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Nutrient analysis of organic strawberries: effect of cultivars and mycorrhizal inoculations

FINAL REPORT

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Executive Summary

Plant tissue analysis has been used as a tool for monitoring nutrient status of conventional strawberries. However, no research has been conducted on a tissue test for organically grown strawberries. The main goals of the study were to 1) demonstrate the relative N performance of standard California cultivars grown under organic management, 2) determine if a commercial arbuscular mycorrhizae (AM) inoculant could provide mineral nutritional benefit, especially for phosphorus, and 3) provide information that will aid organic strawberry producers in fertility management.

In 2000, as the second year of an organic strawberry cultivar/AM inoculation trial funded by the California Department of Pesticide Regulation, randomized block experiments were established in two organic farms on the central coast of California. From the two sites, young-mature leaves of five commercial strawberry cultivars (Aromas, Chandler, Diamante, Pajaro and Seascape) grown with or without AM inoculation were sampled three-times during the growth period; early flowering stage (March, 2001), and mid and late fruit harvesting stage (May and July, 2001). Total nitrogen (T-N) and total phosphorus (T-P) in leaf blades, and nitrate-N (NO_3-N) in petioles, were analyzed for each sample.

T-N and NO_3-N in leaves were high in the early flowering stage and decreased in the fruit harvesting stage. Regardless of the growth stage, however, we found significant differences in T-N in leaf blades and NO_3-N in petioles among cultivars. On average, Aromas and Seascape showed the highest T-N and NO_3-N content in both fields. Pajaro consistently presented the lowest T-N and NO_3-N contents, where Diamante and Chandler's leaf N contents were in the middle among cultivars tested.

Furthermore, positive correlations of N status and total fruit yields were found across cultivars. Especially the most significant correlation ($P < 0.001$) was observed between T-N in leaf blades in the early flowering stage and the total fruit yield. This correlation was consistent across fields, whereas correlations of NO_3-N in petioles in the same stage and total fruit yields varied between fields. This suggests a potential use of T-N in leaf blades rather than NO_3-N in petioles as an indicator for N status in organic strawberries.

AM inoculation did not demonstrate any significant effect on T-P in leaf blades and N status of strawberries. According to a conventional critical standard, T-P in leaf blades was sufficient throughout the growth period despite cultivar and field, reflecting sufficient soil available phosphorus levels of the fields. This might explain the ineffectiveness of the AM inoculation in the experiments.

Introduction

Organic strawberry production in California is growing. A total of 1,279 acres of organic strawberries, which is almost a ten-fold increase from the 134 acres of 1997, were planted in 2002 with a total farm gate value of 12.5 million dollars (Klonsky, 2003).

Virtually nothing is known about factors limiting yield in organic strawberry fields. Most of the research on strawberry production has been conducted in conventional production systems and may not be applicable to organic productions systems. Though choice of variety is very important for success, a study to determine how different strawberry cultivars perform in organic production fields is non-existent and farmers are left to extrapolate from conventional systems. High yield cultivars that are currently used for commercial strawberry production have been evaluated and selected for their yield and fruit quality in conventional agricultural systems (Larson and Shaw, 1995). In organic fields, plants are presented environments that are very different from those in which they were selected.

Dr. Carolee T. Bull, Research Plant Pathologist, USDA/ARS, and her collaborators initiated a project entitled "Evaluation of Cultivars for Yield in Organic Strawberry Production in the Presence or Absence of Mycorrhizal Inoculum" in 1999, receiving partial funding from the California Department of Pesticide Regulation (DPR) and University of California Sustainable Agriculture Research and Education Program (UC-SAREP). This was the first evaluation of strawberry cultivar performance under organic management conditions. The overall goal is to provide farmers with research conducted in an explicitly organic setting so that they can make informed choices about cultivar selection, microbial treatments, and disease management issues.

They conducted the cultivar evaluations and experiments with mycorrhizae during the 1999-2000 strawberry-growing season at four certified organic farms in Monterey, Santa Cruz and San Benito Counties. In summary:

- The cultivars Aromas, Pacific, and Seascape were consistently the top performing of those tested. Cultivars Diamante, Douglas, Hecker, Pajaro, Selva, Sequoia, Capitola, Camarosa, Carlsbad, Cartuno, Irvine, and Gaviota were also evaluated. The data indicated that significant differences in yield occur among cultivars grown under organically managed conditions.
- A commercially available mycorrhizal inoculant provided no benefit to organic strawberry production. Although transplants were initially sparsely colonized, inoculation with a commercial inoculant did not increase the percent of the roots colonized when plants were grown in organic fields. Likewise there was no increase in yield due to the mycorrhizal inoculant. The failure may be due to the presence of adequate mycorrhizal inoculum in the organic production fields or high nutrient levels.
- In these evaluations lethal plant diseases such as Verticillium wilt did not limit organic strawberry production in these fields. Other yield limiting diseases were not detected in high levels at any of the locations or on any of the cultivars.

A second grant from DPR was awarded to repeat and expand the experiments in the 2000-2001 season. As an additional expansion of the project, we conducted nutrient analysis of organic strawberries grown in these experiments in the second season, focusing especially on nitrogen (N) and phosphorus (P). Though nutrient analysis has been used as a valuable tool for monitoring nutrient status of conventional strawberries (Hochmuth et al., 1991; Jones et al., 1991; Pritts and Handley, 1998; Ulrich et al., 1980), no research has been conducted for organically grown strawberries. We particularly focused on N since yield and quality of strawberry fruits are strongly affected by the plant N status. N deficiency reduces leaf area, root mass and fruit size (Johanson and Walker, 1963; Ulrich et al., 1980), and excessive levels of N can lead to soft fruit, delayed ripening, lower yields, increase powdery mildew, and increased mite pressure (May and Pritts, 1990; Miner et al., 1997; Voth et al., 1967).

Objectives

1. Demonstrate the relative nitrogen performance of standard California cultivars grown under organic management.
2. Determine if a commercial arbuscular mycorrhizae (AM) inoculant could provide mineral nutritional benefit, especially on phosphorus, to the cultivars being tested in the first objective.
3. Provide information that will aid organic strawberry producers in fertility management.

Methods

Location of the Field Experiments:
In the 2000-2001 growing season, cultivar performance was evaluated at two certified organic locations. The sites were located in Salinas (USDA/ARS Spence Organic Field, Salinas) and Santa Cruz (UCSC Organic Farm) (table 1). At each site, new experimental plots were established in the fall of 2000. Soil type is Chualar loam (Fine-loamy, mixed, thermic Typic Argixerolls) in the Salinas field and Elkhorn sandy loam (Fine-loamy, mixed, thermic Pachic Argixerolls) in the Santa Cruz field. Soil characteristics of the fields are summarized in table 2.

Table 1. Growers and Locations of Experiments

Location	Farm	Grower
Santa Cruz	UCSC organic farm	Jim Leap
Salinas	Spence Organic Field	Dick Tamangi and Paul Kohatsu

Table 2. Soil Characteristics of the Experimental Sites

Location	SOM *	pH	Olsen-P**	Ex. Ca**	Ex. Mg**	Ex. K**	Ex. Na**
Santa Cruz	2.5	6.6	19	1083	101	117	23
Salinas	1.9	7.1	44	1260	126	105	110

* Soil Organic Matter content % of oven dry soil. ** mg/kg of oven dry soil.

