Final report
Project title: Detecting and correcting soil calcium limitations

Project leaders: T.K. Hartz
Department of Plant Sciences
University of California
Davis, CA 95616
(530) 752-1738 phone
(530 752-9659 fax
tkhartz@ucdavis.edu

Richard Smith and Mike Cahn
UC Cooperative Extension
1432 Abbott St.
Salinas, CA 93901
(831) 759-7350
rifsmith@ucdavis.edu
mdcahn@ucdavis.edu

Executive summary:

A variety of experiments were conducted in 2005-06 to clarify issues regarding calcium availability in California soils, and the agronomic value of calcium fertigation on vegetable crops. A set of 23 representative agricultural soils was collected from fields in vegetable rotations in the Sacramento, Salinas, San Joaquin and Santa Maria Valleys. These soils were evaluated for calcium availability by two common laboratory techniques, ammonium acetate extraction and saturated paste extraction. To simulate the calcium concentration in actual soil solution, samples of all soils at field capacity moisture content were subjected to high-speed centrifugation, with the extracted soil solution analyzed for cation content. A greenhouse experiment evaluated lettuce Ca uptake from 15 of these soils; the study confirmed that soil solution Ca was the most accurate measure of Ca availability, followed by saturated paste extraction; exchangeable Ca was a poor measure of soil Ca availability. Saturated paste Ca was well correlated with soil solution Ca, and is the preferred method of analysis for routine soil testing (centrifugation is a research technique, not well suited to routine use by commercial laboratories). Soil calcium availability was generally high, ranging from 5-80 meq/liter (100-1,600 PPM) in soil solution; across soils, soluble Ca averaged 33 meq/liter (660 PPM), which represented 55% of cation milliequivalents. This level of Ca availability should provide adequate plant nutrition.

The role of soil Ca availability in the development of tipburn in romaine lettuce was evaluated by surveying 15 commercial fields in the Salinas Valley. At harvest, plants were rated for the severity of tipburn on inner leaves (those most prone to the disorder); samples of inner leaves were analyzed for Ca concentration. Soil samples were analyzed for available Ca by saturated paste extraction. Three fields showed a significant level of tipburn. There was no

correlation among tipburn severity, inner leaf Ca concentration and soil Ca availability, suggesting that factors other than Ca availability controlled tipburn development. Restricted crop transpiration appeared to be one of those factors; two of the three fields with tipburn encountered extremely low evapotranspiration conditions in the week before harvest due to fog off the ocean.

A total of 5 field trials (3 on romaine lettuce, one on cantaloupe and one on honeydew) were conducted to determine the effects of fertigation of soluble calcium fertilizers [calcium nitrate (CN), calcium thiosulfate (CATS) and calcium chloride (CC)] through drip irrigation on crop yield, quality and Ca status. One to three fertigations were applied, at seasonal rates up to 30 lb Ca/acre. Calcium fertigation had no effect on lettuce yield or Ca concentration of inner leaves; tipburn was present in only one field, and Ca fertigation had no effect on tipburn severity. Similarly, Ca fertigation did not influence melon yield, fruit firmness (at harvest or after cold storage), or flesh Ca concentration.

The effect of calcium enrichment of irrigation water on water movement through soils was investigated. In a laboratory assay the effect of adding 10 meq Ca/liter (200 PPM) to water on the rate of capillary water movement through three soils of varying Ca/Mg ratios was determined. In a field trial the effect of fertigation with CN, CATS or CC on root zone water distribution was investigated. In neither experiment did Ca enrichment of irrigation water modify water movement in soil.

Introduction:

The issue of calcium availability and activity in alkaline mineral soil has long been a matter of contention. Based on the most common soil test method (ammonium acetate extraction) most California soils are well supplied with Ca. However, in alkaline soils, a substantial percentage of 'exchangeable' calcium identified by this test can be in chemical forms not readily available to plants or active in soil solution. Vegetable growers use significant quantities of calcium-based materials, both for direct effects on crop nutrition, and for improving soil structure and water infiltration. Calcium-related physiological disorders affect many vegetables, including tomato, lettuce, celery, pepper, and melon. Even in the absence of a specific physiological disorder, growers may use calcium fertilizers and amendments to improve product quality, or to improve soil structure and water infiltration characteristics. Unfortunately, there has been relatively little documented research comparing the effectiveness of soil-applied soluble calcium products under California field conditions, particularly when applied through drip irrigation. This project was undertaken to expand knowledge in this area.

