Optimizing Nitrogen Availability in Cherry Growth to Obtain High Yield and Fruit Quality, Final Report

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ABSTRACT

Research Scope

The study addressed nitrogen (N) cycling, supply and demand in sweet cherry using several combinations of N forms, timings and rates that are typical in California production orchards, using two standard (Mahaleb and Mazzard) and one semi-dwarfing (Gisela 6) rootstocks. Goals included better understanding the source-sink relationships and responses in vegetative and reproductive growth.

Main Findings and Interpretations

- The pattern of rising and falling tissue levels was similar among orchards each year, with peak N levels prior to harvest in both shoot and spur leaves during small fruit development, declining levels postharvest as crop and storage of N removed N from leaves, and lowest levels during the dormant season.
- Fruiting spur leaves and spur buds tended to have higher tissue levels of N than vegetative buds and shoot leaves, thus, spring tissue levels, particularly in those bearing spur leaves that most directly support carbohydrate and nitrogen needs of developing fruits, may be the most critical timing and tissue type to assess for in-season N status.
- Approximately 50-75% of the tissue N present prior to bloom, fruiting and harvest was still present postharvest (September), suggesting that about half the nitrogen available in the fruiting spurs was removed by the crop--at an annual rate of either ~45 or 90# actual N/acre/year. Higher N applications (~150# N/A/yr) did not improve yields or fruit quality.
- At the Mahaleb site, (the heaviest cropping of the three orchards), cumulative yield was highest in treatments that included bloom applications (~1# N/A/year), with total annual applied N of ~45 or 90# N/A/year (statistically equal results). At the Mazzard orchard yield efficiency was improved cumulatively by the 45#N postharvest + 45#N urea pre-leaf fall treatment (September-early October).
- At all sites, CAN17 for dormancy release tended to reduce yields by advancing bloom into freeze-prone timings (Linden orchards), or without freeze damage (Lodi).
- At no time did N appear to be limiting at any site, thus this trial cannot deficient levels. However, a range of adequacy-optimal N for April spur leaves is probably ~2.6-3.0%N.
- Vigor (number of shoot breaks, length of new shoot growth), was least in Bing/Mahaleb with bloom N + 45#N mid-summer, however, significant effects of treatment were not consistent.
- Fruit quality measures:
    - No clear effects
    - Large variation in cropping from tree-to-tree probably affected quality more than N treatments. N not limiting.

Fertilizer Management Recommendations

- N levels should be tested in spring on young (1st or 2nd year of bearing) spur leaves, ~1 month after full bloom for preharvest status.
- Mid-summer spur leaf measurements should be used to track N use by the crop, with yield data, to adjust annual N applied post harvest for optimal cropping without loss of fruit quality.

Good cropping appears to be supported by ~45#N mid-summer; should additional N be indicated, a maximum of 45#N applied in early fall should be used (standard rootstocks). Semi-dwarfing rootstocks should require approximately 50-75% total N required by standard rootstocks.

- Unless a clear need for CAN-induced rest-breaking is demonstrated (less than 70% estimated chill accumulation required) prior to appropriate application timing (see UC recommendations), use of CAN is likely to increase frost-related crop loss and should not be used. If a warming period prior to recommended CAN17 application timing is recorded, such that some 'loss' of dormancy could have occurred, risk increases, and the rate of CAN17 and recommended penetrant should be used at a reduced rate, and only if necessary.
- Specific N forms that appeared to provide benefit included: $CaNO_3$ (mid-summer), urea (fall, pre-leaf fall), and PacificHort Grow Plus N (~1# total N in 2-3 equal applications during bloom). There may be equally beneficial products that can be used as a bloom treatment . Because the product has a proprietary formulation of N derived from specific amino acids, there may be certain formulations that are more likely to be beneficial than others.
- Post-bloom urea was not beneficial in this trial.
- No clear and consistent treatment effects on vegetative growth were found.

PROJECT OBJECTIVES

This project directly addresses the research-based development of cost-effective N fertilization practices to improve N fertilizer use efficiency and minimize environment impacts in sweet cherry production. The FREP program goals aligned with this project include 1) nutrient uptake by tree crops, including determination of tissue nutrient thresholds, and 2) guidelines for orchard fertilization patterns, including foliar nutrient management and effective fertilizer timing. Specifically, for sweet cherry, the objectives include:

- Quantify the seasonal pattern of N partitioning to sweet cherry tissues as influenced by soil and foliar applications, formulations, timing, and rootstock.
- Determine the relationship of fruiting spur N reserves to subsequent spring spur leaf development, fruit set, and fruit growth potential.
- Determine the impact of fall dormancy-inducing and late winter dormancy-breaking treatments on fruiting spur N reserves and early spring growth demand for N.
- Develop recommendations to balance soil and foliar N application methods (timing and rates) to optimize annual fruit yields and quality while minimizing excessive vegetative growth.
- Quantify the seasonal pattern of P, K, Zn, Fe, B, Ca, S, Mg, Mn, and Cu partitioning to sweet cherry tissues as influenced by optimized N fertilization recommendations and rootstock. **This objective was achieved in April, 2010 only in Gisela orchard due to budgetary constraints for DANR Lab analyses.**

Introduction

Sweet cherry bears primarily on fruiting spurs and has a short bloom-to-ripening period for fruit development, which impacts the timeframe for nutrient demand from fruit as well as from the leaf populations that are critical for support of fruit growth. Currently, cherry growers know little about efficiently supplying demand-driven nutrients, of which nitrogen (N) is the most critical. Furthermore, due to relatively high chilling requirements of cherry, dormancy-altering treatments in fall and spring often are applied that further impact nutrient (particularly N) storage in, and demand by, tissues and organs. This project addresses these knowledge gaps and examines the potential to optimize N supply efficiency via soil vs. foliar applications and timings chosen among those already in commercial practice and timed to physiologically important events: dormancy induction and termination, bloom and fruit set, fruit rapid growth, postharvest, and end of growing season. Tissue sampling times were chosen to track flux of nitrogen throughout the seasons.

Average sweet cherry yields in California (~3.2 tons/acre; USDA NASS, 2009) are typically less than those in the Pacific Northwest (~5.5 tons/acre), due partly to insufficient chilling in some years and excessive vigor that promotes vegetative growth at the expense of reproduction. It is not known whether the most commonly used fertilization practice—soil-applied nitrogen (N) just after harvest—supplies N in an optimal, demand-driven timing (i.e., to meet reproductive needs without excessively promoting vegetative growth).

