DEVELOPMENT OF A NUTRIENT BUDGET APPROACH AND OPTIMIZATION OF FERTILIZER MANAGEMENT IN WALNUT

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ABSTRACT

With imminent regulations stemming from findings of high fertilizer-related nitrate contamination of groundwater, along with the launch of California's cap-and-trade greenhouse gas regulation marketplace, and many orchard management expenses on the rise, it is critical that California walnut growers are applying their fertilizer efficiently, to reduce nitrate leaching, N_2O emissions and wasted resources. But much of the information necessary to optimize fertilizer usage is lacking. The timing and scale of nutrient needs on typical soils at today's high yields have not been quantified, nor have the assessment tools (e.g. critical values) for today's cultivars.

This project aims to quantify the monthly nutrient needs of walnut orchards, estimate soil nutrient losses and contributions, improve grower nutrient assessment techniques like critical values and leaf sampling, and communicate findings on opportunities for improved nutrient efficiency with a decision support mobile application, publications and presentations. With the support of the Walnut Board last year, the authors of this report completed the second year of a comprehensive multi-objective project to improve the state of knowledge of demands and potential losses of nutrients in walnuts, and to provide new and improved tools to growers to monitor the nutrient status of their trees.

In this second year of a three year project, nutrient content results were received and analyzed for all 2013 samples. Results for total NPK needs per ton of nuts, monthly nut requirements, and changing nutrient content in the leaves for 2013 are detailed below. Samples from 2014 were collected and submitted for nutrient testing. Over the course of the 2014 growing season, leaf and fruit samples were again gathered monthly from 'Chandler' and 'Tulare' orchards in three growing regions – the northern Sacramento Valley, the Delta and the south-eastern San Joaquin Valley –for building a nutrient budgeting and assessment tool. Soil hydrology monitoring equipment was installed at the Delta Chandler site and leaching measurements were taken throughout the growing season. This project is being supported largely by the California Department of Food and Agriculture, with the California Walnut Board supporting about 1/3 of all expenses.

OBJECTIVES

1. Develop a phenology- and yield-based nutrient demand model for walnut.
2. Determine the contribution of, and losses by, soil of nutrients for tree growth.
3. Validate current leaf critical values and determine if nutrient ratio analysis provides useful information to optimize fertility management.
4. Fine-tune sampling protocols to more accurately reflect the true nutrient status of an orchard block and to enable early season tissue sampling.

5. Integrate phenology, weather and orchard-specific details into a phenology-based nitrogen budget decision support tool (online and mobile application) and Best Management Practices publications.

SIGNIFICANT FINDINGS

- Early results indicate walnuts may accumulate less N per ton of harvested nuts than previous research indicated, closer to 30 lbs than 40 lbs N per ton of in-shell nuts. Additional years of data are necessary to confirm or refute these initial results.
- Variability in total N use was higher between sites than between cultivars.
- N accumulation in fruit is fairly evenly distributed over the course of the growing season.
- P accumulation is steady through most of the growing season but tapers in September.
- K accumulation is fairly steady until September, when significant amounts of K are remobilized.

PROCEDURES (Abridged. For more details see 2014 or 2015 proposal)

1. Nutrient Demand Model:
    a. Catkins, Leaf and Fruit Demand:
        i. Samples were taken from 10 trees from Chandler and Tulare orchards at 3 sites per cv. (near Los Molinos, Linden, Hanford) and analyzed for N, P, K
        ii. Catkins: At senescence; Leaves: Apr-Nov; Fruit: May-Sept/Oct
    b. Perennial Parts Demand:
        i. For 3 of the 10 trees from "a" above, perennial parts were sampled for N, P, K
        ii. Sampled January (dormant), April (leaf-out), May (full leaf growth), July (conventional leaf-sample time), and November (post-harvest)
        iii. Roots, Trunk, Scaffold, Canopy branches, 2-3 year old Branches
    c. Yield: The 10 sampled trees were harvested for individual yield.
    d. Phenology: Nut characteristics and weight were measured at each sampling

2. Soil nutrient losses
    a. Soil texture analyses were performed for variability in the Delta Chandler site.
    b. Equipment was installed between March and April 2014 at three locations in the orchard. At each location, soil moisture, soil temperature, EC and nitrogen species were monitored within and below the root zone (depths: 30cm, 90cm, 150cm, 210cm and 280 cm). Tensiometers were installed below the root zone in order to estimate leaching (depths: 260cm and 300cm).
    c. Suction lysimeters were sampled once a week to every other week, depending on rainfall and irrigation timing. Soil solution was analyzed for nitrate, ammonia and total dissolved nitrogen (TDN) content.