Cultural Practices:
Santa Cruz Field: 25 tons per acre of compost was applied on September 25, 2000. Broccoli residues were incorporated on September 29. Strawberries were planted on November 20. Black plastic mulch was applied right after planting. Fruit harvest started on April 18, 2001 and ended on June 25.
Salinas Field: 25 tons per acre of compost was applied in September 2000. Strawberries were planted on November and black plastic mulch was applied right after planting. Fruit harvest started on April 11, 2001 and ended on July 26. Organic liquid fertilizer (7-0-0) was applied at a rate of 6 gallons/acre per week starting from the week of June 25, 2001 until the week of July 9 (for three weeks).
Nutrient contents of composts and nutrient application rates in each site are shown in table 3 and table 4, respectively.

Table 3. Nutrient Content in Composts Applied

Location	Moisture %*	N %**	P%**	K%**
Santa Cruz	39	0.93	0.51	1.1
Salinas	30	0.72	0.18	1.1

* Fresh basis. ** Oven dry basis.

Table 4. Nutrient Application Rates

Location	Material	Rate applied /acre	Nutrient applied lbs/acre N	P	K
Santa Cruz	Compost	25 tons	312	171	369
Salinas	Compost	25 tons	278	69	424
	Liquid fertilizer	176 lbs	12	0	0
	Total		290	69	424

Preparation and Experimental Design of the Field Experiments:
Bed preparation and soil amendments have been consistent with management practices outlined by California Certified Organic Farmers (Health and Safety Code number 26569.11) but determined by the individual farm manager. As separate parts of the experiment ten cultivars were evaluated for yield and mycorrhizal infection at each location. For nutrient analysis, five cultivars, Aromas, Chandler, Seascape, Pajaro, and Diamante were sampled (table 5). Aromas and Seascape represent newer cultivars that consistently showed high performance in the first year of the experiments. Chandler is an older but well-known cultivar among organic growers. Pajaro was chosen as a low performance cultivar in the first year of the experiment. Diamante is a newer cultivar and the most widely planted cultivar by conventional growers. At the time of planting, plants from each cultivar were dipped in either a microbial treatment or a control and planted. The microbial inoculant was a commercially available mycorrhizal inoculant (BioBlend RD, Soil Technology), which consists of seven vesicular arbuscular mycorrhizal species. Each plot consisted of 32 plants of one variety.
As the other part of the experiment, yield was evaluated on 20 plants from each plot and 12 plants were used for destructive root sampling to examine mycorrhizal infection at all sites. The experiments were conducted as a randomized complete block with four replications per treatment at each location.

Table 5. Cultivars Evaluated in the Experiment

Cultivar	Location 1 & 2
Aromas	Y+L
Carlsbad	Y
Chandler	Y+L
Diamante	Y+L
Douglas	Y
Oso Grande	Y
Pacific	Y
Pajaro	Y+L
Seascape	Y+L
Selva	Y

"Y": cultivars that fruit yields were surveyed.
"Y+L": cultivars sampled for nutrient analysis in this project, in addition to fruit yield survey.

Leaf Sampling and Analysis:
The leaf samplings from Spence field (Salinas) and UCSC field (Santa Cruz) were conducted on March 26 (initial flowering stage), May 21 (mid harvest stage), and July 23 (late harvest stage). Leaf samples were taken from 40 plots (5 cultivars with and without mycorrhizal inoculation with four replications) at each location. According to Ulrich et al. (1992), 10 to 15 young-mature leaves were sampled from each plot to make a composite sample. Petioles were detached from leaf blades. Each part was dried at 60 - 70 °C for 48 hrs. After grinding, the samples were sent to DANR Analytical Laboratory at UC Davis for analyzing total nitrogen (T-N) and total phosphorus (T-P) in leaf blades and nitrate-N (NO_3-N) in petioles. Results were expressed as dry weight basis and statistically analyzed using repeated-measure ANOVA method at the $P = 0.05$ level for each field with cultivar and mycorrhizal inoculation as main treatments.

Correlation between Petiole Nitrate and Leaf Blade Total Nitrogen:
The correlation between NO_3-N content in petioles and T-N content in leaf blades sampled in this experiment was analyzed by regression analysis (237 pairs). We chose the best fitted and the simplest linear or polynomial regression curve. Then a probability distribution of the residuals (difference between T-N values estimated by the regression formula and the original T-N values) was selected using a distribution fitting software "BestFit" (Palisade Corporation, 1997). The probability of residuals was examined based on the probability distribution selected.

Relationships between Fruit Yield and Plant Nitrogen Status:
T-N contents in leaf blades and NO_3-N contents in petioles were compared with fruit yield using correlation analysis. In the last year's experiment, we found significant difference in fruit yield between cultivars at each field. With these comparisons therefore we examined if:

- the difference in fruit yields is correlated to N status of the cultivars.
- either T-N in leaf blades or NO_3-N in petioles would show a better correlation or more similar trend with fruit yield than the other.

For the correlation analysis, we used total fruit yield rather than marketable fruit yield because "marketable" criteria differed between growers. We chose the best fitted and the simplest linear or polynomial regression curves.

Comparing with Conventional Critical Levels:
The analysis data were contrasted with conventional critical levels developed in California (Ulrich et al., 1980; University of California Integrated Pest Management Program, 1994) (table 6). This demonstrates if any contradictions exist when we apply conventional critical levels to strawberries grown under organic managements.

Table 6. Plant Analysis Values for Determining the Mineral Status of Strawberries

Nutrient	Plant part tested	Tentative critical concentration	Range showing	
			Deficiency symptoms	No deficiency symptoms
NO_3-N	Petiole	500 ppm*	0 – 500 ppm	700 – 20,000 ppm
Total N	Blade	2.8 %*	2.0 – 2.8 %	3.0 % +
Total P	Blade	0.1 %*	0.03 – 0.11 %	0.15 – 1.3 %

Dry weight basis. Ulrich et al., 1980.
* University of California IPM manual (1994) uses the following critical values: NO_3-N in petioles; 2,800 ppm, T-N in blades; no critical value specified, and T-P in blade; 0.1%.

Results

Strawberry Growth and Fruit Yield
In the Santa Cruz field, wilting symptoms appeared on a few plants in April 2001 and spread to the whole field in two months, resulting in major yield reduction. The damage was brought about by a combination of garden symphylans, *Scutigerella immaculate*, and Verticillium wilt caused by *Verticillium dahliae*. However there was no statistical difference in the levels of damage among treatments. Strawberry plants in the Salinas field had no major diseases and pest problems.
The fruit yield of each cultivar differed significantly (fig. 1). Seascape and Aromas had the highest marketable fruit yield in Santa Cruz and Salinas, respectively. Pajaro's fruit yield was the lowest in both fields. Though average total fruit yield was in higher in Salinas (193 grams/plant) than in Santa Cruz (158 grams/plant), marketable fruit yield was higher in Santa Cruz. This happened because of the difference of the "marketable" standards between the two growers: the Santa Cruz grower sells the fruit through direct marketing, whereas the Salinas grower ships fruits through regular markets that require exact cosmetic standard. Total fruit yield ranged from 21 grams/plant (Pajaro in Santa Cruz) to 313 grams/plant (Aromas in Salinas).