Nutritional status of trees is typically determined by sampling leaves in midsummer (Leece, 1975) when nitrogen content is most stable. For cherry, this is after harvest, so sampling at this time has no impact on the current season cherry production. Foliar sampling earlier in the season may allow growers to diagnose and fix nutritional problems before harvest. Currently, standards available for diagnosing nutritional problems in cherry before midsummer are not available, and standards for midsummer (vegetative shoot leaves) were developed for sweet cherry grown outside of California where growing conditions differ significantly (Righetti and Wilser, 1988; Hanson and Proebsting, 1996; Hansen, 1997). For peach, foliar nutrients at 60 days after bloom were more closely correlated with yield than foliar nutrients later in the season (Sanz et al., 1992). Furthermore, crop load can affect nutrient levels (Sadowski et al., 1995), but nutrient standards do not account for this variability. Sweet cherry growers in California may rely on nutritional recommendations for other California-grown stonefruits or on empirical observations and/or unsupported theories of nutrient benefits for disease prevention or crop load increase. Although, non-fruiting spurs are typically used for foliar analysis, fruiting spurs, in closer association with fruit, may show a stronger relationship to fruit quality. We have sampled buds and leaves from ‘young’ spurs – those in their first year of production —and from new season extension shoots to have a nitrogen profile of the most vigorous and productive tissues.

Standards are typically based on the appearance of symptoms or on reductions in yield. No deficiency or toxicity symptoms attributable to N have been observed, and yields, while observed in this trial, have been atypical in that they have been more affected by weather conditions (freeze or very optimal conditions in the same year at different sites) than by treatment. Fruit quality has largely been ignored in the development of standards, yet fruit quality, particularly size, color, firmness, Brix, and presence and appearance of attached stems, in the case of sweet cherry, may be affected by nutrient status. Sweet cherries with the best fruit quality have a 9 to 10 ‘row size’ (measure of diameter), soluble solids (Brix) of at least 17%, balanced ratio of soluble solids to titratable acids (%/%) of 0.8 and a uniform color of dark red to mahogany using either the CTIFL color chart (Kappel et al., 1996) or the California Cherry Advisory Board (CCAB) color card. Stems should be fresh and green at harvest and preferably well-attached to the fruit.

Proper nutrition can influence fruit quality, and this has been well documented for apple. Our knowledge of relationships of tree nutrient status and cherry fruit quality is lacking for California

growers, although nitrogen uptake from dormancy-breaking treatments was reported in research funded by the CCAB, in 1997, and a nutrient /fruit quality survey of California growers' orchards was funded in 1998. Increasing levels of nitrogen fertilization in cherry have been shown to delay maturity (Hansen, 1997; Stanberry and Clore, 1950; Walker and Fisherr, 1955). Improved calcium and copper nutrition may lead to firmer fruit, and fruit that is less susceptible to rain cracking (Brown et al., 1995). Growers strive to find the right balance of nutrients, but standards based on optimum fruit quality have not been established.

Project/Workplan Description

TASK 1: Seasonal pattern of N partitioning to fruiting spur and shoot storage and growth.

Knowledge of how nitrogen is used, stored and required by the tree throughout the season will enable growers to maximize their nitrogen inputs for the desired balance between vegetative growth and reproduction. Storage of nutrients for subsequent spring bloom, fruit set and first growth is necessary at adequate levels until the tree has developed a full canopy and is able to 'mine' soil nutrients. Furthermore, knowledge of which tissues have the highest demand during growth and the highest concentration of nitrogen at critical growth phases (e.g. fruit-bearing spurs and their leaves for fruit production) may enable growers to structure the tree canopy in a targeted manner, allowing sufficient canopy to support fruit production without sacrificing critical nutrients to excessive vegetative growth. Tissue sampling throughout the growing season in different tissues (vegetative vs reproductive) coincidentally with application of nitrogen at different timings and levels will enable us to develop nitrogen management recommendations for sweet cherry in California.

Subtask 1.1: Assign treatments to develop baseline data – Three experimental orchards were selected by rootstock and location. All were planted in 1998 with 'Bing' as the scion cultivar. Orchard 1 is on *P. mahaleb* seedling rootstock near Lodi on Acampo Sandy Loam soil; trees are planted at 13'x 18' spacing (186 trees per acre). Orchards 2 and 3, located near Linden and contiguous within a single site, were, respectively, on dwarfing clonal rootstock Gisela 6 (*P. cerasus* x *P. canescens*) and Mazzard (*P. avium*) seedling rootstock. Soil at Orchards 2 and 3, which were in adjacent blocks, was Cogna Loam. Orchard 2 was planted at 14' x 17' (183 trees per acre), and Orchard 3 was planted at 12' x 16' (227 trees per acre). Trees at Orchard 1 were trained to a traditional open vase; Orchards 2 and 3 to a 'steep leader' system with three primary scaffold branches. Each trial site was planned as a randomized complete block design with six single-tree replicates separated by one to three "'guard" trees and rows separating treated trees.

Fertilization treatments were initiated during bloom in March 2008. By February 2009, an entire set of treatments had been applied. Inherent differences of training system (tree architecture) and precocity (earliness to bear) are also differences between orchards, based on rootstock. Physiologically-timed nitrogen treatments, (10 nitrogen regimes, **Table 1**) were chosen based on the range of commercial practice. Foliar N treatments were applied by backpack mist-blower sprayer at a carrier volume (based on tree canopy volume) of 150 gallons/acre at Orchards 1 and 3 and 75 gallons/acre at Orchard 2 during 2008 due to smaller tree size, however, all foliar applications were applied at 150 gallons/acre beginning in 2009. Soil-applied nitrogen (postharvest) was applied by spreader. Rates of dormancy-release chemicals (CAN and KNO_3), included in the N treatments in 2009, and CAN included in the 2010 treatments were below those often used commercially due to warm weather in January, with caution due to risk of phytotoxicity. Thus, by the end of the growing season in 2009, all treatments had been applied twice with the exception of dormancy-release treatments (the project was initiated past the appropriate time for treatment in 2008).

In 2010 certain treatments were eliminated from the treatment list (in 2010, as indicated in Table 1) as it became apparent they were not contributing to the project goals and/or were increasing potential for late frost damage.

Because applications were timed to physiological events, actual dates of application varied annually, but were similarly-timed with respect to bloom date, harvest date and early fall.