3. Assessment Tool Refinement: CVs and Nutrient Ratios – Leaves from 10 trees from Obj 1a.iii sampled in May and July are being analyzed for S, Ca, Mg, B, Zn, Fe, Mn, Cu in addition to N, P, K. Values are being compared with true individual tree yield, as well as PAR- and LAI-adjusted individual tree yield from Obj. 1c to validate or revise critical values

4. Assessment Tool Refinement: Sampling Protocol – Leaves from 30 trees (20 additional plus 10 from Obj 3) were sampled in May and July for N, P, K. Spatial statistics are being applied to nutrient content from the 30 trees to quantify inter-tree and intra-orchard variability. May leaf nutrient content will be compared with July leaf content to build a predictive model.

5. Lessons and Tools Dissemination: The majority of this work will be completed in 2016 when data has been analyzed, models have been developed and conclusions have been drawn. See proposals for more details.

RESULTS

Samples were collected as outlined above in 2014. Data was analyzed for 2013 samples. Many 2014 nutrient content results have not yet been received from the analysis lab, so have not been statistically analyze. Some results from 2013 samples are presented here.

1. Nutrient Demand Model:

   A. *Annual Nutrient Content per Ton of Harvested Nuts - 2013*

Nuts were collected at harvest, as well as stuck hulls. Nutrient content of nuts at harvest were received as dry weight percent nutrient content. This amount was transformed to pounds of nutrient per ton of in-shell nuts at 8% moisture. Based on the ratio of nut weight to stuck hulls at harvest, an addition quantity was added for the nutrients in the hulls. This was minimal for N and P, but large and highly variable for K. Table 1 shows the combined NPK removed from a given orchard in one ton of harvested in-shell nuts and associated hulls.

Table 1. N, P, and K removed from an orchard in 1 ton of harvested nuts and associated hulls. Letters behind nut values indicate significant difference when values were compared within cultivar (e.g. nitrogen content of all Tulare sites).

	Nitrogen (lbs/ton)			Phosphorus (lbs/ton)			Potassium (lbs/ton)		
Site	Nuts	Hulls	Total	Nuts	Hulls	Total	Nuts	Hulls	Total
North Chandler	25.86 a	0.66	26.52	4.05 a	0.14	4.19	9.09 a	6.74	15.83
Delta Chandler	30.90 a	0.52	31.42	3.51 b	0.09	3.60	8.45 a	3.87	12.32
South Chandler	24.62 a	0.68	25.30	3.48 b	0.10	3.58	8.76 a	4.94	13.70
North Tulare	24.82 b	0.75	25.57	3.53 a	0.12	3.64	6.50 b	5.91	12.40
Delta Tulare	31.82 a	1.29	33.11	3.77 a	0.18	3.94	9.53 a	10.47	20.01
South Tulare	26.94 b	1.91	28.85	3.50 a	0.33	3.83	8.28 c	17.99	26.27

Nutrient content varied widely within sites, in some cases, and from site to site (e.g. Nitrogen, Figure 1). No significant nitrogen accumulation difference was found among sites when all six were analyzed together. When grouped by cultivar, there was no significant difference found among Chandler sites (Table 1). The N content at the Delta Tulare site was significantly higher than the other two Tulare sites. When sites were grouped together by cultivar, there was no significant difference in nitrogen content found between cultivars (Figure 2). In other words, there was more variability between sites across cultivars than there was between cultivars. This is shown below for nitrogen (Figure 1).

Figure 1. Box and whisker plot for pounds of nitrogen per ton of in-shell harvested nuts *by site*, 2013. Site names are given by initials. D = Delta (Linden), N = Northern (Los Molinos), S = Southern (Hanford). C = Chandler, T= Tulare. The dark line in each box shows the average value. The upper and lower ends of the box show the upper and lower quantile - where 25% of the values above and below the average value fell. The whiskers represent the highest and lowest value, with the exception of extreme outliers.