NO_3-N Content in Petioles
NO_3-N content in petioles was high in March (673-3960 mg N/kg), decreased in May, and remained low in July regardless of field and cultivar (fig. 2). In May and July, NO_3-N content (mg/kg) was higher in the Salinas field (155-1660) than in the Santa Cruz field (167-669), probably reflecting the plant damage in the Santa Cruz field and the

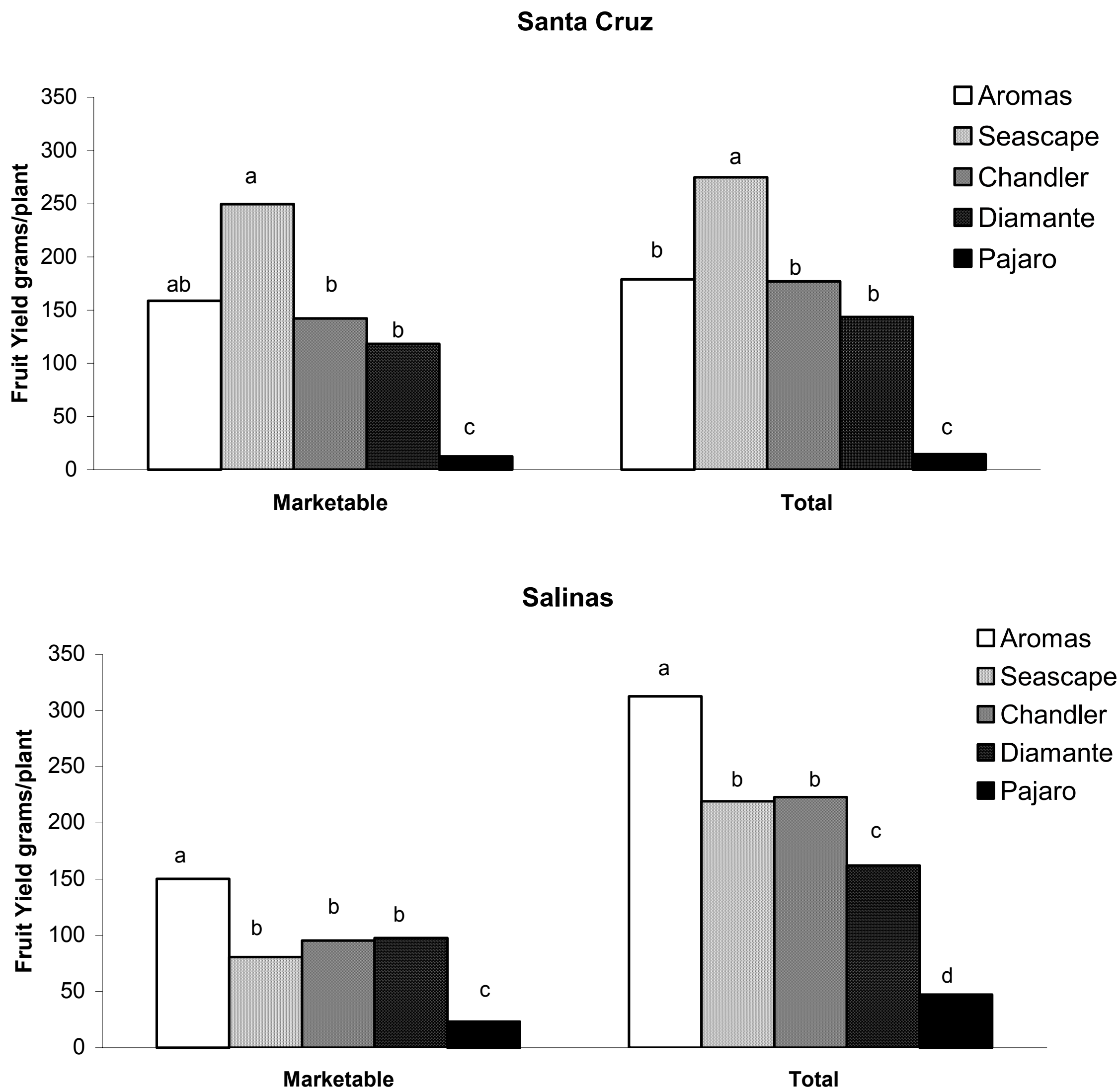


Figure 1. Cumulative fruit yield of five strawberry cultivars grown under organic management. Means having the same letters were not significantly different at the P=0.05 level according to l.s.d. test. n=8 for each cultivar.

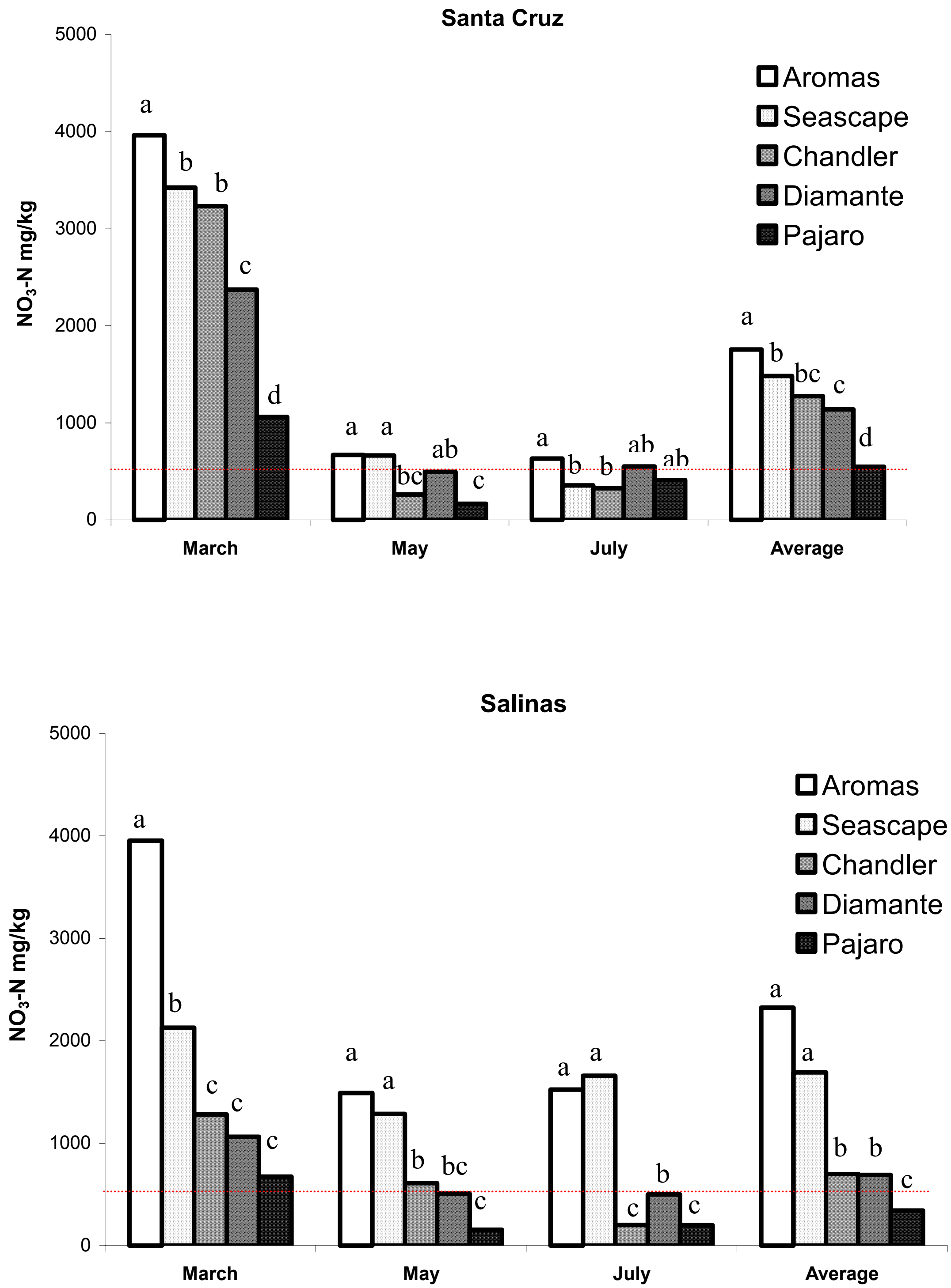


Figure 2. Nitrate content in petioles of five strawberry cultivars grown under organic management. Means having the same letters were not significantly different at the P=0.05 level according to l.s.d. test. "Average" was tested by repeated measure analysis method. n=8 for each cultivar. .... Tentative critical level by Ulrich et al., 1980.