Subtask 1.2: Seasonal tissue sampling – Baseline data on N content began in February 2008; seasonal collection of tissues in 2008 included dormant and growing spur and terminal shoot buds, young (fully-expanded, April) and mature (post-harvest in June, and September) spur and shoot leaves, and small fruits collected at 20 days after full bloom, prior to 'pit-hardening' (**Table 2**). We identified the type of buds to be collected as those most representative of high seasonal demand, thus, the spur buds were those entering into the first year of bearing on 2-year-old wood on precocious Mahaleb and Gisela 6 rootstocks and on 3-year-old wood on Mazzard rootstock. Terminal buds from vegetative shoots were selected for tissue analysis. In each case, at least 10 buds were obtained. Shoot and spur leaves were collected from the same types of shoots, at least 10 leaves of each type. Tissue N sampling protocol (bearing spur leaves, extension shoot leaves, small fruits, dormant spur and terminal shoot buds) was adapted in 2009 and in 2010, based on results of tissue analyses for the preceding year to reflect N fluxes (rising and falling tissue levels) as the appropriate periods of nutrient sampling. Nitrogen content on a leaf area basis was tested as an alternative to dry weight basis to compare treatment effects, however, the standard method of nitrogen measurement, as a percentage of the dry weight, was found to better represent nitrogen treatment differences.

Although it has not been possible to quantify the seasonal pattern of P, K, Zn, Fe, B, Ca, S, Mg, Mn, and Cu partitioning to sweet cherry tissues as influenced by optimized N fertilization recommendations and rootstock (Objective 5), we were able to obtain some baseline data in a single orchard (Gisela) after all treatments had been applied. In April, 2010, shoot and bearing spur leaves from the Gisela orchard were sampled for nutrients (**Table 4).** These data allowed us to test for tissue and N level (treatment) differences.

Subtask 1.3: Seasonal growth measurements -- Phenological and productivity data, including full bloom date and duration of bloom, yield per tree, yield efficiency (yield/TCSA), and fruit quality (size, firmness, maturity, Brix and fruit removal force, or 'pull force') were collected during the 2008 season. Trunk cross-sectional area (TCSA) was measured for vegetative growth, calculated from trunk circumferences taken at 6 inches above ground level in March and in October (2008), in December (2009) and July 1 (2010). Vegetative vigor has also been measured by shoot growth and number of new shoot 'breaks' (July 1, 2010). Leaf area was measured in April using digital image analysis (DIA) of leaf photographs (Bakr, 2005; O'Neal, 2002). Leaf size for spurs and vegetative shoots is an indirect measure of photosynthetic capability and carbohydrate production, thus, photosynthate source for growing fruit, and leaf size may be enhanced by appropriate nutrient level.

Harvest for all orchards was a single 'strip pick'. Samples of fruit were obtained at random from pickers' bins and evaluated on the day following harvest for maturity, firmness, size, stem/fruit removal force (FRF) and soluble solids. Maturity was measured by color, as per picking and grading guidelines (CDFA and California Cherry Advisory Board). Only salable mature fruit were evaluated for quality, after a 50-fruit random subsample from bin-collected fruit was evaluated for spread in maturity (by 6 color grades). Maturity, as measured by color, includes color grades of green, straw, colorbreak (change from straw to pink), light red, dark red, mahogany and dark mahogany color categories with light red (minimum marketable color) through dark mahogany (overripe) standardized by California Cherry Advisory Board color reference cards. A protocol

was developed to convert Minolta Color Reader CR-10 readings to the equivalent color grades to eliminate lack of agreement common to visual evaluation. This protocol is similar to industry standards for cling peach (Slaughter and Crisosoto, 2006) and other commodity quality evaluations (Mitcham et al., 1996). Once fruit was graded, a subsample of 25 salable (defect-free, light red to mahogany) fruit were selected and used for fruit firmness, size, fruit removal force (FRF) and soluble solids determinations. Firmness and size (BioWorks FirmTech II) and FRF (Imada digital force gauge) measurements were made on individual fruits; a single soluble solids value was determined using juice extracted from each subsample.

Subtask 1.4: Tissue N analyses. Tissue analyses for nitrogen have shown a consistent pattern across all orchards of nitrogen cycling during the year with peak tissue content during rapid fruit development and reduced levels prior to annual rest (**Figure 1**). Some differences in levels were found between reproductive and vegetative leaves and buds, with reproductive tissues typically higher in N than vegetative tissues.

Subtask 1.5: Data, statistics and reporting -- Statistical analyses of data were performed with SAS (version 9.2; SAS Institute Inc., Cary, NC), for normality, distribution, frequency, and means separation, primarily using General Linear Model (Proc GLM) for 'fixed' effects, Proc Mixed for mixed-effects evaluation of fixed and random effects, Proc Univariate (basic measures, summary statistics, normality (Shapiro-Wilk test) and distribution), Proc Reg or Proc RobustReg for linear regressions, Proc Npar1way non-parametric equivalent of ANOVA (Kruskal-Wallis test) for non-normally distributed data, and where significant differences were found, multiple comparisons (means separation) were performed by Least Squares Means (estimated marginal means), Least Significant Differences, Duncan's or Tukey's tests, correcting treatment means for block effects by the use of Type III Mean Squares and *F*-test, level of significance $P = 5\%$. Outliers were identified using the above tests. In some cases, where no treatment (N regime) differences were found, Proc T-test was used to compare group means with Satterthwaite test for unequal variances applied when *F* tests indicated the need.

TASK 2: Relationship of fruiting spur N reserves to subsequent spring spur leaf development, fruit set, and fruit growth potential

The intent is to create different levels of total N in fruiting spurs with pre-dormant and post-dormant applications of N in different forms and amounts, then to correlate tissue N to subsequent flowering, fruit set, quality, and vegetative growth. This will lead to a recommendation for the most effective strategies to optimize N supply at the most critical times of N demand by fruit and fruiting support tissues.

Subtask 2.1: Assign treatments to develop baseline data and impose varied N – as in Subtask 1.1, 10 nitrogen treatments have been assigned and applied. Total N per acre per year varies from ~46-47 lb to ~153 lb annually, to induce variable N levels in tissues.

Subtask 2.2: Seasonal tissue sampling – as in Subtask l.2; tissue N of reproductive buds was measured prior to end of rest (February, 2008 and January, 2009), budswell (March, 2008), and in early spring at full leaf expansion (mid- to end of April). Small fruits were sampled at the end of Phase I (pit tip-hardening, cellularization of endosperm) for nitrogen as well. Spur leaves were also sampled in July, 2008, September 2008 and 2009 and spur buds September 2008 and 2009.