Objectives:

a) develop information on calcium availability in representative California soils to improve soil testing and interpretation

b) compare the efficacy of soil-applied calcium products on vegetable crop nutrition and soil water infiltration characteristics

Materials and Methods:

Characterization of soil calcium status:

A set of 23 representative agricultural soils was collected from fields in vegetable rotations in the Sacramento, Salinas, San Joaquin and Santa Maria Valleys. These soils were chosen to represent a range of texture and soil Ca status. Samples (top foot of soil) were air-dried, sieved through a 10 mesh screen, and subjected to the following extraction procedures:

1) ammonium acetate extraction
2) saturated paste extraction
3) centrifugation to recover soil solution

The first two methods are standard laboratory techniques. In the centrifugation method soil was wetted with deionized water to field capacity (defined as the gravimetric water content of soil at 20 centibars tension), allowed to equilibrate overnight, then spun at 2,000 rpm (equivalent to a force approximately 800 times the force of gravity, *g*). In all cases Ca, Mg, K and Na concentrations were determined using atomic emission spectrometry.

To determine the validity of these soil test methods in estimating plant-available soil Ca a greenhouse assay was performed using 15 of these soils. The soils were packed into 0.8 inch deep, 5 inch wide horizontal trays placed over reservoirs of a nutrient solution containing 100 PPM N, 30 PPM P and 95 PPM K. The soils were in contact with capillary matting, which extended into the reservoirs; the matting wicked solution from the reservoirs into the soil. A set height differential between the reservoir solution level and the bottom of the soil tray was maintained to keep soil moisture near field capacity.

Seed of 'Green towers' romaine lettuce were germinated in rock wool cubes, then placed in 4" x 4" pots in which the bottoms had been replaced with a layer of thin, 400 mesh nylon fabric. The pots were placed on the wetted soil in the trays on September 31, 2005. The pores of the nylon fabric were sufficiently small to prevent roots from penetrating into the soil, while allowing the penetration of root hairs, effectively creating a two-dimensional root interface. This approach was used to minimize the effects of differences in soil texture and structure that could affect rooting density and cation uptake.

The greenhouse was maintained at 75 / 64 ^{o}F day/night regime. The experiment was arranged in a randomized complete block design with 4 replicate trays of each field soil, and one lettuce plant per tray, for a total of 60 plants. Lettuce plants were harvested on November 11. Whole plants (excluding roots) were oven-dried, ground to pass a 20 mesh screen, and analyzed for cation (Ca, Mg, K, and Na) concentration.

Lettuce tipburn survey:

A total of 15 commercial fields of romaine lettuce were sampled in 2005-06 to document the relationships among weather conditions, soil Ca status, leaf Ca concentration and tipburn severity. Soil samples (top foot) were analyzed for Ca availability by saturated paste extraction. At commercial maturity 24 plants per field were evaluated for tipburn severity, rated as the number of affected leaves per plant. Inner leaves (those expanding over the final week of growth and most likely to show tipburn) were oven-dried, ground and analyzed for Ca concentration.

Environmental conditions that affect the rate of crop transpiration have been linked by other researchers to tipburn development. To evaluate if weather was a significant factor, for all survey fields daily air temperature and reference evapotranspiration (ET_o) were obtained from the nearest CIMIS weather station for the final 2 weeks of growth. A transpiration index was calculated by dividing daily ET_o (in mm) by the number of growing degree days (DD, calculated using 86^{o}F and 41^{o}F as upper and lower temperature thresholds). This index estimated crop transpiration per unit of growth potential.

Calcium fertigation effects on lettuce and melons:

Two field trials were conducted in the Salinas Valley in 2005 and another in 2006 to document the effects of calcium fertigation on romaine lettuce growth, inner leaf Ca concentration and tipburn severity. Cultural details are given in Table 1. In the 2005 trials three Ca fertilizers [calcium nitrate (CN), calcium thiosulfate (CATS) and calcium chloride (CC)] were injected into surface drip systems twice, approximately 2 and 1 week before harvest. Injections were made over approximately 4 hours at a concentration of 300 PPM Ca (15 meq/liter), delivering 15 lb Ca/acre in each application. In the 2006 trial two calcium fertilizers (CN and CATS) were injected in a single application 1 week before harvest. Application rate was 25 lb Ca/acre, injected at a concentration of approximately 450 PPM Ca. In all trials these Ca fertigation treatments were compared to a control treatment not receiving Ca fertigation. A randomized complete block experimental design was used in all trials, with 5 single-bed replicates 400 ft long.

The percent of plants considered marketable was determined by taking plant counts before and after the commercial harvest. Just prior to commercial harvest 32 random plants per plot were evaluated for total and marketable weight. Tipburn was rated on 16 plants per plot by scoring the number of inner leaves (those that had expanded during the time period of the Ca applications) with tipburn symptoms. Samples of inner leaves were oven-dried, ground and analyzed for Ca concentration. In both 2005 trials 8 trimmed heads per plot were taken to UC Davis and stored for 5 days at high humidity at 86^oF (prior research had reported that high temperature postharvest storage induced tipburn). High temperature storage did not induce or enhance tipburn in either trial, and was not done for the 2006 trial.