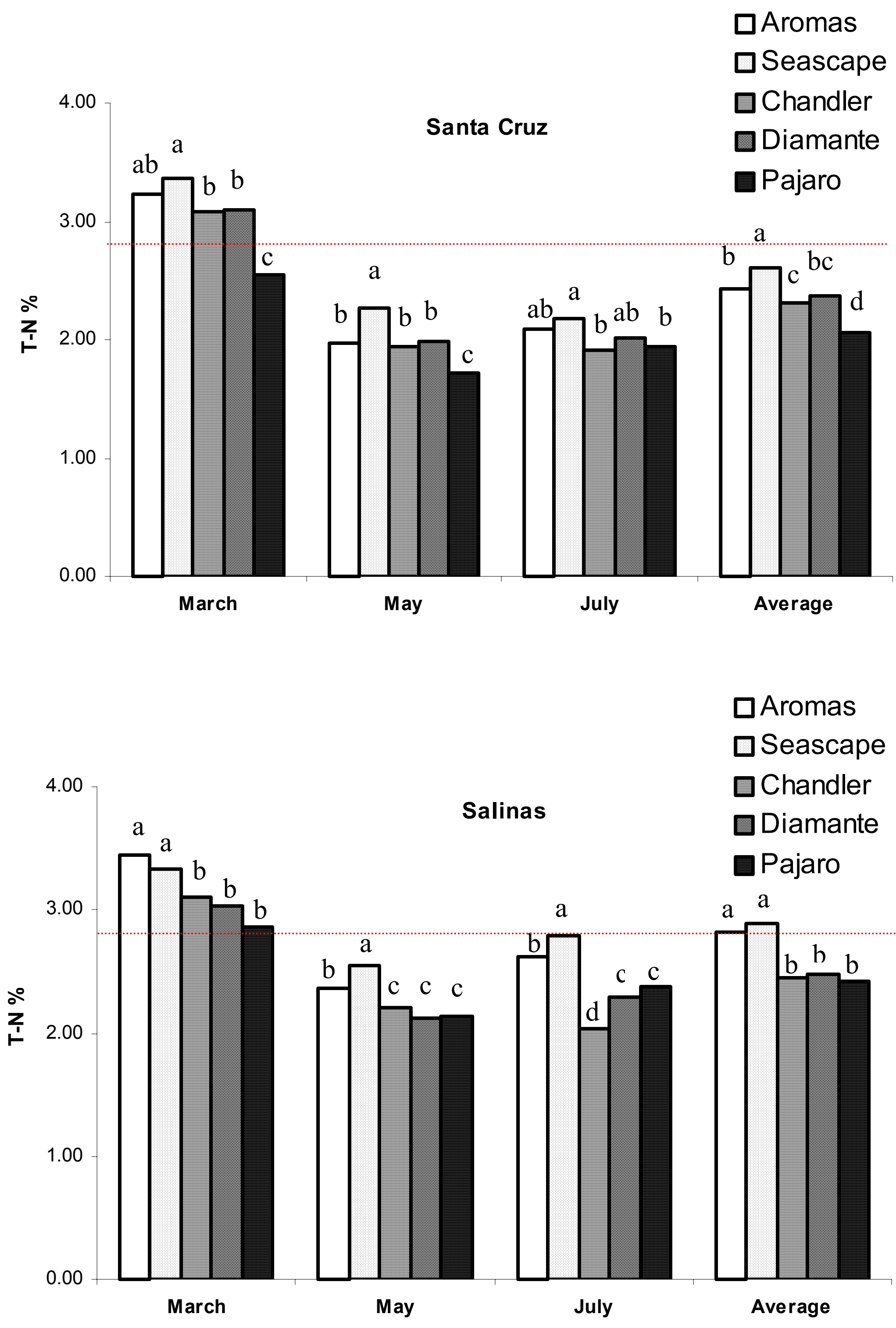


Figure 3. Total nitrogen content in leafblades of five strawberry cultivars grown under organic management. Means having the same letters were not significantly different at the P=0.05 level according to l.s.d. test. "Average" was tested by repeated measure analysis method. n=8 for each cultivar. .... Tentative critical level by Ulrich et al., 1980.

supplemental N application in the Salinas field. At each growth stage, a significant difference in NO_3-N contents was found among cultivars but not in mycorrhizal treatments and the interaction. Average NO_3-N content during the three sampling periods was in order of Aromas > Seascape > Chandler > Diamante > Pajaro despite field. Pajaro consistently showed the lowest NO_3-N content and was significantly lower than Diamante in both fields.

T-N Content in Leaf Blades
T-N in leaf blades was 2.6-3.5% in March and decreased to 1.7-2.8% in May and July in both fields (fig. 3). Again, at each growth stage, cultivar treatment was significantly different but mycorrhizal treatment and the interaction was not. In cultivar treatment, average T-N content was in order of Seascape > Aromas > Diamante > Chandler > Pajaro regardless of field. In Santa Cruz, leaf T-N in Seascape was significantly higher than the rest, and leaf T-N in Pajaro was significantly lower than the other cultivars. In Salinas leaf T-N in Seascape and Aromas was not significantly different though the two cultivars had significantly higher leaf T-N than the others did. There was no significant difference in leaf T-N contents in Diamante, Chandler, and Pajaro in Salinas field.

Correlation between Petiole NO_3-N and Leaf Blade T-N Contents
T-N in leaf blades showed a significant correlation with NO_3-N in petioles (2nd order polynomial regression r^2=0.73, n=237. P < 0.001. fig. 4). However, a fitted probability distribution (Gamma(3.00,0.18) + -0.55) of residuals showed that ~50% of residuals were larger than ±0.2% (fig. 5).

Correlations between N Status and Fruit Yield
In examining correlations between plant N status and fruit yield, we chose to use the total fruit yield rather than the marketable fruit yield. The reason was to avoid different standards used for marketable fruit yield between two fields.
Positive correlations of N status and total fruit yields were found across cultivars in each site in different stages. Especially, the most significant correlation was observed between T-N in leaf blades in the early flowering stage and the total fruit yield (P < 0.001). This correlation was consistent across fields, whereas correlations of NO_3-N in petioles in the same stage and the total fruit yields differed between fields (fig. 6).