Subtask 2.3: Seasonal growth measurements – the outcome of flowering, fruit set, crop load and reproductive growth (in this case fruit diameter), as well as spur leaf area in the same leaves evaluated for N content were measured and analyzed for their relationship to N content. Vegetative growth as number of new shoot breaks and total length of new shoots were measured

on each replicate tree (2 limbs per tree) and evaluated for their relationship to cropping and N content.

Subtask 2.4: Tissue N analyses. – As in Subtask 1.4.

Subtask 2.5: Data, statistics and reporting – as in Subtask 1.5.

TASK 3: Determine the impact of fall dormancy-inducing and late winter dormancy-breaking treatments on fruiting spur N reserves and early spring growth demand for N

Subtask 3.1 Assign treatments --The objective of this task was addressed primarily by the following Treatments (Table 1):

(Treatment 2) Soil applied N at 90 lb/acre after harvest plus $ZnSO_4$+urea applied in fall for defoliation plus late-winter KNO_3 for breaking dormancy.

(Treatment 3) Soil applied N at 90 lb/acre after harvest plus fall $ZnSO_4$+urea plus late winter CAN-17 for breaking dormancy.

(Treatment 4) Soil applied N at 45 lb/acre after harvest plus fall $ZnSO_4$+urea plus late winter CAN-17 for breaking dormancy. The rationale is to develop data on tissue N levels and growth from low soil applied N plus dormancy induction/breaking treatments.

Post-harvest applications as soil-applied $CaNO_3$ have been made in both 2008 and 2009. Fall $ZnSO_4$+urea application was be made at timings based on chill portion accumulation (Dynamic Model, Erez et al., 1990.).

Late winter applications were on Jan 20 made at timing consistent with typical commercial practice for CAN-17 (approximately 49-55 chill portion accumulation). Dataloggers were placed in the trial orchards in mid-October to collect chill data for timing of dormancy-inducing and dormancy-breaking treatments, as well as effects of treatments on flowering and fruiting, with respect to amount of chilling received.

The following subtasks are as in the corresponding subtasks in Task 1, with the exception of Subtask 3.3.

Subtask 3.2: Seasonal tissue sampling

Subtask 3.3: Seasonal growth measurements

Subtask 3.4: Tissue N analyses.

Subtask 3.5: Data, statistics and reporting.

RESULTS AND CONCLUSIONS

Detailed results for 2008-2009 are not repeated in this report, other than in the context of cumulative effects over the 3-year trial life. Those results can be found in the Annual Reports for 2008 and 2009.

Tissue Nitrogen, Nitrogen Cycling and Partitioning, Nitrogen Content and Reproductive Potential

Task 1: Seasonal pattern of N partitioning to fruiting spur and shoot storage and growth

The patterns of rising and falling tissue levels is very similar among trials, so that they could be averaged out to fit a 'demand-supply' curve (Figure 1) that illustrates movement of tissue N out of storage tissues and into rapidly growing buds with peak N levels prior to harvest.

N content varied by tissue type (leaf or bud type) and by year, but not among treatments or orchards (Table 3). N content of shoot and spur leaves was consistently higher in April, prior to harvest, than post harvest (July and September), indicating the removal of N by the crop, and probably also cycling of N into storage tissues. Thus, N status for the current season crop is best measured preharvest, from bearing spur leaves, which have higher N content and support fruit growth most directly.

Treatments had effect on N content of spur and shoot leaves in Mahaleb when measured preharvest, but only on shoot leaves in 2010 (Table 4). In both types of leaf in Mahaleb, treatments that included CAN17 and/or urea (PLF, DI) generally had the highest N content in Mahaleb, but not Mazzard. While reasons for this difference between rootstocks is not clear, it could be due either to rootstock capability of uptake or might be due to N being more limiting in Mahaleb, as this orchard was consistently much more heavily cropped than the Mazzard orchard.

N, P, Ca, S, Zn, Mn and Cu were significantly higher in spur leaves than shoot leaves in Gisela, measured in April, 2010 (Table 5). Although these nutrients were not measured at any other time (with the exception of N), it is interesting that this is true for many of the nutrients, not just N. These data are for a single sampling time and rootstock, but the consistent results confirm that preharvest nutrient sampling of bearing spur leaves is more appropriate than postharvest shoot leaves.

Task 2: Relationship of fruiting spur N reserves to subsequent spring spur leaf development, fruit set, and fruit growth potential

Critical values for N established elsewhere were for shoot leaves measured postharvest (Figure 1); the values found for shoot leaves postharvest in this study would indicate that all rootstocks for all years tended to have low N status, yet cropping in Mahaleb was strong every year and vegetative growth, in general, did not appear excessive. There do not appear to be strong trends for cropload (yield; Tables 6 and) as affected by N treatments in this study, thus, either N is not limiting in any case, or sweet cherry may be somewhat insensitive to N levels used in this study. Fruit set does not appear to be affected by treatment; CAN17 applied during late dormancy has, however, shown strong indications of reducing bloom and limiting fruit growth potential by delaying harvest.

Subtask 2.3: Seasonal growth measurements – the outcome of flowering, fruit set, crop load and reproductive growth (in this case fruit size) were measured and analyzed for their relationship to N content. Vegetative growth as number of new shoot breaks and total length of new shoots were measured on each replicate tree (2 limbs per tree) and evaluated for their relationship to cropping and N content.

Task 3: Determine the impact of fall dormancy-inducing and late winter dormancy-breaking treatments on fruiting spur N reserves and early spring growth demand for N

The effect of CAN17 treatments in these trials has been to advance bloom into frost-prone timing (especially in 2009), reducing yields drastically, but also negatively affected yield in

Mahaleb without frost (2009). Perhaps application of CAN during late dormancy enhances metabolic activity to promote earlier bloom and leafing out by satisfying early spring demand for N. This has not been an advantage when late freezes occur, nor has there been a 'payoff' in earlier harvest or increased yields.

Yield, Yield Efficiency and Fruit Maturity

Task 1: Seasonal pattern of N partitioning to fruiting spur and shoot storage and growth

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Task 3: Determine the impact of fall dormancy-inducing and late winter dormancy-breaking treatments on fruiting spur N reserves and early spring growth demand for N

Yield and yield efficiency (Mahaleb, Table 6; Mazzard, Table 7)

Yields for 2010 in **Mahaleb** (Table 6) were not different among treatments; cumulative yields (2009+2010) were different in that the 45#N postharvest + CAN + dormancy-inducing urea yield was much lower than any other treatment, but not significantly different from the 90#N postharvest or the 45#N postharvest + urea (pre-leaf fall). What is quite interesting, is that the percentage of the crop in the first harvest is significantly reduced y both treatments with CAN--despite the 'popular wisdom' that use of this rest-breaking treatment advances harvest as it typically advances bloom. Yield efficiency was significantly different by treatments, but this was due to TCSA differences as well as yield differences (despite lack of significant treatment effect for yields).