Two drip-irrigated field trials were conducted to evaluate the effects of fertigated calcium on the yield and quality of melons. In 2005 a honeydew trial was conducted at UC Davis, and in 2006 a cantaloupe trial was conducted at the UC Westside Research and Extension Center in Fresno County. Cultural details of both trials are given in Table 2. In 2005 three calcium fertilizer treatments (CN, CATS and CC) were compared to a control treatment receiving no Ca application. An additional Ca treatment, the incorporation of two tons of gypsum/acre the previous fall, was also included. The Ca fertilizers were applied through the drip system in 3 weekly applications beginning 30 days before harvest (during early fruit development). Fertigation rate was 10 lb Ca/acre per application, at a concentration of approximately 200 PPM Ca. Experimental design was randomized complete block, with 5 replications; each plot consisted of a single 100 ft long bed. The standard 'Green Flesh' open-pollinated variety was used. Fruit were harvested and sized on 25 Aug., and 16 fruit per plot of commercial sizes 6 and 8 (fruit count per 30 lb net weight carton) of equivalent maturity were selected for quality evaluation. Eight fruit per plot were evaluated the day following harvest for flesh firmness (by mechanical firmness tester) and soluble solids concentration (SSC, by refractometer). Samples of the edible flesh were oven-dried, ground and analyzed for Ca concentration. The remaining fruit were evaluated for firmness and SSC after 2 weeks of storage at 45 ^oF.

In the 2006 trial the hybrid cantaloupe cultivar 'Oro Rico' was used. Three calcium fertigation treatments were evaluated:

- applications of CC 20 and 13 days before harvest initiation
- applications of CC 13 and 6 days before harvest initiation
- applications of CATS 20 and 13 days before harvest initiation

Each application delivered 15 lb Ca/acre at a concentration of approximately 400 PPM Ca. Experimental design was randomized complete block, with four 75 ft long single row plots per treatment. Fruit were harvested at 'full slip' (fruit separating cleanly from the vine with minimal pressure) from 12-24 July, and melons were graded by condition and size; the traditional commercial sizes 18, 15, 12, and 9 (fruit count per 40 lb net weight carton) were considered marketable. Twelve fruit per plot of sizes 12 and 15 harvested on 14 July were selected for quality evaluation. Fruit firmness and SSC were measured as previously described for the 2005 experiment; half of the fruit were evaluated on 14 July, the other half after 7 days of storage at 39^{o}F.

Effect of Ca fertigation on capillary water movement in soil:

A laboratory assay was conducted to determine whether the application of Ca to irrigation water affected the rate of capillary wetting of soil. Three of the soils from the Ca characterization study were selected, chosen to represent low, medium and high soil solution Ca/Mg ratio (0.5, 2.1 and 3.4 Ca/Mg ration for soils 1, 2 and 3, respectively); Ca/Mg ratio is one indicator of soil structure. Air-dried, screened soil was packed into 1" by 1" by 8" long trays at a bulk density approximating that in a typical seedbed in the field. Capillary matting was used to wick water from a solution reservoir into the soil at one end of the tray; a negative head of 6 cm (2.5 inches) was maintained between the soil and the solution reservoir. The time required to wet the entire column was recorded. Three solutions were compared: tap water, and tap water augmented by 200 PPM (10 meq) Ca from either CN or CATS. There were 3 replicate trays per solution per soil.

An additional evaluation of the effect of calcium fertigation on soil wetting patterns was conducted in the second romaine Ca fertigation trial of 2005. One day after the final calcium fertigation the soil volumetric water content of the top 6 inches of soil was measured using a time-domain reflectometry probe. Measurements were made 2, 4, 6, 8 and 10 inches away from the drip tape in 4 replicate plots of the control (no Ca ferigation), CN, CATS and CC treatments. Four measurements were taken for each distance from the tape in each plot, a total of 20 measurements per plot.

Results:

Characterization of soil calcium status:

The soils used to compare analytical techniques for characterizing soil Ca status varied in texture from sandy loam to clay, and in pH from 6.7-7.8. These soils generally had high Ca availability, with soil solution Ca ranging from 5-80 meq/liter, representing 29-71 % of cation milliequivalents (meq). To put these results in context, consider hydroponic solutions used in greenhouse vegetable production. These solutions typically range between 4-8 meq Ca/liter, and comprise 30-50% of total cation meq. Since hydroponic solutions are formulated to provide optimal nutrient balance, one could infer that most California soils contain ample available Ca to provide adequate crop nutrition.