T-P in Leaf Blades
T-P content in leaf blades ranged from 0.25% (Chandler in July in Santa Cruz) to 0.48% (Aromas in March in Salinas) across all sampling stages and treatments (fig. 7). In both fields, cultivar treatment was significant but mycorrhizae treatment was not. Among cultivars tested, Aromas showed the highest T-P content in both fields but the rest of the order was not consistent between the fields.

Comparing with Conventional Critical Levels:
NO_3-N content in petioles and T-N and T-P content in leaf blades from this experiment were contrasted with the conventional tentative critical levels established by Ulrich et al. (1980, table 6).
In evaluating N status, we found a discrepancy between critical levels of NO_3-N and T-N. According to the tentative critical level for NO_3-N in petioles (500 mg/kg (= ppm)), the plant N status of Aromas and Diamante in July grown in Santa Cruz field were still above

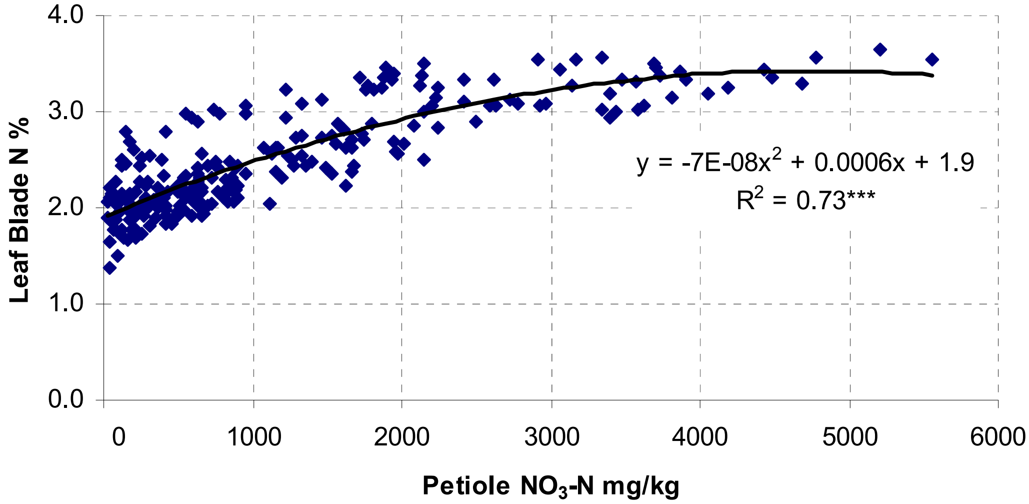


Figure 4. Correlation between NO_3-N in Petioles and Total N in Leaf Blades of Organic Strawberries. n=273.

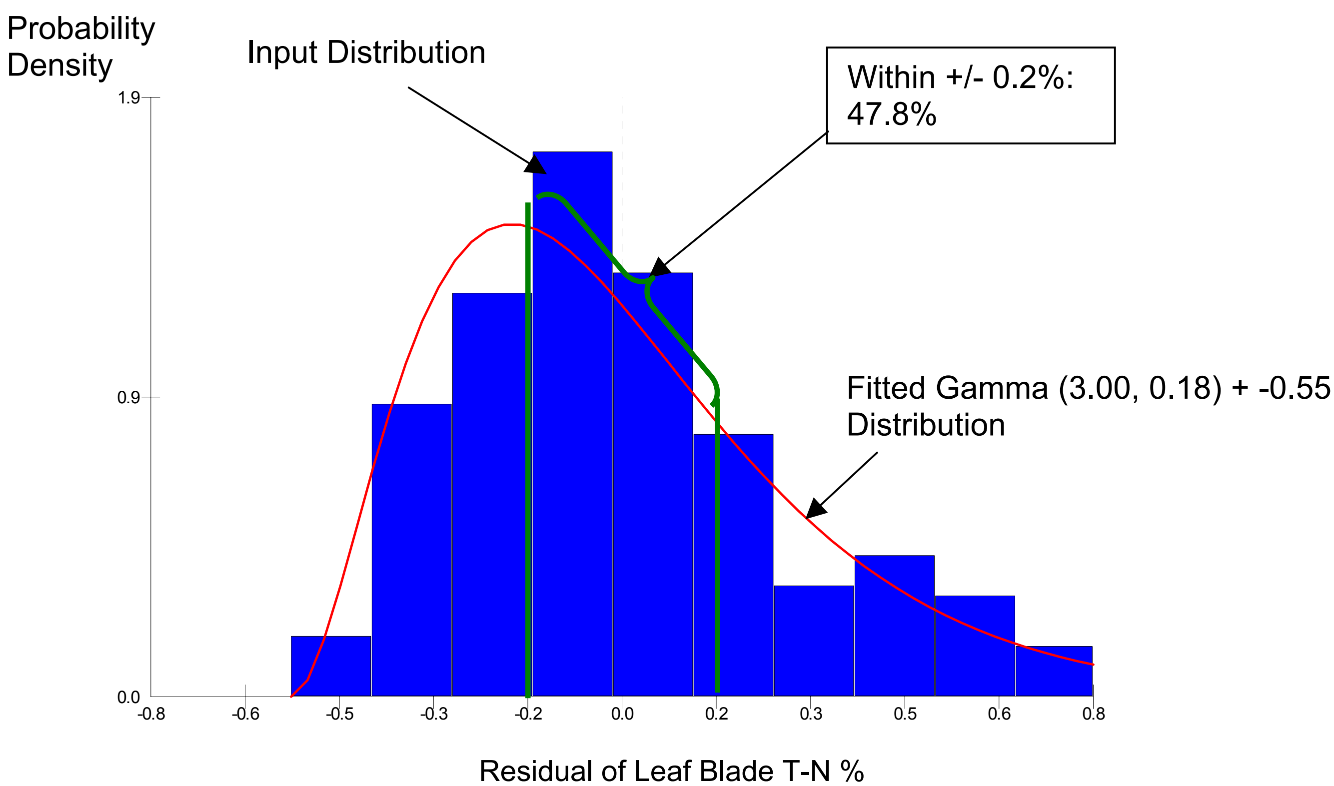
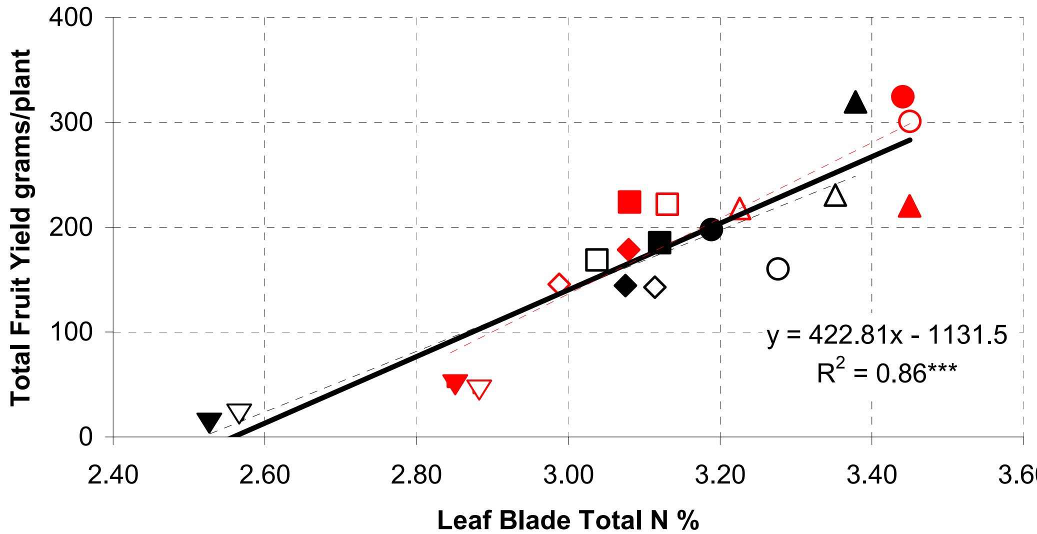


Figure 5. Probability Distribution of Residuals of Leaf Blade Total N in Organic Strawberries.