No differences by treatment were significant for **Mazzard** (Table 7) in any yield component, although cumulative yields were much lower (numerically) for both CAN treatments. The yields were significantly lower in 2009 due to crop loss to frost for these treatments, contributing to the numeric differences in cumulative yields.

It is important to note that increasing rates of applied N did not improve yields, and that only about 25% of the preharvest N is removed by the crop.

Fruit maturity as affected by N treatment and yield: Crop loads were not affected by treatment in 2010 and neither was maturity, except in Mahaleb treated with CAN, which showed a delay in maturity, as measured by percentage of the crop harvested on the first date (Table 6).

The harvest at the Mazzard orchard in 2010 was a 'single pick' and no noticeable maturity differences were found.

Fruit Quality (Tables 8 and 9)

Task 1: Seasonal pattern of N partitioning to fruiting spur and shoot storage and growth

Task 2: Relationship of fruiting spur N reserves to subsequent spring spur leaf development, fruit set, and fruit growth potential

Task 3: Determine the impact of fall dormancy-inducing and late winter dormancy-breaking treatments on fruiting spur N reserves and early spring growth demand for N

Fruit quality (firmness, soluble solids, stem removal force, and fruit size) were unaffected by N treatment in the Mahaleb orchard (Table 8), except that firmness at the second harvest was slightly improved by 45#N postharvest + urea pre-leaf fall, and decreased by 90#N postharvest + CAN + dormancy-inducing urea. Firmness and other quality measures were high overall and the differences in firmness are not clearly explained by treatment.

In the Mazzard orchard, soluble solids and rowsize were unaffected by treatment, however, firmness was slightly reduced in the 90#N postharvest, 45#N postharvest + urea pre-leaf fall. Stem attachment force was significantly reduced by 90#N postharvest + CAN + dormancy-inducing urea (Table 9). It is interesting that the highest rate of N cased reduced stem attachment force, although the reason for the treatment effect is not clear.

Vegetative vigor -- Subtask 3.3: Seasonal growth measurements; Tables 10 and 11.

Of the vegetative growth indices measured, only TCSA for 2010 was affected by N treatment (Table 10). The 45#N postharvest + bloom treatment significantly reduced TCSA and numerically reduced the number of shoot breaks and overall shoot growth. No growth measures were affected by treatment in Mazzard (Table 11).

OUTREACH ACTIVITIES

January 27, 2009

California Cherry Advisory Board Annual Research Review; San Joaquin UCCE County Building, Robert J. Cabral Agricultural Center
2101 E. Earhart Avenue, Stockton, California 95206-3949
Optimizing nitrogen availability in cherry growth for high yield and fruit quality
Presented by Dr. G. Lang
Approximately 300 growers and PCAs in attendance
The annual report (2008 FREP annual report) was included in the annual Proceedings

November 18, 2009
Annual FREP Conference; Visalia Convention Center, Visalia
Optimizing nitrogen availability in cherry growth for high yield and fruit quality
Presented by Dr. K. Glozer
Approximately 200 PCAs, researchers and other agribusiness personnel in attendance
The interpretive summary was included in the annual Proceedings; a handout of the PowerPoint presentation was passed out at the meeting

November 17, 2010
Annual FREP Conference; Visalia Convention Center, Visalia
Nitrogen Application Timing and Practices in Sweet Cherry Orchards
Presented by Dr. G. Lang
Approximately 300 growers and PCAs in attendance
The interpretive summary was included in the annual Proceedings

January, 2010
California Cherry Advisory Board Annual Research Review; San Joaquin UCCE County Building, Robert J. Cabral Agricultural Center

2101 E. Earhart Avenue, Stockton, California 95206-3949
Nitrogen Application Timing and Practices in Sweet Cherry Orchards
Presented by Dr. G. Lang
Approximately 250 growers and PCAs in attendance
A written report was included in the annual Proceedings

September, 2011
Optimizing Nitrogen Availability in 'Bing' Cherry Growth for High Yield and Fruit Quality
Presented in poster format at the American Society for Horticultural Science Annual conference

We appreciate the participation of Dr. Maria Paz Garcia-Suarez, Visiting Scholar, in the 2009 growing season.

RELEVANT LITERATURE

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Table 1. Nitrogen (N) treatments applied to 'Bing' (Prunus avium) sweet cherry at three orchards[x] in 2008-2010, comparing 'standard' postharvest (PH) soil application ($CaNO_3$ 15.5% N) with reduced soil-applied $CaNO_3$ and foliar N. Foliar N treatments include: CAN17 (16.7% v/v, 17% N) or KNO_3 (13.7% N) for dormancy release (DR[y]), PacificHort Grow Plus N (BLOOM; 15% ammoniacal N) applied twice (60 oz/A twice, prior to full bloom+ post-petal fall or 20-30% full bloom + full bloom), low-biuret urea (46% N) applied post-bloom (PBLM), pre leaf-fall (PLF; two applications late Sept-late Oct 7 days apart), or pre leaf-fall with 20 lb/acre $ZnSO_4$ for dormancy induction (DI; applied late October-early November at ~3 chill portions, Dynamic Model).

Treatments and N actual lb/acre (shaded treatments not applied in 2010).						
PH July 9	DR	BLOOM	PBLM	PLF	DI	Total actual N (lb/acre/yr)
90 $CaNO_3$						90
90 $CaNO_3$	KNO_3 0.7				9.2	99.9
90 $CaNO_3$	CAN 26.8 or 53.5[y]				9.2	126 or 152.7
45 $CaNO_3$	CAN 26.8 or 53.5				9.2	81 or 98.5
45 $CaNO_3$				25 + 20		90
45 $CaNO_3$		1.12				46.12
45 $CaNO_3$		1.12		25 + 20		91.12
45 CaNO3			2.3			47.3
45 CaNO3			2.3	25 + 20		92.3
45 CaNO3		1.12	2.3	25 + 20		93.42