Soil solution collection by centrifugation is not a practical test for commercial laboratories to routinely perform. Using soil solution as the standard of accuracy, saturated paste extraction provided a much more accurate estimate of soil Ca status than did ammonium acetate extraction (Fig. 1a); in fact, on the basis of meq extracted, there was no significant correlation between soil solution Ca and ammonium acetate exchangeable Ca. In general, it takes approximately twice the field capacity water content to prepare a saturated paste extract; therefore, if the techniques were removing equivalent amounts of Ca, the Ca concentration in a saturated paste extract should be approximately half that in soil solution. In fact, on average the saturated paste extracts contained only 20% of the Ca concentration in soil solution (the regression slope = 0.20). This means that to estimate Ca concentration in actual soil solution one would have to multiply the saturated paste Ca concentration by 5. This disparity was only significant for the divalent cations (Ca and Mg); for the monovalent cations (K and Na) the concentration in saturated paste extracts was close to that in soil solution, after adjusting for the difference in water volume used.

When expressed as a percentage of cation milliequivalents in the extract, Ca removed by both extraction techniques was correlated to soil solution Ca, with the saturated paste correlation much stronger (Fig. 1b). Ammonium acetate extraction overestimated soil solution Ca (regression slope = 1.31), while saturated paste extraction marginally underestimated it (regression slope = 0.84). There was a nearly perfect relationship between the Ca/Mg ratio in soil solution and that in saturated paste extracts (Fig. 1c). Across the wide range of Ca/Mg ratios in this group of soils the correlation between ammonium acetate exchangeable Ca/Mg ratio and that in soil solution was reasonably strong (r^2 = 0.70); however, within the range of the majority of soils (soil solution Ca/Mg ratio between 1.5 and 3.5) these techniques were poorly correlated. It is also important to note that on average exchangeable Ca/Mg ratio was nearly twice as high as the soil solution ratio (regression slope = 1.76), while the saturated paste Ca/Mg was very near soil solution values (regression slope = 0.93).

Results of the greenhouse lettuce bioassay confirmed that soil Ca availability was best predicted by soil solution Ca, with exchangeable Ca of only marginal value. Both soil solution Ca and saturated paste Ca (expressed as % of cation meq) were significantly correlated with lettuce whole plant Ca concentration (r^2 = 0.51 and 0.40, respectively); the correlation of exchangeable Ca and lettuce Ca concentration was not statistically significant. When lettuce Ca concentration was expressed as a % of all cations in the plant tissue (meq basis), all soil extraction procedures were positively correlated (r^2 = 0.75, 0.63, 0.35 for soil solution, saturated paste and exchangeable, respectively, Fig. 2).

Lettuce tipburn survey

In the romaine fields surveyed, the percent of plants with at least one leaf showing tipburn ranged from 0-88%, while tipburn severity, defined as the mean number of affected leaves per plant, ranged from 0-2.8. There were no apparent relationships among soil Ca availability, inner leaf Ca concentration and tipburn severity (Fig. 3 a-c); in fact, the field with the most severe tipburn had both the highest saturated paste soil Ca and the highest leaf Ca concentration, suggesting that factors other than soil Ca availability governed tipburn development. Limited transpiration may have been such a factor. Two of the 3 fields with significant tipburn had the lowest transpiration indices over the final two weeks of growth (Fig. 3d). These two fields, located several miles apart near Castroville, were both harvested 27 July, 2005. Persistent marine fog from 9 to 6 days before harvest resulted in an extremely limited transpiration index over that period (Fig. 4).

Calcium fertigation effects on lettuce and melons:

All three fields produced well, as reflected by the high percentage of plants harvested by the commercial crews (Table 3). Applying calcium fertilizers through surface drip irrigation had no measurable effect on romaine yield or Ca concentration in the inner leaves of the head. No tipburn was observed in any treatment in the first or third trial; a low level of tipburn was detected in the second trial, but Ca fertigation did not reduce it.

Melon yield was high in both trials, and unaffected by calcium treatment (Table 4). Fruit soluble solids concentration was within an acceptable range for all treatments, with no significant treatment effects. Honeydew firmness in the 2005 trial was greater than cantaloupe firmness in the 2006 trial, reflective of the fact that the cantaloupe were more mature at harvest ['slip' stage for the cantaloupe compared to maturity stage 2 ('mature, ripening') for the honeydew]. As expected, flesh firmness declined in storage for both melon types. However, calcium treatment had no effect on flesh firmness, either at harvest of after storage. Similarly, flesh Ca concentration was unaffected by calcium treatment. The very low honeydew flesh Ca concentrations in the 2005 trial appeared to reflect the more limited soil Ca availability at that site (only 24% of saturated paste cations, meq basis). The soil at the 2006 trial site had more bioavailable Ca (40% of saturated paste cations), and the fruit Ca concentration was correspondingly higher. In neither trial was 'glassiness' (flesh breakdown commonly attributed to low tissue Ca) observed, either at harvest or after storage.