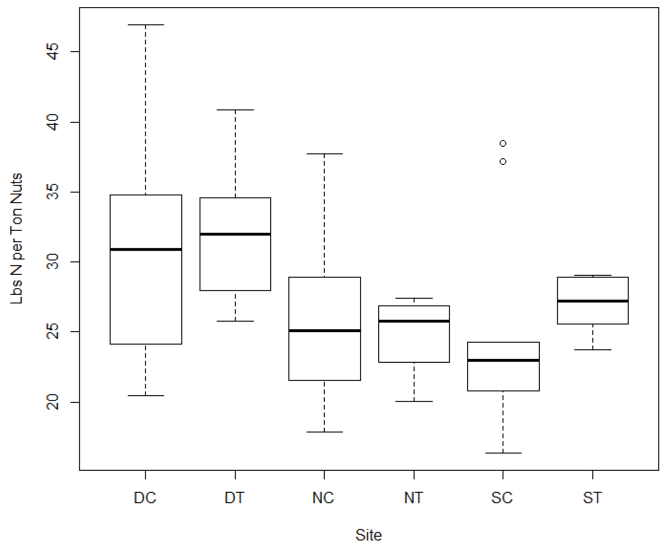
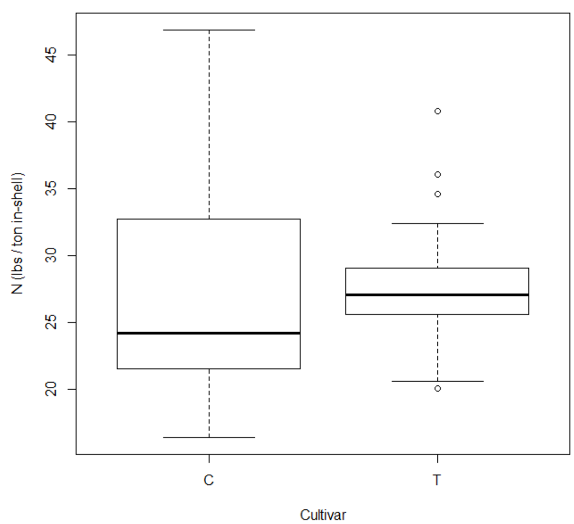


Figure 2. Box and whisker plot for pounds of nitrogen per ton of in-shell harvested nuts by cultivar, 2013. C = Chandler, T= Tulare. For explanation of box and whisker formatting, see Fig 1.



Total nitrogen use varied from 24.62-30.90 lbs per ton of in-shell nuts for Chandlers with 0.52-0.68 lbs N in the hulls, and 24.82-31.82 lbs for Tulares (plus 0.75-1.91 lbs in hulls) (Table 1). The North Chandler site had significantly higher phosphorus use than the other two Chandlers. No significant difference was found among Tulare sites for phosphorus. Phosphorus use varied from 3.48-4.05 lbs per ton of in-shell nuts for Chandlers (plus 0.09-0.14 lbs in hulls) and 3.50-3.77 for Tulares (plus 0.12-0.33 lbs in hulls) (Table 1). There was no difference found among Chandler sites regarding potassium. The Tulare site were all significantly different from each other in potassium use. Potassium use varied from 8.45-9.09 lbs in Chandler (plus 3.87-6.74 lbs in hulls) and 6.50-9.53 lbs in Tulare (plus 5.91-17.99 lbs in hulls) (Table 1).

B. Monthly Nutrient Allocation – Fruit – 2013

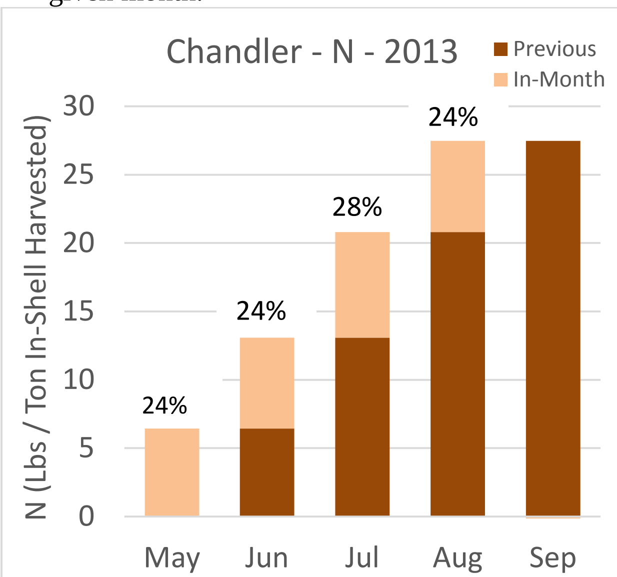
Fruit (kernel, shell and hull) were collected monthly, weighed for growth and tested for nutrient content. Total weight of nuts per tree at harvest was estimated by weight of all shaken content – nuts, hulls, leaves, etc. – and the ratio of these parts in a five gallon bucket sub-sample. The number of nuts was then derived using the total weight of nuts per tree and the average individual nut weight for that tree at harvest. The number of nuts for any given tree was then combine with the average individual nut weight and average nutrient (NPK) content of four nuts per tree for a given month (Tables 2-4). Negative numbers represent a decrease in nutrient content from the previous month. Nuts were not collected in May, 2013, at the southern sites because they had not yet been established. Nor were they collected in August, 2013, at the Delta sites because an Omite spray prevented orchard entry. In Figure 3 & 4, average values of monthly nitrogen accumulation are given for Chandler and Tulare, along with the percent of total annual nitrogen accumulation that was accumulated in a given month, on average.