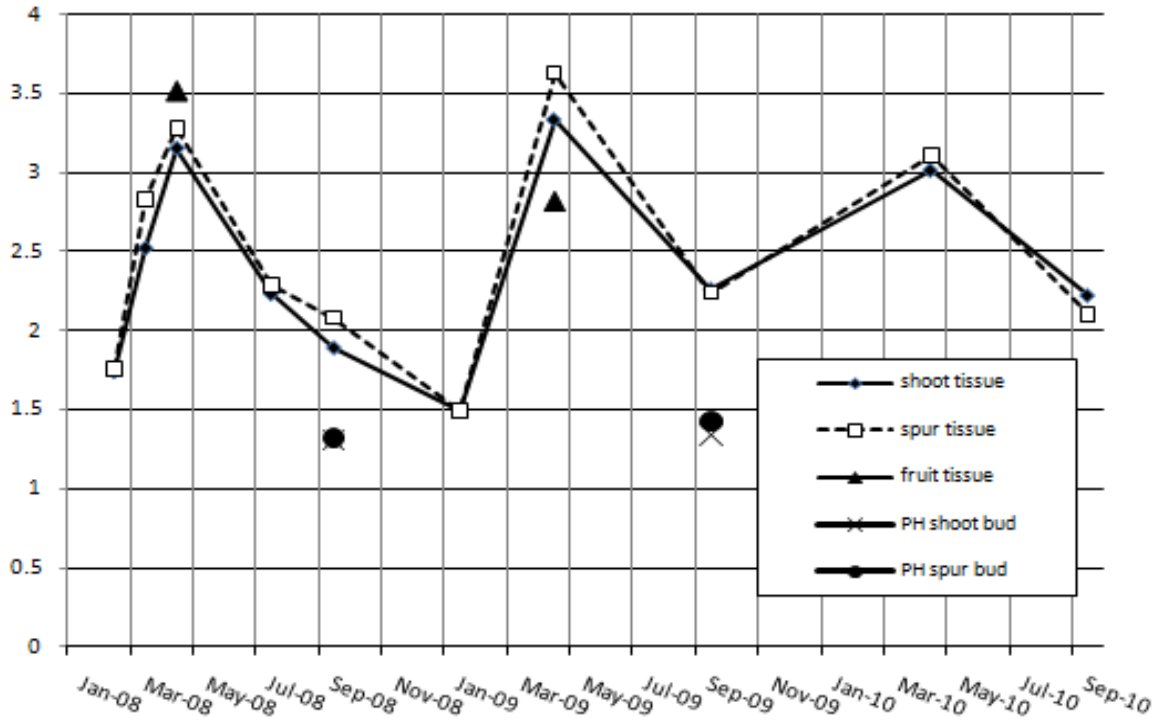
[x]Orchards vary by rootstock and location [*P. mahaleb* in Lodi, CA; 'Gisela 6' or 'Mazzard' (both *P. avium*) in Linden, CA].
[y]DR treatment applied either 150 gal/acre (2008) or 75 gal/acre (2009-10) for 'Gisela 6' trees (dwarfing rootstock); for CAN17 actual N was either 53.5 or 26.8 lb/acre. Moderate rates of rest-breaking agents were used to reduce the risk of phytotoxicity in unseasonably warm pre-bloom periods. In 2010, applied Jan 9, at 47 chill portions (chill accumulation, Dynamic Model).

Table 2. Sampling of sweet cherry tissues and timing to determine impact of N applications.

2008 Initial year of trial [x]					
Timing	Bud		Leaf		Fruit
	Fruiting spur	Shoot terminal	Fruiting spur	Shoot terminal	
Dormant	X	X			
Early bud swell	X	X			
Fully expanded, spring			X	X	X
Mid-summer			X	X	
Early fall	X	X	X	X	
Late fall	X	X			
2009 Sample schedule changes based on Year 1 (2008) results					
Dormant	X	X			
Fully expanded, spring			X	X	X
Summer, postharvest [y]			X	X	
Early fall	X	X	X	X	
2010 sample schedule changes based on Year 1 and 2 results					
Fully expanded, spring			X	X	
Early fall			X	X	

[x]Samples from Feb-March, 2008 were from all trees/treatments; spring sampling 2008 only included those treatments imposed during and after bloom.
[y] Postharvest samples taken in June, just prior to summer pruning.

Figure 1. 2008-2010 Change in tissue N over time in vegetative and reproductive tissues of 'Bing' sweet cherry averaged from data collected at three orchards. Recommended tissue content (%N) shown below (developed in cherry-growing areas other than California).



Recommended Cherry Leaf %N (summer, vegetative shoot leaf)	Deficient	Low	Optimum	High	Excessive
	< 1.7	1.7 - 2.1	2.2 - 2.6	2.7 - 3.4	> 3.4

Table 3. Nitrogen content (%dry weight), orchards and treatments combined; values across orchards and treatments were not significantly different when all were compared, thus tissue differences only are shown.

		shoot bud	spur bud	shoot leaf	spur leaf	fruit
2008	Feb	1.74	1.76			
	Mar	2.52	2.83	.	.	.
	Apr	.	.	3.15	3.28	3.52
	Jul	.	.	2.23	2.29	.
	Sept	1.32	1.31	1.89	2.08	.
2009	Jan	1.49	1.49	.	.	.
	Apr	.	.	3.33	3.63	2.82
	Sept	1.34	1.43	2.26	2.24	.
2010	Apr	.	.	3.01	3.11	.
	Sept[x]	.	.	2.22	2.10	.

[x] September, 2010 values represent only Mahaleb and Mazzard orchards.

Table 4. **2010** N content of vegetative (first year) shoot leaves and bearing spur leaves (first year spurs) in 'Bing' (*Prunus avium*) sweet cherry at 2 orchards, comparing standard post-harvest soil application ($CaNO_3$ 15.5%N) with reduced soil application supplemented with physiologically-timed foliar applications. Actual pounds N per acre shown; foliar applications of N are low-biuret urea (DI, dormancy-inducing; 46% N) or PacificHort Grow Plus N (bloom, 15% ammoniacal N).

N (lb/A/yr) and treatment		Mahaleb				Mazzard			
		April (5-7 weeks after full bloom)		Sept		April (5-7 weeks after full bloom)		Sept	
		shoot	spur	shoot	spur	shoot	spur	shoot	spur
~50	45PH+bloom	2.58 c [x]	2.85 b	2.46 a	2.30 a	2.66 c	2.73 c	2.22 ab	2.10 a
~90-100	90PH	2.96 ab	3.02 ab	2.40 ab	2.26 a	2.90 b	2.96 b	2.27 a	2.11 a
	45PH+CAN+Urea DI	3.07 ab	3.25 a	2.36 abc	2.24 a	2.88 b	2.88 bc	2.07 ab	1.92 b
	45PH+Urea PLF	3.02 ab	3.10 a	2.33 abc	2.20 a	2.70 c	2.79 c	2.00 b	1.92 b
	45PH+bloom+Urea PLF	2.90 c	3.04 ab	2.24 bc	2.10 a	2.73 c	2.86 bc	2.04 ab	1.94 ab
150	90PH+CAN+Urea DI	3.20 a	3.26 a	2.18 c	2.14 a	3.04 a	3.12 a	2.10 ab	1.94 ab
Significant difference by treatment		***	***	***	NS	***	***	***	***

[x] Mean separation within columns by Least Squares Means, mixed linear model (replicate as random effect, treatment as fixed effect; $P = 5\%$); means with same letter(s) not significantly different. $P = 5\%$, 1%, 0.1%, NS (*, **, ***, non-significant, respectively).