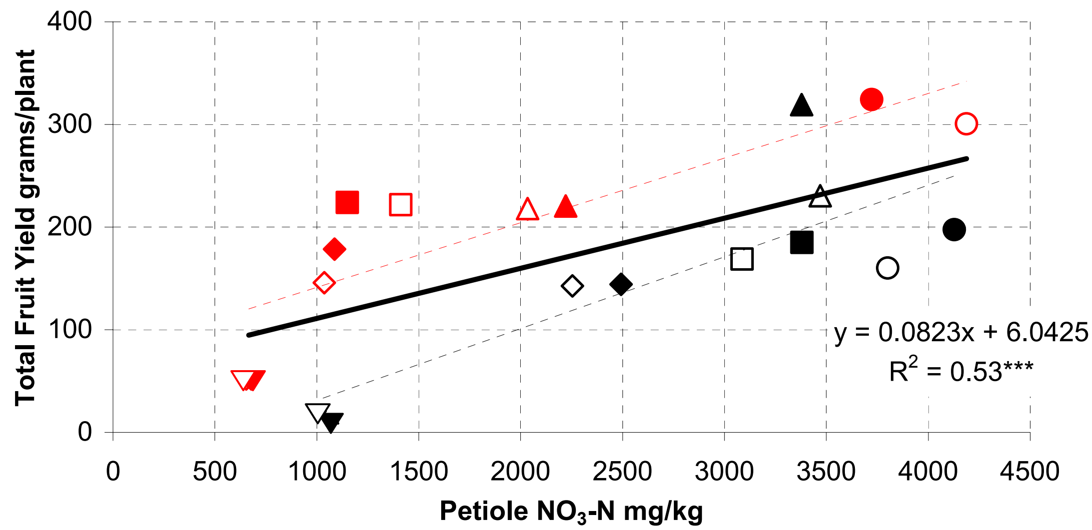
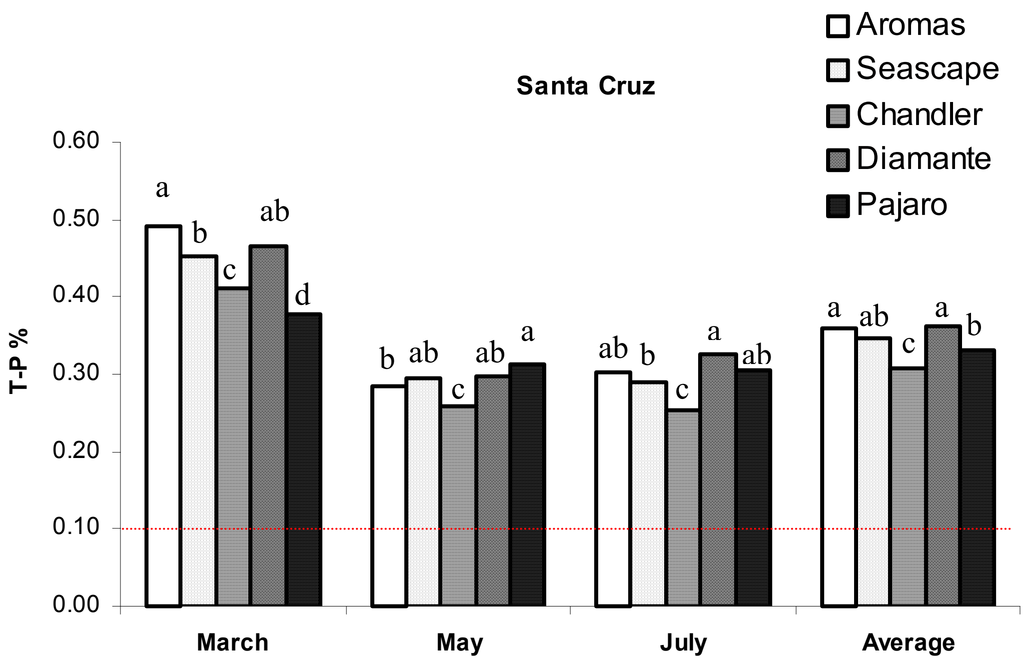


Figure 6. Correlations between total fruit yield and N status in early flowering stage (March) of organic strawberries. T-N in leaf blade (above) and NO_3-N in petioles (bottom) are used as indicators of N status. Each symbol indicates the following: symbol with black; Santa Cruz, red; Salinas, solid; with mycorrhizae, open; without mycorrhizae, circle; Aromas, triangle up; Seascape, square; Chandler, diamond; Diamante, and triangle down; Pajaro. Each point is the average of four replicates.



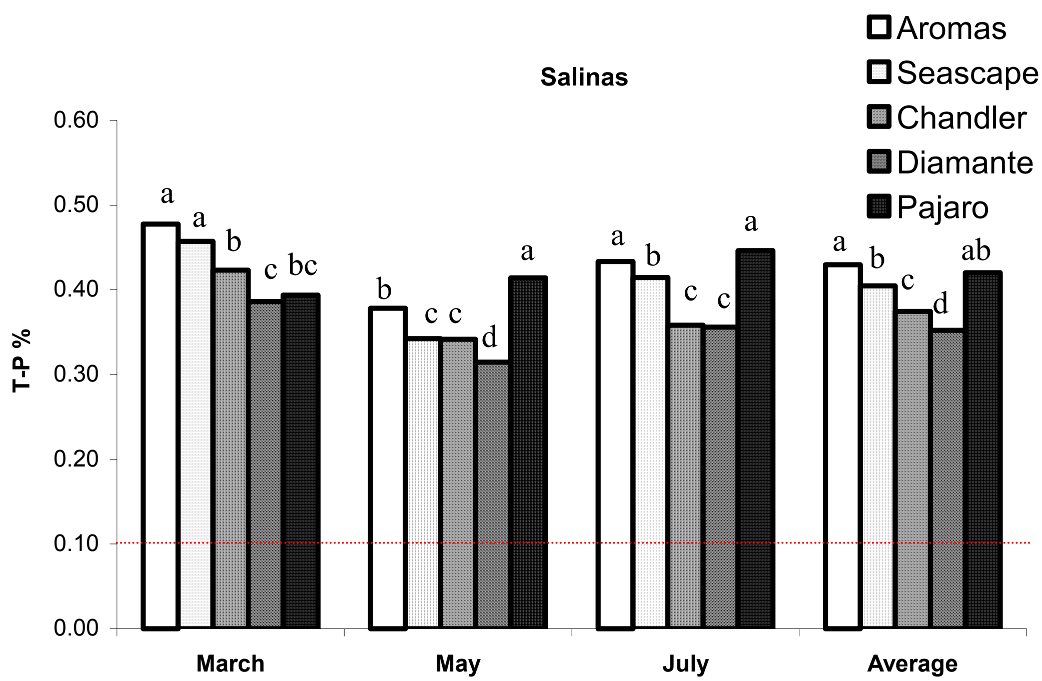


Figure 7. Total phosphorus content in leaf blades of five strawberry cultivars grown under organic management. Means having the same letters were not significantly different at the P=0.05 level according to l.s.d. test. "Average" was tested by repeated measure analysis method. n=8 for each cultivar. ——— Tentative critical level by Ulrich et al., 1980.

the critical level (fig. 1). On the other hand, the T-N tentative critical level (2.8%) indicated all cultivars were N deficient in May and in July despite the field (fig. 2). On T-P in leaf blades (fig. 7), all samples contained T-P in well above the tentative critical level of 0.1% tentatively suggested by Ulrich et al. (1980).