There were significant differences in monthly nutrient accumulation among sites for some months, depending on the cultivar and the nutrient in question. For nitrogen, there were significant differences in monthly accumulation in July in the Tulare sites, August for the Chandler sites and September for both the Chandler and Tulare sites (Table 2). For phosphorus, there was a significant difference between Chandler sites in May and September for Tulare sites (Table 3). For potassium, there was a significant difference between Chandler sites in May and Tulare sites in July and September (Table 4).

Table 2. Nitrogen accumulated each month in the fruit for every in-shell ton of nuts that would be harvested, 2013. As above N, D, S = northern, Delta, southern; C, T = Chandler, Tulare.

Nitrogen (Lbs / Harvest Ton In-Shell)					
	May	Jun	Jul	Aug	Sep
NC	7.07 a	6.09 a	8.62 a	2.46 b	1.61 a
DC	5.81 a	6.65 a	8.13 a	10.31	
SC	13.65		6.37 a	10.67 a	-6.08 b
NT	5.54 a	6.74 a	3.14 b	3.48 a	5.93 a
DT	5.86 a	7.55 a	5.89 ab	12.51	
ST	15.35		6.47 a	4.99 a	0.13 b

Figure 3 & 4. Average nitrogen accumulated monthly in fruit for every in-shell ton of nuts that would be harvested, 2013. Percents indicate percent of total nitrogen that was accumulated in a given month.



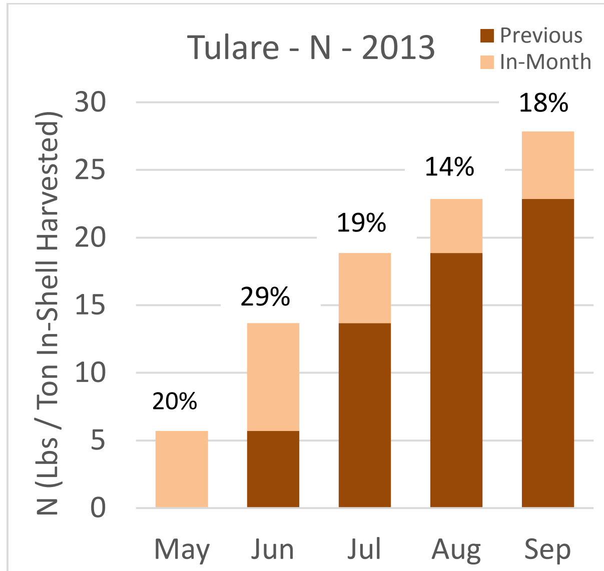


Table 3. Phosphorus accumulated each month in the fruit for every in-shell ton of nuts that would be harvested, 2013.

Phosphorus (Lbs / Harvest Ton In-Shell)					
	May	Jun	Jul	Aug	Sep
NC	0.83 a	0.94 a	1.04 a	1.08 a	0.16 a
DC	0.62 b	0.91 a	0.99 a	0.99	
SC	1.81		1.00 a	1.07 a	-0.39 b
NT	0.69 a	0.93 a	0.76 a	1.01 a	0.13 a
DT	0.68 a	0.98 a	0.70 a	1.40	
ST	2.07		1.01 a	0.73 a	-0.31 b

Table 4. Potassium accumulated each month in the fruit for every in-shell ton of nuts that would be harvested, 2013.

Potassium (Lbs / Harvest Ton In-Shell)					
	May	Jun	Jul	Aug	Sep
NC	8.10 a	11.45 a	12.45 a	15.93 a	-38.84 a
DC	5.33 b	10.95 a	8.53 a	-16.37	
SC	19.15 a		11.71 a	15.43 a	-37.54 a
NT	7.53 a	11.97 a	9.89 b	13.19 a	-36.10 a
DT	7.10 a	12.80 a	8.77 b	-19.14	
ST	24.42 a		14.58 a	14.50 a	-45.22 b

C. Monthly Leaf Nutrient Content – 2013

Leaves were collected monthly and analyzed for nutrient content. Figure 5 illustrates the temporal change in mean %N in leaf tissue by site for 2013. A general decline from May to October is illustrated for all the sites. Leaf nitrogen concentrations were relatively stable between late June and the end of July. Average July N ranged from 2.95-3.62% dry matter in Chandler and 2.95-3.21% in Tulare, depending on location (Figure 6). At the Delta sites, both Chandler and Tulare, %N concentrations were significantly higher than at other sites.

Figure 5. Leaf nitrogen content as a percent of dry matter weight, 2013.

