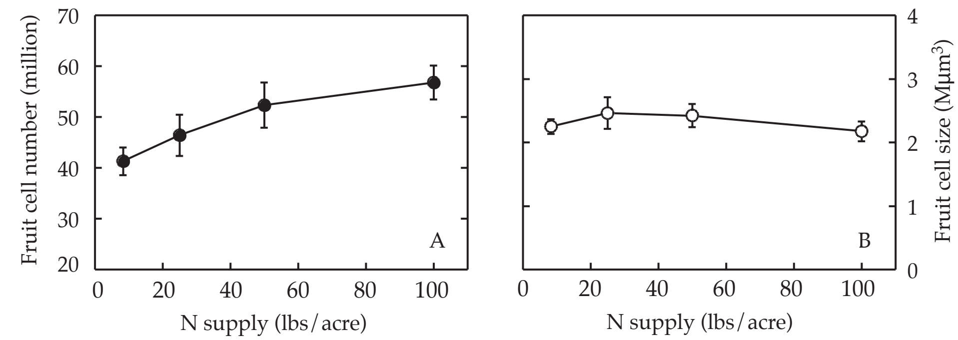

Figure 5. The number of cells per fruit (A) and average cell size (B) in response to nitrogen supply.

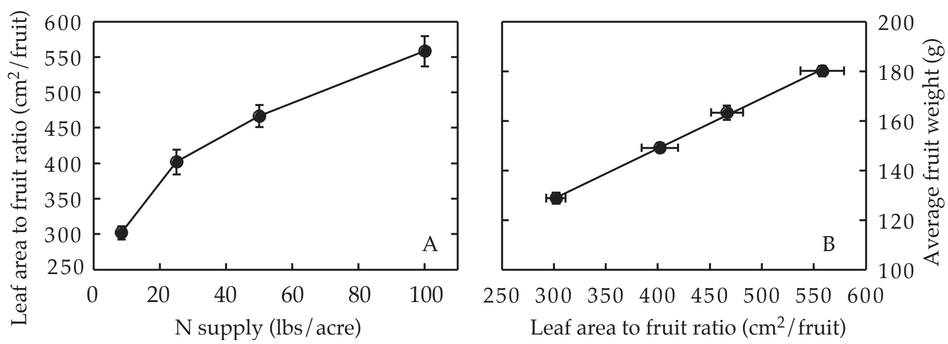

Figure 6. Leaf area to fruit ratio in response to nitrogen supply (A) and average fruit weight in relation to leaf area to fruit ratio (B).

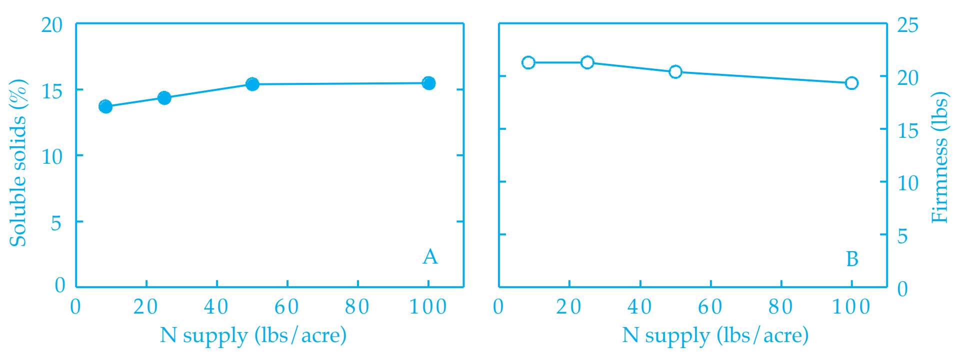

Figure 7. Fruit soluble solids (A) and firmness (B) in response to nitrogen supply.

2. Leaf area to fruit ratio is critical for producing large size Gala

We found a tight linear relationship between leaf area to fruit ratio and average fruit size in this study (Figure 6B). This clearly indicates the importance of having sufficient number of leaves for each fruit in determining final fruit size. There are two ways to increase the leaf area to fruit ratio. First, improve tree vegetative growth and total leaf area per tree. Because Gala trees generally have heavy fruit set and good return bloom every year, tree vegetative growth tend to decrease, leading to smaller total tree leaf area and small fruit size. Stimulating shoot growth is important for maintaining good tree vigor and total tree leaf area. As shown in Figure 2, increasing nitrogen supply improved shoot growth and leaf area. Pruning studies also demonstrated that stubbing back is very effective in promoting shoot growth while reducing cropload. Second, adjust cropload to a medium level. Very often, we encounter situations where trees have good nutrient status and healthy canopy, but end up producing small size fruit due to too heavy a cropload. Under these situations, each fruit just does not get enough carbon supply from leaves to support its growth. Therefore, cropload management is extremely important for producing large size Gala. Based on the results of this study and others, we think the optimal cropload for producing good size (180g) Gala is 6.5 to 8.0 fruit per cm² TCA. If the cropload is too heavy, it's unlikely to produce large size fruit no matter what you do.

In conclusion, to grow large size and good quality 'Gala', 1) sufficient nutrient supply must be provided to achieve a leaf N status (2.0 to 2.2%) that supports high leaf and canopy photosynthesis and early fruit growth; 2) a sufficient leaf area to fruit ratio (550 cm²/fruit) must be achieved to provide enough carbon to each fruit; and 3) nutrient management has to be integrated with many other cultural practices (irrigation, thinning, pruning, insect and disease control, etc) that affect tree vigor, cropload, and canopy photosynthesis.

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