Effect of Ca fertigation on capillary water movement in soil:

Ca application to irrigation water had little effect on water movement in soils. In the second 2005 lettuce fertigation trial there was no significant effect of calcium fertigation on the volumetric water content of the soil one day after the final calcium application, either in the entire width of the wetted zone (measured to 6 inch depth) or in the outer reaches of the wetted zone (Table 5). In the capillary wetting test in the laboratory, calcium addition to the water had no effect on the speed of capillary wetting in two of the three soils evaluated (Fig. 5). On the third soil the addition of calcium thiosulfate significantly increased the time required to wet the soil column; there was no clear explanation for this phenomenon. Across soils, wetting time decreased with increasing Ca/Mg ratio.

It is important to note that the effect of fertigated Ca on water movement in soils is a complex issue, and these initial efforts were by no means comprehensive investigations of this subject. Additional research is clearly needed on this point.

Discussion:

The general lack of effect of calcium enrichment of soil on crop Ca status or product quality can be explained by several factors. First and foremost, most mineral soils in California have high levels of Ca availability. The laboratory extraction techniques comparison showed high Ca concentrations in soil solution. Across these soils, broadly representative of those used for vegetable crop production in coastal and central California, soil solution Ca averaged 33 meq/liter (equivalent to 660 PPM), representing 55% of cation milliequivalents. Using the standard estimate of 4,000,000 lb dry soil/acre in the top foot, and a mean gravimetric water content of 25% at field capacity, these soils would average more than 600 lb Ca / acre in soil solution. Calcium fertilizers like CN or CATS are typically applied in relatively small amounts, usually less than 25 lb Ca / acre per application. In most California soils this represents a very small addition to the amount of soluble calcium already present in the soil.

Why then do calcium disorders like lettuce tipburn continue to occur? The problem is not lack of soil Ca, but rather the limitation on calcium movement in plants. Calcium moves only in the transpirational stream, and concentrates in tissues that transpire freely; it cannot be effectively redistributed from one plant part to another, as some other nutrients can. This is why calcium-related disorders occur on plant parts that have low transpiration rates, such as melon or tomato fruit (which have waxy skins) or inner leaves of lettuce (which are sheltered within the developing head). Even a temporary disruption in Ca supply to these rapidly growing tissues can cause problems. The lettuce tipburn survey showed that soil Ca availability was not an important factor in tipburn development; weather appeared to have a more profound effect.

There are situations in which soil calcium application can be agronomically useful. In very sandy soils, which have little cation exchange, calcium availability can be limited, particularly if the irrigation water used also has low Ca concentration. In these circumstances calcium fertigation may make sense. However, such conditions are relatively rare in California.

It is more common to find soils in which calcium represents an undesirably small percentage of soluble or exchangeable cations; this is particularly the case in the Sacramento Valley, where many soils have high soil Mg. In such soils, plant Ca uptake can be reduced through cation competition. However, to significantly increase Ca as a percentage of soluble cations can require large calcium applications. This is because cations in soil solution are in equilibrium with those on cation exchange sites; to substantially increase soluble Ca you must also increase Ca on the cation exchange. Since fields often have in excess of 5 tons of cations / acre on the cation exchange sites in the top foot of soil, large amounts of calcium are required to make a substantial change. Economics favor the application of less expensive amendments like gypsum or lime rather than more soluble but more expensive calcium fertilizers.

It is also the case that in large portions of the Central Valley irrigation water with low electrical conductivity (EC) removes calcium from the soil surface, causing crusting and slow water infiltration. Calcium application either to the soil surface or to the irrigation water can remedy this problem. For soil application a slowly soluble calcium product like gypsum is preferable to a more highly soluble one, both from an economic and efficacy standpoint. To increase the calcium concentration of irrigation water any Ca product can be used, the choice being based on both economics and ease of use.

Outreach activities:

The results of this project have been disseminated through a number of grower meetings and publications. In addition to a presentation at the FREP conference in Monterey in November, 2006, project results have been presented at grower meetings around the state. These events included:

- Five Points – 31 January and 30 November, 2006
- Woodland – 12 January, 2007
- Salinas – 20 February, 2007
- Gilroy – March 20, 2007

Newsletter articles summarizing project results have been submitted for publication in several venues:

- San Joaquin Valley Vegetable Notes
- Monterey County Crop Notes
- Vegetables West magazine

Additionally, a presentation was made to the UC Vegetable Crops Continuing Conference (16 January, 2007) to familiarize UC Farm Advisors statewide with this study. Activities for academic audiences beyond California include the presentation of a poster at the American Society of Agronomy annual meeting, and a manuscript has been submitted for publication in the journal HortScience.

Table 1. Summary of soil characteristics and crop management practices for the 2005 and 2006 calcium fertigation trials on romaine lettuce.