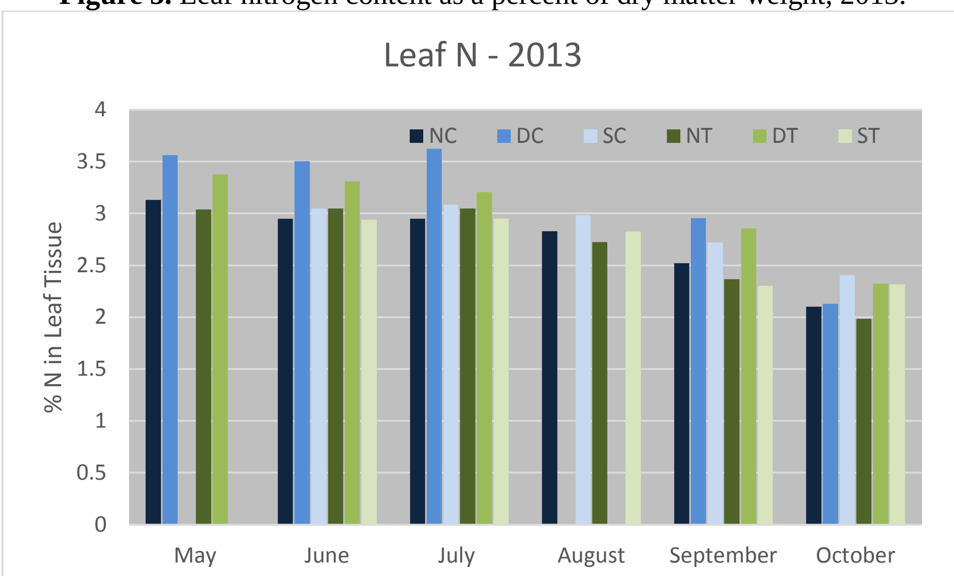


Figure 6. Box and whisker plot for % nitrogen in July leaf samples by site, 2013. For explanation of box and whisker formatting, see Fig 1.

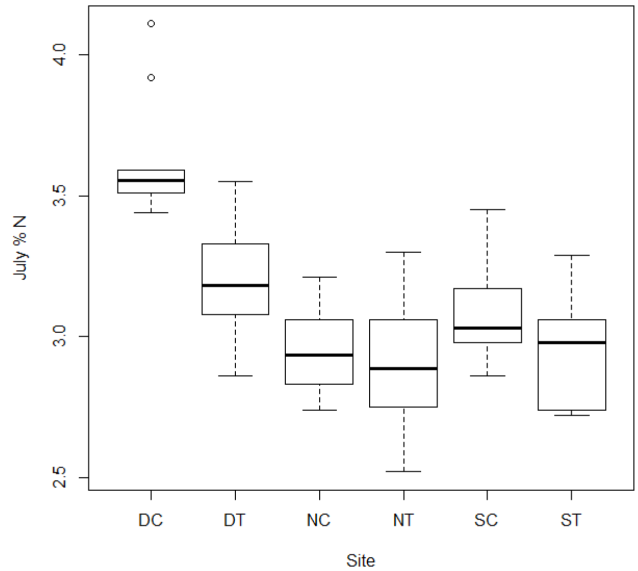


Figure 7 illustrates the temporal change in mean %P in leaf tissue by site for 2013. A general decline from May to June and relatively stable values for June, July and August is illustrated for all the sites, with an increase on a dry weight basis in September for some sites, followed by a decline in October. Average July P ranged from 0.15-0.18% depending on location and cultivar.

Figure 7. Leaf phosphorus content as a percent of dry matter weight, 2013.