Table 5. Nutrient values for 'Bing' cherry, Gisela orchard in April, **2010**. Nutrient levels did not vary by N treatments, therefore values are shown only by tissue sampled.

Leaf type	% Dry weight					ppm					
	N	P	K	Ca	Mg	S	B	Zn	Mn	Fe	Cu
Shoot	3.26b	0.29b	0.93	0.73b	0.25b	1947b	41.8	23.5b	49.2b	52.8b	13.1b
Bearing spur	3.35a	0.31a	0.96	0.90a	0.26a	1994a	40.2	26.9a	55.9a	54.8a	15.3a
Significance by part	***	***		***	*	***		***	***	*	***

[x]Means in the same column and orchard with different letters differ by Least Squares Means (Tukey) at P = 0.05; ***, **, * or NS = significance at 0.1, 1, 5% level, or non-significant, respectively.

Table 6. Y**ield, cumulative yield and yield efficiency, 2010** for 'Bing' (*Prunus avium*) sweet cherry on **Mahaleb** rootstock in response to nitrogen (N) fertilization, comparing only treatments in common. Treatments include postharvest (PH; 45 or 90lb actual N) soil application [$CaNO_3$15.5% N], supplemented with foliar N applications 'timed' to phenological events) in most cases. Foliar N treatments include: **CAN17** (16.7% v/v, 17% N) for dormancy release (DR), **PacificHort Grow Plus N** (bloom; 15% ammoniacal N) applied twice during bloom, **low-biuret urea** (46% N) applied pre leaf-fall (PLF; two applications late Sept-Oct 7 days apart), or pre leaf-fall with 20 lb/acre $ZnSO_4$ for dormancy induction (DI; applied late October-early November at ~3 chill portions, Dynamic Model).

Treatment	N_{actual} (lb/A/yr)	Total yield (kg/tree)	Percentage of crop in first harvest	TCSA (cm^2) 2010	Yield efficiency (kg/tcsa) 2010	Yield 2009-2010
45PH+Bloom	50	40.0[x]	59.0 a	544.5 b	0.074 ab	108.8 a
90PH	100	38.8	53.8 ab	662.6 ab	0.060 ab	97.4 ab
45PH+CAN+Urea DI	100	46.5	27.8 b	775.1 a	0.062 ab	73.4 b
45PH+Urea PLF	100	47.0	52.0 ab	724.3 a	0.064 ab	97.7 ab
45PH+Bloom+Urea PLF	100	38.7	61.4 a	732.7 a	0.054 b	114.2 a
90PH+CAN+Urea DI	150	59.4	25.2 b	789.9 a	0.075 a	104.3 a
Significance for treatment means differences		NS	***	***	***	***

[x] Analysis by Mixed Model, replicate effects 'random' and treatment effects 'fixed'. Means in the same column and orchard with different letters differ by Least Squares Means (Tukey) at P = 0.05; ***, **, * or NS = significance at 0.1, 1, 5% level, or non-significant, respectively. Percentage data arcsine square root-transformed for analysis; actual means shown.

Table 7. Y**ield, cumulative yield and yield efficiency, 2010** for 'Bing' (*Prunus avium*) sweet cherry on **Mazzard** rootstock in response to nitrogen (N) fertilization, comparing only treatments in common. Treatments include postharvest (PH; 45 or 90lb actual N) soil application [$CaNO_3$15.5% N], supplemented with foliar N applications 'timed' to phenological events) in most cases. Foliar N treatments include: **CAN17** (16.7% v/v, 17% N) for dormancy release (DR), **PacificHort Grow Plus N** (bloom; 15% ammoniacal N) applied twice during bloom, **low-biuret urea** (46% N) applied pre leaf-fall (PLF; two applications late Sept-Oct 7 days apart), or pre leaf-fall with 20 lb/acre $ZnSO_4$ for dormancy induction (DI; applied late October-early November at ~3 chill portions, Dynamic Model). Harvest occurred on a single date.

Treatment	N_{actual} (lb/A/yr)	Total yield (kg/tree)	TCSA (cm^2) 2010	Yield efficiency (kg/tcsa) 2010	Yield 2009-2010
45PH+Bloom	50	27.4	560.2	0.050	64.7
90PH	100	28.1	542.4	0.053	59.5
45PH+CAN+Urea DI	100	27.1	561.5	0.049	31.0
45PH+Urea PLF	100	33.6	496.2	0.070	67.8
45PH+Bloom+Urea PLF	100	26.9	522.4	0.052	59.6
90PH+CAN+Urea DI	150	34.0	516.7	0.066	41.8
Significance for treatment means differences		NS	NS	NS	NS

[x] Analysis by Mixed Model, replicate effects 'random' and treatment effects 'fixed'. Means in the same column and orchard with different letters differ by Least Squares Means (Tukey) at P = 0.05; ***, **, * or NS = significance at 0.1, 1, 5% level, or non-significant, respectively shown.

Table 8. **Fruit quality, 2010** for 'Bing' (*Prunus avium*) sweet cherry on **Mahaleb** rootstock in response to nitrogen (N) fertilization, comparing only treatments in common. Treatments include postharvest (PH; 45 or 90lb actual N) soil application [$CaNO_3$15.5% N], supplemented with foliar N applications 'timed' to phenological events) in most cases. Foliar N treatments include: **CAN17** (16.7% v/v, 17% N) for dormancy release (DR), **PacificHort Grow Plus N** (bloom; 15% ammoniacal N) applied twice during bloom, **low-biuret urea** (46% N) applied pre leaf-fall (PLF; two applications late Sept-Oct 7 days apart), or pre leaf-fall with 20 lb/acre $ZnSO_4$ for dormancy induction (DI; applied late October-early November at ~3 chill portions, Dynamic Model). Harvest occurred on a single date.