	Trial 1	Trial 2	Trial 3
Soil characteristics			
texture	sandy clay loam	sandy loam	sandy loam
pH	7.0	6.8	6.9
saturated paste Ca			
(meq/liter)	4.4	8.9	8.6
(% of cations, meq basis)	54	52	59
Cultivar	Harvest Gold	Harvest Gold	Sunbelt
Ca fertigation date(s)	22 July, 2 Aug.	22 Aug., 6 Sept.	14 Aug.
Harvest date	9 Aug., 2005	15 Sept., 2005	21 Aug., 2006

Table 2. Summary of soil characteristics and crop management practices for the 2005 and 2006 calcium fertigation trials on melons.

	2005 honeydew	2006 cantaloupe
Soil characteristics		
texture	silt loam	clay loam
pH	7.2	7.7
saturated paste Ca		
(meq/liter)	2.1	3.0
(% of cations, meq basis)	24	40
Cultivar	Greenflesh	Oro Rico
Ca fertigation date(s)	26 July, 2 and 9 Aug.	22 and 29 June, 6 July
Harvest initiation	25 Aug.	12 July

Table 3. Effects of calcium fertigation on romaine lettuce yield, inner leaf Ca concentration and tipburn severity.

Trial	Ca Treatment[z]	Mean plant wt. (lb)	Marketable plants (%)	Tipburn rating[y]	Leaf Ca (%)
1	no Ca	1.67	97	0	0.43
	CN	1.74	98	0	0.47
	CATS	1.74	97	0	0.46
	CC	1.76	98	0	0.44
		ns	ns	ns	ns
2	no Ca	1.85	98	0.3	0.37
	CN	1.87	98	0.4	0.41
	CATS	1.83	97	0.2	0.39
	CC	1.83	98	0.2	0.39
		ns	ns	ns	ns
3	no Ca	1.58	97	0	0.42
	CN	1.54	98	0	0.39
	CATS	1.52	95	0	0.43
		ns	ns	ns	ns

[ns] Ca treatments not significantly different at $p < 0.05$
[z] CN = calcium nitrate; CATS = calcium thiosulfate; CC = calcium chloride
[y] mean number of affected leaves per plant

Table 4. Effect of calcium fertigation on melon fruit yield, soluble solids concentration, flesh firmness and calcium concentration.

Trial	Ca Treatment[z]	Fruit yield (boxes/acre)	Soluble solids (°brix)	Flesh firmness (lbs) at harvest	Flesh firmness (lbs) after storage	Fruit Ca (% dry wt)
2005 honeydew	no Ca	1,362	11.5	9.2	6.6	.041
	gypsum	1,273	11.8	8.8	6.7	.038
	CN	1,279	12.0	8.5	7.3	.043
	CATS	1,234	11.8	8.7	6.3	.040
	CC	1,355	11.8	8.4	6.1	.040
		ns	ns	ns	ns	ns
2006 cantaloupe	no Ca	1,252	11.2	4.1	2.0	.070
	CATS	1,344	11.0	4.1	2.0	.075
	CC early	1,139	10.3	3.8	2.0	.093
	CC late	1,247	11.0	4.1	2.0	.080
		ns	ns	ns	ns	ns

[ns] Ca treatments not significantly different at $p < 0.05$
[z] CN = calcium nitrate; CATS = calcium thiosulfate; CC = calcium chloride

Table 5. Effect of calcium fertigation on soil volumetric water content (top 6 inches) one day after the final calcium application, second 2005 lettuce Ca fertigation trial.

	Soil volumetric water content (%)	
Calcium treatment	0-10 inches from drip tape	8-10 inches from drip tape
no calcium	18.9	18.6
calcium nitrate	19.2	18.4
calcium thiosulfate	18.4	18.5
calcium chloride	19.7	18.3
	ns	ns