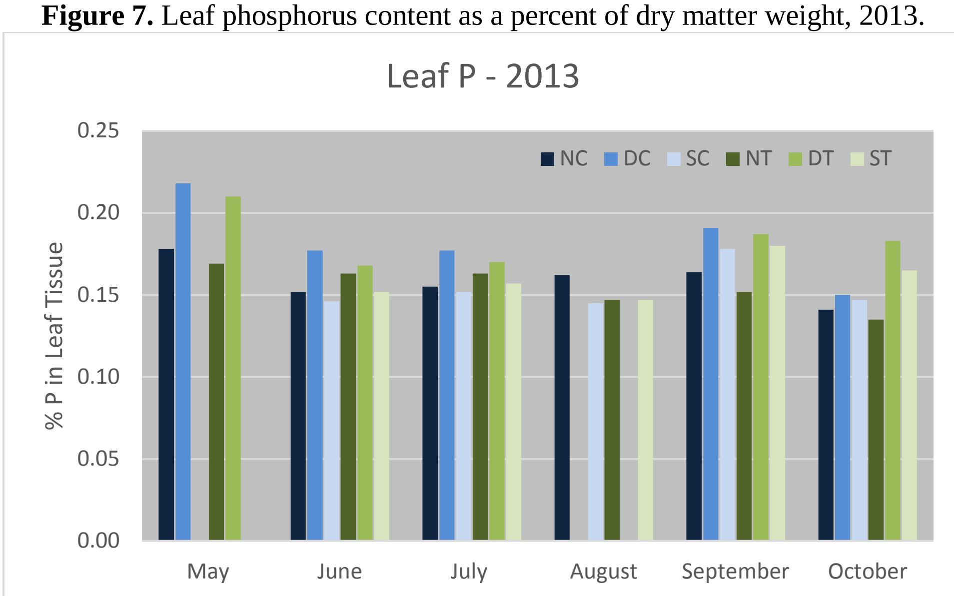
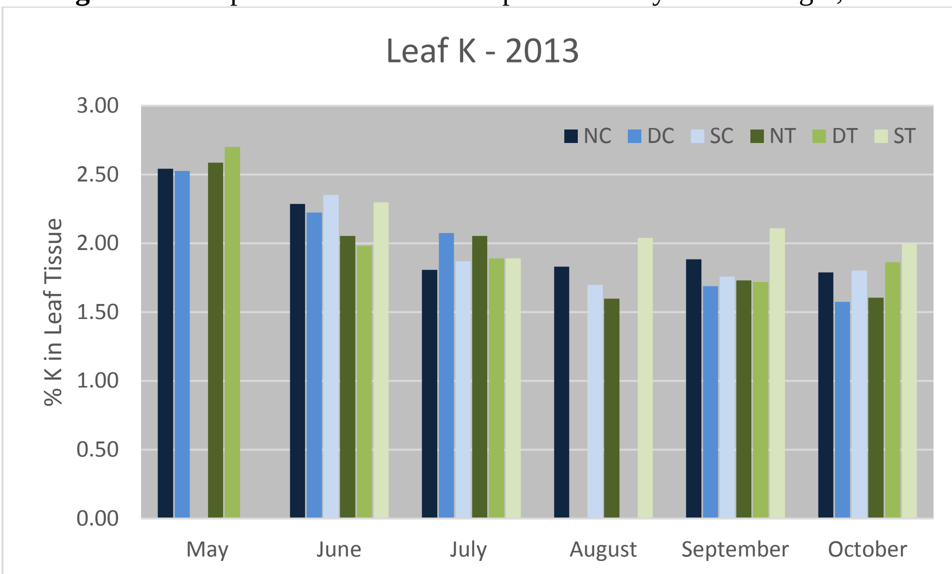


Figure 8 illustrates the temporal change in mean %K in leaf tissue by site for 2013. A general decline from May to July, on a dry weight percent basis is illustrated for all the sites, with relatively stable values thereafter. Average July K concentrations ranged from 1.81-2.08, depending on location and cultivar.

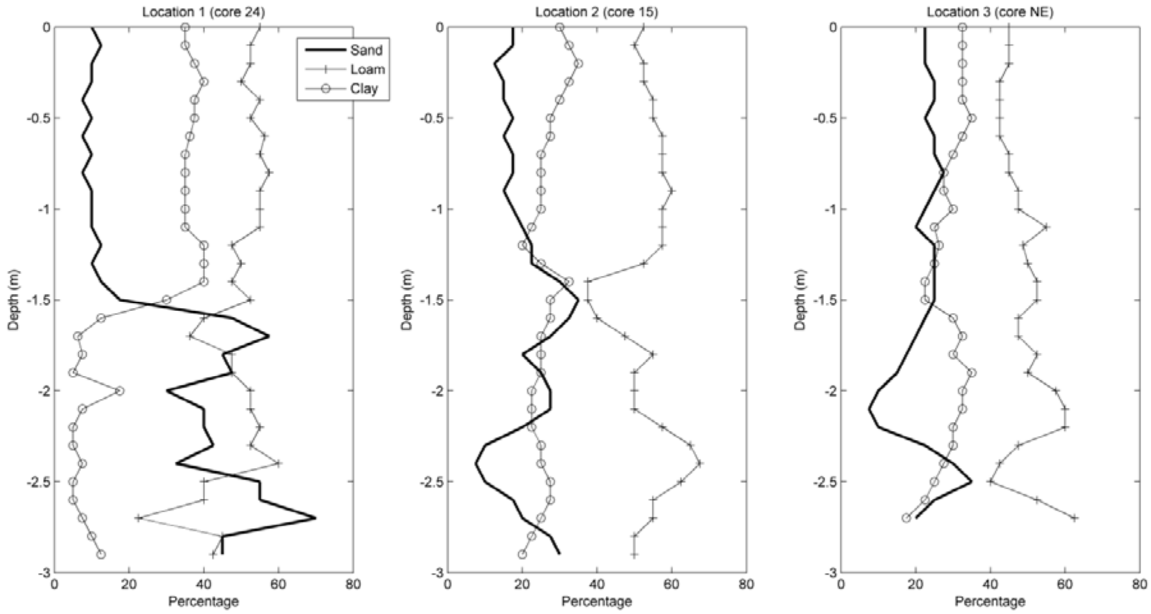
Figure 8. Leaf potassium content as a percent of dry matter weight, 2013.