Discussion

N performance of Five Cultivars Grown in Organic Systems
Each strawberry cultivar had unique N response and performance (Hochmuth et al., 1996; Voth et al., 1967) and N performance diversity reflects the differences in foraging capacity of the roots for soil N, or growth habit under given environmental conditions (Ulrich et al., 1980). We compared N performance of the currently available five strawberry cultivars grown under organic management. Both NO_3-N in petioles and T-N in leaf blades showed significant differences among cultivars tested. As a general trend, Aromas and Seascape are the two cultivars that always showed the highest N status across the growth stages and fields, followed by Chandler and Diamante, while Pajaro consistently showed the lowest N status.

This finding may be useful information for growers in terms of N fertility management. For example, Chandler and Diamante are likely to require more N than Seascape and Aromas, to obtain a similar N status; hence, probably a similar fruit yield. However it should be noted that the N response curve of each cultivar might be different as well (Hochmuth et al., 1996; Voth et al., 1967).

Correlation between T-N in Leaf Blade and Total Fruit Yield
Further, in this particular case, the total fruit yield was highly correlated with the N status across cultivars, especially with the T-N in leaf blades in the early flowering stage. The interpretation of the result, however, requires a careful consideration on the following factors: the fruit yield level, N application rate, and the effect of N status on fruit yield.

A typical fruit yield of organic strawberries in this area is ~1,000 grams/plant of total fruit for 6-7 months of harvest (Bolda et al., 2003). Compared to that level, the fruit yield in this experiment was low even for Aromas in Salinas (~300 grams/plant), though with a shorter harvest period (4 months. fig. 1).

Total N application rate in this experiment was ~300 lbs/A (table 4), and mostly from compost that is slowly mineralized, where a typical grower applies a similar amount of total N but a 1/3 of total N is from relatively soluble organic fertilizers (i.e. blood meal, liquid organic fertilizers) (table 7). From a N fertility perspective, therefore, this experiment can be seen as N performance of commercial strawberry cultivars under “compost-based (low-mineral N)” organic production.

Indeed, as seen in fig. 3, if we adopt the tentative critical level of T-N 2.8 % (Ulrich et al., 1980), all cultivars were under the critical level in May and July in both fields. In light of the low fruit yield, it seems reasonable to say that all cultivars were N deficient since sometime after March.

Table 7. An Example of Nitrogen Application Rate for Organic Strawberries on the Central Coastal California.

Fertilizer	Application rate	N %	N application rate lbs-N/A	
Pre-plant				
Compost	10 tons/A	1		220
Blood meal	500 lbs/A	13		65
			Total:	285
Supplemental				
Phytamin 800*	5 gallons/A x 7 times	7		24
Fish emulsion*	5 gallons/A x 7 times	6		20
			Total:	44
			Grand total:	330

* 9.75 lbs/gallon.

Application methods: Compost: Broadcast immediately after incorporating the cover crop or cash crop, but before subsoiling, leveling, and disking. Blood meal: Pre-planted in the bed using a fertilizer drill with a bed shaper. Phytamin 800 & fish emulsion: Fertigation during Feb. to Sep. (5 gallons/A each time at every other week. A total of ~ 7 times). Adopted from Bolda et al. (2003).

The highly positive correlation between N status in the early flowering stage and total fruit yield then might be interpreted as the following: under the low-mineral N condition particularly during the harvest period, the N status in the early flowering stage was crucial in determining total fruit yield.

Even in the early reproductive stage where N uptake by the plants are rather low (Muramoto, 2003), an appropriate amount of N is needed to stimulate bud formation (May and Pritts, 1990). In addition, the sooner the N deficiency appears, the more difficult to recover even by supplemental N applications in later stages (Ulrich et al., 1980). Though supplemental N was applied from the end of June for three weeks in the Salinas field, and although the leaf N status especially T-N in Aromas and Seascape responded to the supplemental N application (fig. 3), it was too late to increase the total fruit yield by the end of the season.

T-N in Leaf Blade as a Better Choice for Organic Strawberries

We also found T-N in leaf blades to be more consistent across fields than NO_3-N in petioles in terms of correlation with the total fruit yield (fig. 6). In addition, though the correlation between T-N in leaf blades and NO_3-N in petioles were highly significant (fig. 4), the residuals seem too large to use NO_3-N to predict T-N (fig. 5). Therefore, it appears that T-N in leaf blades may provide a better indicator for N status in organic strawberries. The difference between fields might be caused by difference in soil N dynamics and/or in other environmental factors' effects on plants (i.e. temperature, irrigation regime) between the two fields.

Smith reported that NO_3-N content in fresh sap of the root tissue of organic onions was significantly lower than for conventional even though there were no significant difference between their yields (Smith and Miller, 1996). As part of the Sustainable Farming System

Experiment conducted at UC Davis (Shennan, unpublished data), processing tomatoes receiving either organic input alone, or in conjunction with supplemental fertilizer, both showed petiole NO_3-N levels below those under conventional fertilizer management, even when yields were similar. In both cases, T-N contents appeared to better correlate with crop yield than NO_3-N contents. There is some evidence showing higher availability of ammonium versus NO_3-N in organic systems, which would be consistent with tissue NO_3-N underestimating plant N status (Drinkwater et al., 1995).

Table 8 summarized historical critical levels for N in strawberries developed for annual hill cultural systems in the US. Interestingly, while cultivars have been constantly changing, critical levels of T-N in leaf blades (or, whole leaves) in early flowering stage (or, any stage) have always been 2.5-3%.

Table 8. Interpretational Values for Leaf Total Nitrogen in Strawberries (Annual Hill Systems)

Plant part sampled*	Time of sampling	Low N%	High N%	Site	Reference
Blade	Not specified	< ~3.0		California	Voth, et al. (1967)
Blade	Not specified	< 2.8		California	Ulrich, et al. (1980)
Blade + petiole	At flowering	< 2.5	4.0 <	Not specified	Jones, et al. (1991)
Blade + petiole	Transplants	< 2.8	3.5 <	Florida	Hochmuth, et al. (1991)
	Initial flower	< 3.0	4.0 <		
	Initial harvest	< 3.0	3.5 <		
	Mid season	< 2.8	3.0 <		
	End of season	< 2.5	3.0 <		

* Young matured leaf or most recently matured leaf.

It also should be noted that some critical levels specify the growth stage to be sampled, while none of Californian guideline do. Many studies (Hochmuth et al., 1996; Locascio and Martin, 1985; Voth et al., 1961) and local growers (Schmida, personal communication) observed a high N content in leaves in the early growth stage and a lower N status during the harvesting stage. Thus, it is important to specify growth stage for sampling in developing critical N levels.