^{ns} treatments not significantly different at $p < 0.05$

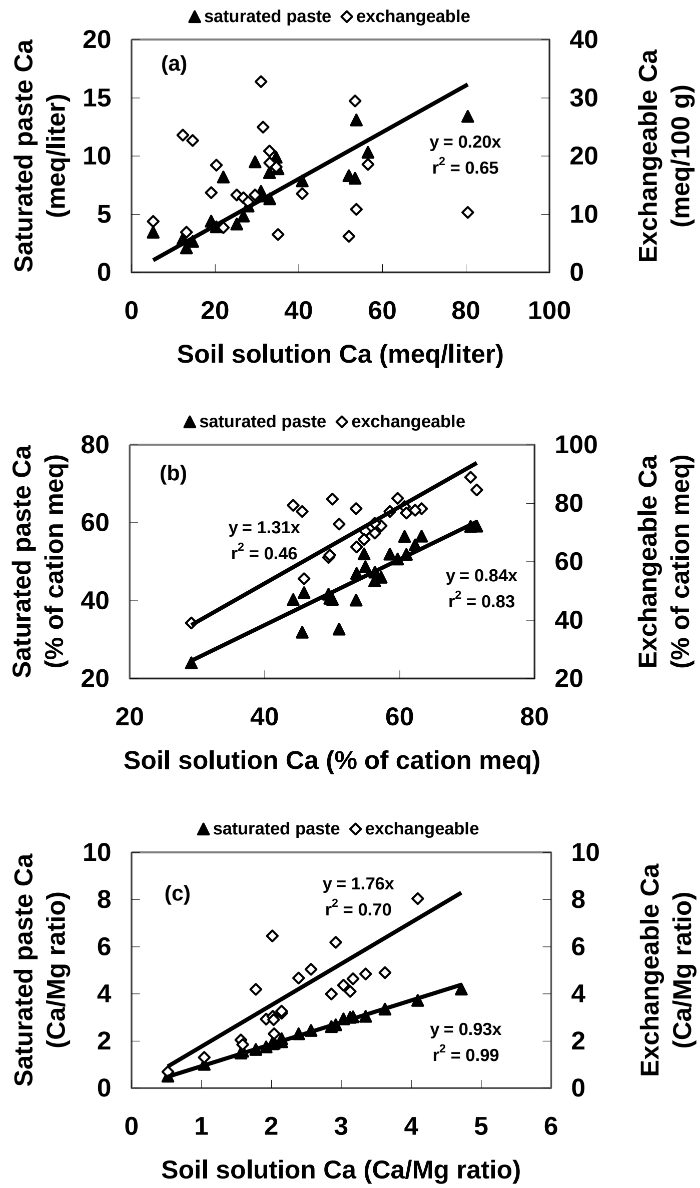

Fig. 1. Comparison of ammonium acetate and saturated paste extraction methods with soil solution extraction by centrifugation for estimating soil Ca status. Comparison made on the basis of meq extracted (a), Ca as a % of cations (b) and Ca/Mg ratio (c).

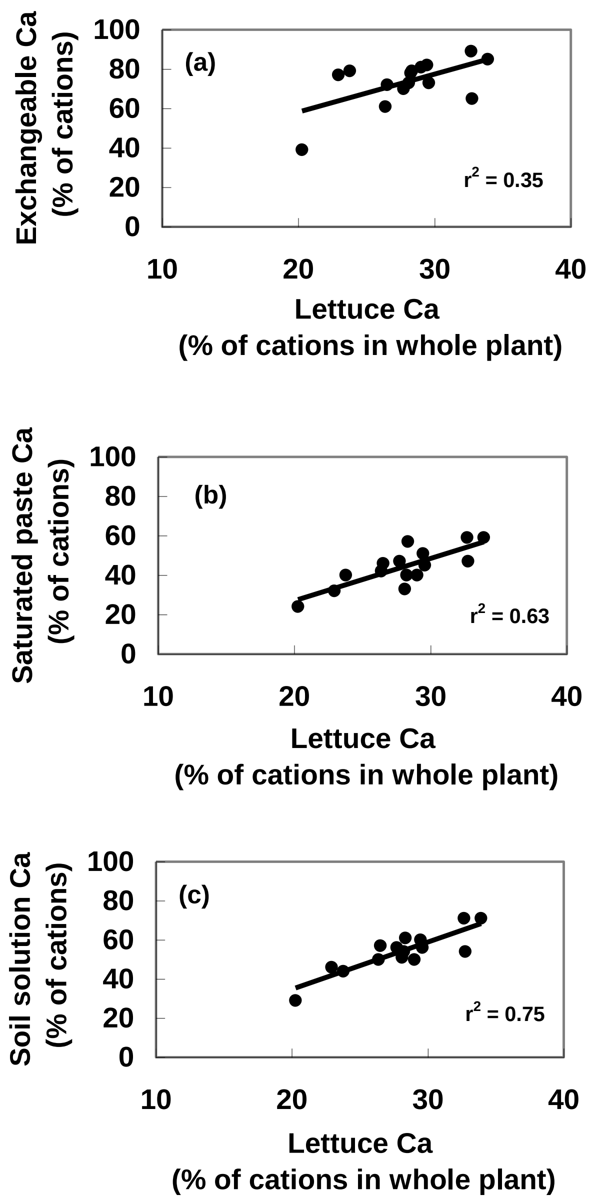

Fig. 2. Relationship between greenhouse-grown lettuce whole plant Ca content (expressed as % of cations in dry biomass, meq basis) and soil calcium status as estimated by ammonium acetate extraction (a), saturated paste extraction (b) or soil solution extraction by centrifugation (c).