2. Soil Nutrient Losses

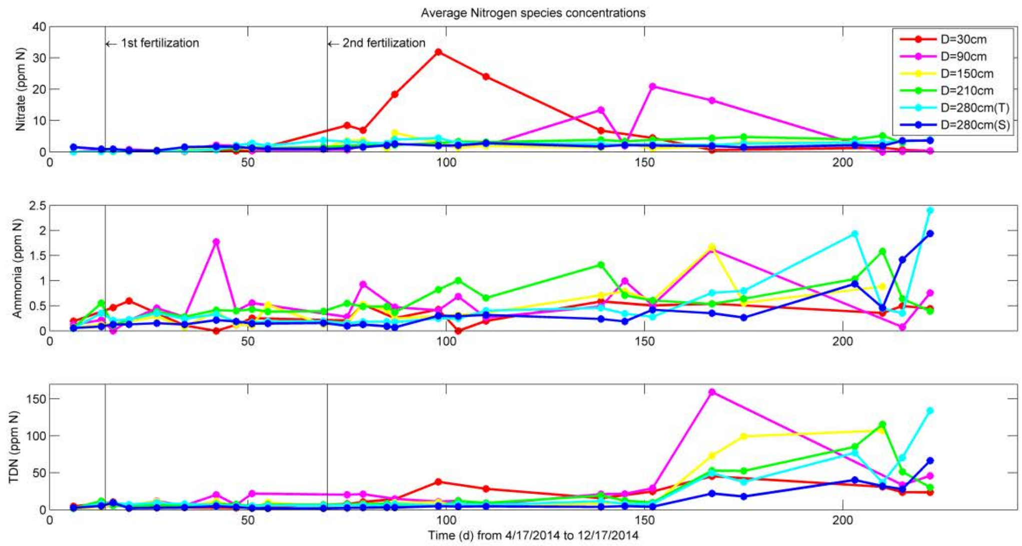
For all three trees monitored at the soil nutrient loss site (Chandler near Linden) texture analyses showed a relatively homogeneous layer of silt loam to clay loam on the first 5 feet (Figure 9). Between 5- and 10-ft depths, soil texture varies significantly down the soil profile and across the orchard. Spatial variations seem to change from sandy loam to silt loam and then clay loam on a South-to-North axis. Presence of a harder layer has also been observed.

Figure 9. Texture analyses shown on chosen locations in Delta Chandler (1m = 3.3ft).



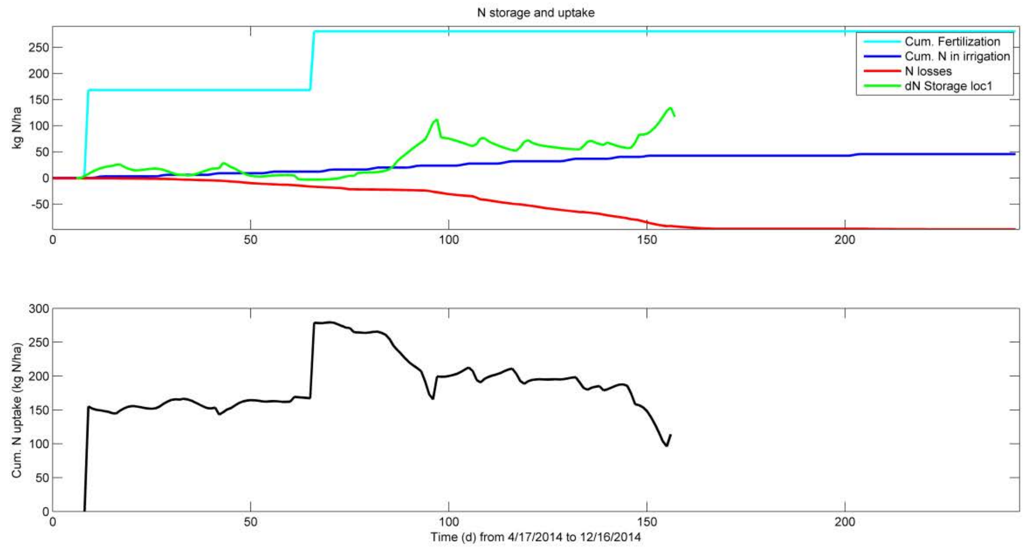
Water storage is paired with nitrogen content in soil solution samples to estimate nitrogen dynamics. Water storage in the soil was estimated with two methods: (i) through Penman-Monteith equation (ii) by integrating VWC values. Water storage is a function of run-off (assumed to be negligible), irrigation and precipitation events, evapotranspiration and drainage under the root zone. Drainage under the root zone is estimated from soil water content and the vertical hydraulic gradient. First analytical results from 2014 show increase of different forms of nitrogen in the soil solution a few weeks after fertilization and also possible preferential water flows below the root zone (Figure 10). In 2014, the first fertilizer application was in late April, the second in late June. A substantial increase in nitrogen at many depths in the soil profile was not seen until after the second irrigation event. Note when examining Figure 10 that the scales of the y-axes are very different.