Treatment	N_{actual} (lb/A/yr)	%Soluble solids		Firmness (g/cm^2)		Rowsize		Stem removal force (g/cm^2)	
		June 2	June 10	June 2	June 10	June 2	June 10	June 2	June 10
45PH+Bloom	50	21.5[x]	21.1	264	272	9.8	9.3	792	756ab
90PH	100	21.1	20.7	265	256	10.0	9.4	825	733b
45PH+CAN+Urea DI	100	21.5	21.1	275	272	10.3	9.7	800	772ab
45PH+Urea PLF	100	22.2	21.3	282	271	10.0	9.5	759	802a
45PH+Bloom+Urea PLF	100	21.6	20.5	257	248	10.0	9.4	774	728b
90PH+CAN+Urea DI	150	22.0	20.9	275	257	10.2	9.7	773	604c
Significance for treatment means differences		NS	NS	NS	NS	NS	NS	NS	*

[x] Analysis by Mixed Model, replicate effects 'random' and treatment effects 'fixed'. Means in the same column and orchard with different letters differ by Least Squares Means (Tukey) at P = 0.05; ***, **, * or NS = significance at 0.1, 1, 5% level, or non-significant, respectively.

Table 9. **2010 Fruit quality** for 'Bing' (*Prunus avium*) sweet cherry on **Mazzard** rootstock in response to nitrogen (N) fertilization, Treatments include postharvest (PH; 45 or 90lb actual N) soil application [$CaNO_3$15.5% N], supplemented with foliar N applications 'timed' to phenological events) in most cases. Foliar N treatments include: **CAN17** (16.7% v/v, 17% N) for dormancy release (DR), **PacificHort Grow Plus N** (bloom; 15% ammoniacal N) applied twice during bloom, **low-biuret urea** (46% N) applied pre leaf-fall (PLF; two applications late Sept-Oct 7 days apart), o pre leaf-fall with 20 lb/acre $ZnSO_4$ for dormancy induction (DI; applied late October-early Novembe at ~3 chill portions, Dynamic Model). Firmness and rowsize measured by FirmTech II (BioWorks, KS), soluble solids by Atago 3810 PAL-1 digital refractometer and stem removal force by Imada DS2-4 digital force gauge . Rowsize indicates larger fruit with smaller rowsize.

Treatment	N_{actual} (lb/A/yr)	%Soluble solids	Firmness (g/cm^2)	Rowsize	Stem removal force (g/cm^2)
45PH+Bloom	50	16.2	247 a	9.9	555 a
90PH	100	15.6	232 b	10.0	542 a
45PH+CAN+Urea DI	100	15.8	240 ab	10.2	560 a
45PH+Urea PLF	100	15.1	233 b	10.2	542 a
45PH+Bloom+Urea PLF	100	15.4	245 a	13.8	545 a
90PH+CAN+Urea DI	150	15.6	233 b	10.2	452 b
Significance for treatment means differences		NS	***	NS	***

[x] Analysis by Mixed Model, replicate effects 'random' and treatment effects 'fixed'. Means in the same column and orchard with different letters differ by Least Squares Means (Tukey) at P = 0.05; ***, **, * or NS = significance at 0.1, 1, 5% level, or non-significant, respectively.

Table 10. **2010:** Nutritional effects on **vegetative growth** in '**Bing'/'Mahaleb'**, (PH) soil application [$CaNO_3$ 15.5% N] supplemented with foliar N applications 'timed' to phenological events. Treatments include postharvest (PH; 45 or 90lb actual N) soil application [$CaNO_3$15.5% N], supplemented with foliar N applications 'timed' to phenological events) in most cases. Foliar N treatments include: **CAN17** (16.7% v/v, 17% N) for dormancy release (DR), **PacificHort Grow Plus N** (bloom; 15% ammoniacal N) applied twice during bloom, **low-biuret urea** (46% N) applied pre leaf-fall (PLF; two applications late Sept-Oct 7 days apart), or pre leaf-fall with 20 lb/acre $ZnSO_4$ for dormancy induction (DI; applied late October-early November at ~3 chill portions, Dynamic Model).

Treatment	N_{actual} (lb/A/yr)	TCSA (cm^2) 2010	# Shoot breaks	Total shoot growth (cm)	Growth/shoot (cm)
45PH+bloom	50	544.5b	7.2	325.3	45.6
90PH	100	662.6ab	11.8	545.5	50.0
45PH+CAN+Urea DI	100	775.1a	11.3	657.5	59.8
45PH+Urea PLF	100	724.3a	10.5	654.3	60.2
45PH+bloom+Urea PLF	100	732.7a	12.2	611.5	49.9
90PH+CAN+Urea DI	150	789.9a	16.8	607.8	48.0
Significance for treatment means differences		***	NS	NS	NS

[x]Means in the same column and orchard with different letters differ by Least Squares Means (Tukey) at $P = 0.05$; ***, **, * or NS = significance at 0.1, 1, 5% level, or non-significant, respectively.

Table 11. **2010:** Nutritional effects on **vegetative growth** in '**Bing'/'Mazzard'**, (PH) soil application [$CaNO_3$ 15.5% N] supplemented with foliar N applications 'timed' to phenological events. Treatments include postharvest (PH; 45 or 90lb actual N) soil application [$CaNO_3$15.5% N], supplemented with foliar N applications 'timed' to phenological events) in most cases. Foliar N treatments include: **CAN17** (16.7% v/v, 17% N) for dormancy release (DR), **PacificHort Grow Plus N** (bloom; 15% ammoniacal N) applied twice during bloom, **low-biuret urea** (46% N) applied pre leaf-fall (PLF; two applications late Sept-Oct 7 days apart), or pre leaf-fall with 20 lb/acre $ZnSO_4$ for dormancy induction (DI; applied late October-early November at ~3 chill portions, Dynamic Model).

Treatment	N_{actual} (lb/A/yr)	TCSA (cm^2) 2010	# Shoot breaks	Total shoot growth (cm)	Growth/shoot (cm)
45PH+bloom	50	560.2	6.2	254.8	41.8
90PH	100	542.4	5.5	270.8	50.7
45PH+CAN+Urea DI	100	561.5	5.7	260.3	45.2
45PH+Urea PLF	100	496.2	6.5	325.7	51.7
45PH+bloom+Urea PLF	100	522.4	5.8	243.8	41.8
90PH+CAN+Urea DI	150	516.7	5.0	218.3	42.8
Significance for treatment means differences		NS	NS	NS	NS

[x]Means in the same column and orchard with different letters differ by Least Squares Means (Tukey) at *P* = 0.05; ***, **, * or NS = significance at 0.1, 1, 5% level, or non-significant, respectively.