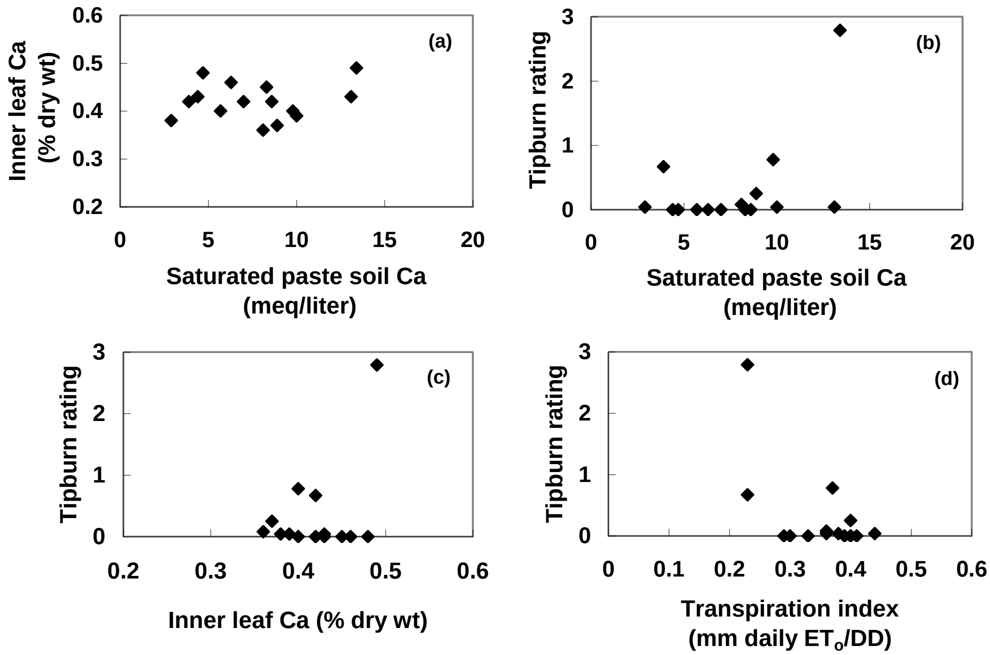

Fig. 3. Relationships among saturated paste soil Ca, inner leaf Ca concentration, average daily transpiration index over the final two weeks of growth, and tipburn rating in the tipburn survey fields; tipburn rating is mean number of affected leaves per plant.

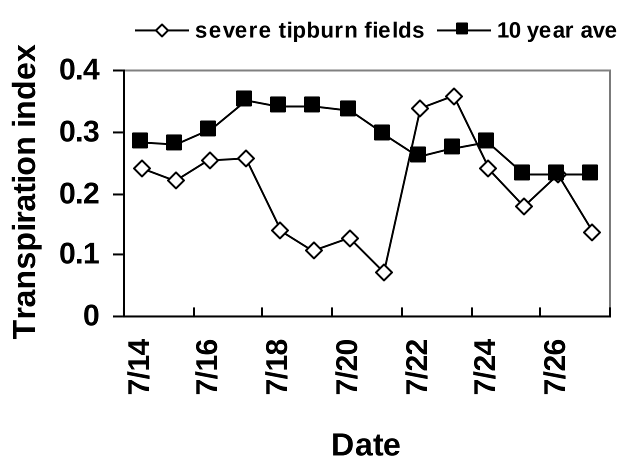

Fig. 4. Transpiration index (in mm ET_o / growing degree day) for Castroville, site of two survey fields with significant tipburn.

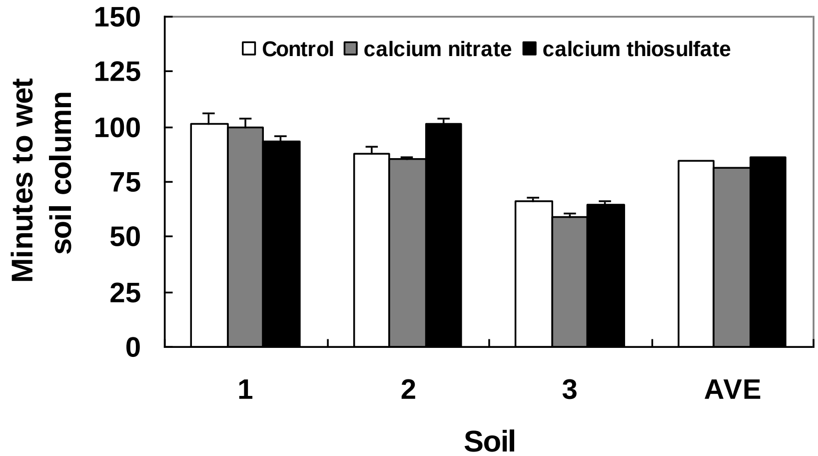

Fig. 5. Effect of calcium application to irrigation water on speed of capillary wetting of soil columns; data are means of three columns per field soil, bars are standard error of measurement.