Though further trials are needed, given the discussion above and the correlation in fig. 6, a critical level of T-N in leaf blades in organic strawberries is considered to be approximately 3% in the early flowering stage.

The tentative critical level developed by Ulrich et al. (1980) does not specify time to be sampled. Moreover the tentative critical level of 500 mg/kg NO_3-N in petioles appears to be too low and misleading. 2800 mg/kg NO_3-N in petioles (University of California Integrated Pest Management Program, 1994) seems more reasonable from the regression (fig. 4), but for organic strawberries, as discussed, T-N in leaf blade might be a better choice.

T-P in Leaf Blades and Mycorrhizae Application

Studies reported nutritional benefits especially P from mycorrhizal applications to strawberries (Dunne and Fitter, 1989; Hughes et al., 1978). However, we did not find any significant effect of mycorrhizae application on the P status in strawberry leaves and on fruit yield in this experiment. In light of T-P content in leaves (fig. 7) and soil Olsen P level of fields (table 2), it seems that high P fertility of the field soils provided sufficient P to strawberries, by which a role of mycorrhizae might be diminished (Mader et al., 2000). In general, the longer the history of organic farming, the higher the available P in soils. This is especially true at the farms that applied manure-based composts (Muramoto, unpublished data). This may restrict effective use of mycorrhizae amendments in organic farms unless inoculum is applied in small plant cells in nurseries (Khanizadeh et al., 1995).

Future Studies
Typical organic strawberry growers apply significant amount of commercial organic fertilizers that are more soluble in form (table 7). Such practice has been criticized as “high input organic agriculture” that may not convey environmental benefits that usual organic farming provides (Appropriate Technology Transfer for Rural Areas (ATTRA), 2003).

Therefore, future studies should demonstrate 1) sufficient leaf blade T-N level of organic strawberries, 2) improved nitrogen use efficiency in organic strawberry production, and 3) environmental impact of organic strawberry production. Field trials that evaluate impacts of diverse N rates and N sources on the plant N status, the soil N status (incl. N leaching potential), the fruit yield, and their interactions in organic strawberry production are needed.

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References:

Appropriate Technology Transfer for Rural Areas (ATTRA) (2003). High-input organic agriculture. Vol. 2003.

Bolda, M., Tourte, L., Klonsky, K., and Bervejillo, J. E. (2003). "Sample costs to produce organic strawberries: Central coast, Santa Cruz and Monterey Counties," University of California Cooperative Extension http://www.agecon.ucdavis.edu/outreach/crop/cost-studies/StrawbOrgCC03.pdf.

Drinkwater, L. E., Letourneau, D. K., Workneh, F., van Bruggen, A. H. C., and Shennan, C. (1995). Fundamental differences in organic and conventional agroecosystems in California. *Ecological Applications* **5**, 1098-1112.
Dunne, M. J., and Fitter, A. H. (1989). The phosphorus budget of a field-grown strawberry (*Fragaria ananassa* cultivar Hapil) crop: Evidence for a mycorrhizal contribution. *Annals of Applied Biology* **114**, 185-194.
Hochmuth, G. J., Albregts, E. E., Chandler, C. C., Cornell, J., and Harrison, J. (1996). Nitrogen fertigation requirements of drip-irrigated strawberries. *Journal of the American Society for Horticultural Science* **121**, 660-665.
Hochmuth, G. J., Maynard, D., Vavrina, C., and Hanlon, E. (1991). "Plant Tissue Analysis and Interpretation for Vegetable Crops in Florida," Florida Cooperative Extension Service Special Series, SSVEC-42.
Hughes, M., Martin, L. W., and Breen, P. J. (1978). Mycorrhizal Influence on the Nutrition of Strawberries. *Journal of American Society for Horticultural Science* **103**, 179-181.
Johanson, F. D., and Walker, R. B. (1963). Nutrient Deficiencies and Foliar Composition of Strawberries. *Proc. Amer. Soc. Hort. Sci.* **83**, 431-439.
Jones, J. B., Wolf, B., and Mills, H. A. (1991). "Plant analysis handbook : a practical sampling, preparation, analysis and interpretation guide," Micro-Macro, Athens, GA.
Khanizadeh, S., Hamel, C., Kianmehr, H., Buszard, D., and Smith, D. L. (1995). Effect of three vesicular-arbuscular Mycorrhizae species and phosphorus on reproductive and vegetative growth of three strawberry cultivars. *Journal of Plant Nutrition* **18**, 1073-1079.
Klonsky, K. (2003). Growth of the Organic Strawberry Industry. *In* "Organic Strawberry Production: A Short Course 2003". University of California Sustainable Agriculture Research and Education Program (UC-SAREP), Davis, CA.
Larson, K. D., and Shaw, D. V. (1995). Relative performance of strawberry genotypes on fumigated and nonfumigated soils. *Journal of the American Society for Horticultural Science* **120**, 274-277.
Locascio, S. J., and Martin, F. G. (1985). Nitrogen Source and Application Timing for Trickle Irrigated Strawberries *Fragaria-Ananassa*. *Journal of the American Society for Horticultural Science* **110**, 820-823.
Mader, P., Edenhofer, S., Boller, T., Wiemken, A., and Niggli, U. (2000). Arbuscular mycorrhizae in a long-term field trial comparing low-input (organic, biological) and high-input (conventional) farming systems in a crop rotation. *Biology and Fertility of Soils* **31**, 150-156.
May, G., and Pritts, M. (1990). Strawberry nutrition. *Advances in Strawberry Production* **9**, 10-24.
Miner, G. S., Poling, E. B., Carroll, D. E., Nelson, L. A., and Campbell, C. R. (1997). Influence of Fall Nitrogen and Spring Nitrogen-Potassium Application on Yield and Fruit Quality of 'Chandler' Strawberry. *Journal of the American Society for Horticultural Science* **122**, 290-295.
Muramoto, J. (2003). Nitrogen Management in Organic Strawberries. *In* "Organic Strawberry Production: A Short Course". University of California Sustainable Agriculture Research and Education Program (UC-SAREP), Davis, CA.
Palisade Corporation (1997). "User's Guide BestFit," Palisade Corporation, Newfield, NY.

Pritts, M., and Handley, D., eds. (1998). "Strawberry Production Guide for the Northeast, Midwest, and Eastern Canada," pp. 1-162. Natural Resouce, Agriculture, and Engineering Service (NRAES), Ithaca, New York, 14853-5701, USA.

Smith, R., and Miller, R. O. (1996). "Nitrogen fertility monitoring in organic and conventional vegetable systems." SAREP grants final report.

Ulrich, A., Mostafa, M. A. E., and Allen, W. W. (1980). "Strawberry deficiency symptoms: A visual and plant analysis guide to fertilization," Agricultural Experiment Station, University of California, Division of Agriculture and Natural Resources, Oakland, CA.

University of California Integrated Pest Management Program (1994). "Integrated pest management for strawberries," University of California Division of Agriculture and Natural Resources, Oakland, Calif.

Voth, V., Proebsting, E. L., Sr., and Bringhurst, R. S. (1961). Response of Strawberries to Nitrogen in Southern California. *Proc. Amer. Soc. Hort. Sci.* **78**, 270-274.

Voth, V., Uriu, K., and Brihghurst, R. S. (1967). Effect of High Nitrogen Applications on Yield, Earliness, Fruit Quality, and Leaf Composition of California Strawberries. *Journal of the American Society for Horticultural Science* **91**, 249-256.