Figure 10. Analytical results per depth for nitrate (a), ammonia (b) and total dissolved nitrogen (TDN, c), averaged for three trees, 2014. Different colors represent different depths of sensors. 280cm (T) and 280cm (S) are two sensors sets at the same depth located closer to the tree and closer to the sprinkler, to account for differenced in uptake based on proximity to roots. The x-axis spans from 0 days, the start of measurements, April 17th, until December 17th, 2014.



Shallower solution samplers and VWC sensors allow us to determine the amount of total N stored in the soil. Cumulative nitrogen uptake is assessed by adding cumulative inputs (fertilization, N in irrigation water) and cumulative outputs (N losses via drainage and difference in soil N storage through time). N content in the first foot of soil and potential microbial activity are not monitored, which could explain why the cumulative uptake is decreasing in Figure 11 (b). Computation is being refined to increase the quality of the assessment. This result will later be compared to the nitrogen budget in the trees through the season.

Figure 11. Estimating N fertilizer and irrigation water contributions, N uptake and N losses**.** The x-axis spans from 0 days, the start of measurements, April 17th, until December 17th, 2014.



DISCUSSION

1. Nutrient Demand Model:

   A. Annual Nutrient Content per Ton of Harvested Nuts – 2013

Observed total N content in one ton of nuts (Table 1) is lower than that observed by Weinbaum et al. (1991) by about one quarter. At some sites, some nuts did use as much as previously reported, indicating that our larger sample size my show more of the variability than was captured by the six trees in Weinbaum's study. Additional years of data will confirm or refute whether the generalized accumulation is lower than previous research indicated. The wide range in nitrogen content shown in Figure 1 indicates there may be a wide range between the minimum amount of nitrogen necessary fir high yields and the maximum amount that walnuts can accumulate.

Total P content (Table 1) of walnuts have not been the topic of much research to date, so there is little information to compare our findings against. Total K needs were researched by Olson (1991). They found highly variable K content in the hulls, as we have observed to date (Table 1).

   B. Monthly Nutrient Allocation – Fruit – 2013

N accumulation in fruit was observed to be fairly evenly distributed over the course of the growing season for both cultivars (Table 2, Figures 3 & 4). This is in keeping with research previously done in almonds in California, and research done on walnuts in Europe (Drossopoulos et al., 1996b). P accumulation was observed to be steady through most of the growing season but tapers in September (Table 3), and K accumulation was observed to be fairly steady until September, when significant amounts of K are remobilized (Table 4). These patterns are also in keeping with previous research in Europe (Drossopoulos et al., 1996b).

C. Monthly Leaf Nutrient Content – 2013

The general trend in leaf NPK concentrations are in keeping with previous research (Drossopoulos et al., 1996a). N was stable through July then declined. P declined early in the season and was then stable. K declined through July and was then stable. Average N leaf concentrations in July, which ranged from 2.95-3.62 (Figure 5 & 6), were well above the critical value of 2.7% from Weinbaum et al. (1991). Levels were more in line with those reported by Reil et al. (1992) of 3.03-3.51 for Chandler and 2.60-3.39 for Tulare, depending on year and location. Only one of the trees sampled at one of the sites had leaves below 2.7% N in July.

The P concentrations observed in July (0.15-0.18%, Figure 7) are similar to those found by Reil et al. (1992), who found July P concentrations ranged from 0.17-0.19, depending on year, location and cultivar. These values are squarely within the UC critical value range (Brown and Uriu, 1998). The K concentrations observed in July (1.81-2.08%, Figure 8) are higher than most of those observed by Reil et al. (1992) (Chandler: 1.07-2.35, Tulare 0.94-2.12). The Walnut Production Manual sets the critical value for K at 1.2% (Brown and Uriu, 1998), however, Olson (1991) found yield drops below 1.4-1.5%. Our sites are thus all well above yield declining levels of potassium.

2. Soil Nutrient Losses

Soil analysis has shown high soil variability even in a small area of the orchard. Monitoring three locations within the orchard with so much variability should improve the predictive capacity of our models. Initial results show leaching of nitrate as early as late July (Figure 10), increasing towards the end of the season with heavy precipitation events. Leaching of nitrate does not appear to be high in the growing season because there is limited water movement below the root zone.

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