ORGANIC FARMING RESEARCH FOUNDATION

Organic farming research project report submitted to the Organic Farming Research Foundation:

Project Title:

Maintaining nutrient balances in systems utilizing soluble organic fertilizers

FINAL PROJECT REPORT

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1. **Project Summary:** Three organic fertilizers, including 2 commercial mixes and a nutritionally balanced 'in-house blend', were compared to a conventional fertilizer for production of greenhouse tomatoes in containers. All fertilizers were applied to a peat/perlite substrate using a drip irrigation system. There were no differences between any of the treatments in the rate of plant development over the course of this experiment, but by the end of the experiment, plant vigor was excessive in one organic fertilizer treatment and low in another. Two of the three organic fertilizers tested had similar percentage of marketable fruit to the conventional fertilizer, but all had significantly lower yields than the conventional fertilizer. Our 'in-house blend', which most closely resembled the conventional fertilizer in N-P-K, had comparable vigor to conventionally grown plants and good pH and CEC characteristics. The nitrogen source (bloodmeal) had the disadvantage of being difficult to keep in solution, however, and lower yields compared to conventional may have been a result of initial difficulties in getting N into solution and associated emitter clogging. Substrate pH levels were lower than in our previous study (Miles, 2000), in which above-optimal pH levels were experienced in an organically fertilized substrate containing 15% vermicompost. This demonstrates the difficulty of predicting pH in organically fertilized container-grown plants. This work also demonstrates, as did our previous work (Miles, 2000), that for container-grown greenhouse tomatoes, best results are obtained with organic fertilizers when they are formulated to approximate the N-P-K values of conventional fertilizers.

2. **Introduction to Topic:** There are several possible approaches to developing organic fertilization regimes for container-grown greenhouse tomatoes, and to comparing these regimes to conventional fertilization practices. Three constraints in any approach are 1) the cropping period is long- up to 10 months from seeding to crop removal; 2) during this period they have an extremely high demand for nutrients as per plant fruit production can be as high as 40-50 lbs.(18-23 kg); 3) tomatoes are highly sensitive to the ratio between N and K, which regulates whether new growth occurs in vegetative tissue (shoots and leaves) or in the fruit and roots (generative growth). In conventional production, this ratio is carefully manipulated to balance the growth of the plant.

   In our earlier studies (Miles, 2000) we compared organic, conventional and biorational systems for producing greenhouse tomatoes over 5 growing seasons. The principle we applied was to try to optimize each system, while utilizing similar cultural practices to the extent possible. Conventionally fertilized and organically fertilized plants were kept in separate greenhouses, since different pest control practices were utilized.

   Substrates also differed. For conventionally fertilized tomatoes, we used the standard potting mix with a starter charge and wetting agent recommended for upright bag culture (Carpenter, 1982). For the organic substrates we had to design our own mix. No guidelines were available for organic fertilization of drip-irrigated greenhouse tomatoes or for organic production in containers. Our initial approach in the organic fertility treatments was to apply as much of the fertilizer as possible to the substrate, with the assumption that the nutrients would become available over time. Soluble fertilizers were

applied according to manufacturers' recommendations, which were very low (1 tablespoon/gal/month). This approach, however, resulted in alternating symptoms of nutrient stress, and salt stress, as additional fertilizers were top-dressed after the appearance of deficiency symptoms, as well as high initial EC and pH levels in the early experiments. After the first experiment, organic fertilizer additions through the drip system were increased so they approximated those in the conventional treatment. By the final experiment, pH had been reduced by substituting sulfur for limestone, and high initial EC and burning reduced by incorporating less bloodmeal, bonemeal and potassium sulfate into the substrate, but pH and initial EC levels were still higher than in the conventional system. By the final experiments, yields and % marketable were similar in conventional and organic systems. However, the formula developed for organic fertilization required the use of 5 separate ingredients from a commercial supplier, all of which were expensive, not available in large quantities, and complicated to mix (Photo 1). Clogging continued to be somewhat of a problem as well.

3. **Objectives Statement:**

The purpose of the present study was to simplify the previous experiments by utilizing the same substrate (peat:perlite), the same additions (low rates of limestone), the same greenhouse, and the same pest management practice (biological control with Encarsia) for all treatments. We also wanted to try several recently-OMRI certified materials which would potentially be easier to formulate, less expensive, and easier to apply with the drip system. Although two were recommended by their manufacturers as complete fertilizers, as far as we are aware, neither had previously been tested on tomatoes either in the field or in containers.

By simplifying the comparisons, we hoped to determine the best way to overcome problems with high salts and pH and otherwise optimize a container system for organic greenhouse tomato production. Another objective in using these two fertilizers was to compare plant performance both with the fertilizers previously used and with a new formulation made in-house with a combination of commercial and generic ingredients that potentially could be made inexpensively on-farm as well. All the ingredients in this in-house formulation would be allowable in the new national standards.

4. Materials and Methods: Greenhouse tomato plants (*Lycopersicon esculentum* Mill. 'Trust') were seeded Dec. 13, 2000 then transplanted Feb. 21 into soilless medium (Photo 2, mixing substrate) made of 70% Canadian sphagnum peat moss and 30% perlite to which dolomitic limestone was added at a rate of 3 lbs $\cdot$ yd^{-3} (1.82 kg $\cdot$ m^{-3}). Treatments consisted of one conventional fertilizer (CV), two commercially available, flowable, organic fertilizers: "Natural Organic-Grow" [(NOG) Jedward's International, Inc., Quincy, Mass.], analysis: 3-2-0.3 (3N-0.88P-0.25K), "Omega" [(OM) Peaceful Valley Farm Supply, Grass Valley, CA], analysis: 6-6-6 (6N-2.64P-4.98K), and "NCSU Blend" that was formulated from readily available, organically certifiable products (NCS). Materials used in NCS were blood meal: 14-0-0 (14N-0P-0K), Micro Phos: 0-2-0 (0N-0.88P-0K) (Peaceful Valley Farm Supply, Grass Valley, CA), and Maxicrop: 1-0.11-12 (1N-0.05P-10K) plus micronutrients (Maxicrop U.S.A., Inc., Arlington Hts., Ill.) The CV fertilizer was "Chem-Gro" fertilizer from HydroGardens (HydroGardens, Colorado

Springs, Colo.), supplemented with calcium nitrate [$Ca(NO_3)_2$], calcium chloride ($CaCl_2$), potassium nitrate (KNO_3), and $MgSO_4$. Fertilizer formulations are listed in Table 1. The commercial organic fertilizers, OM and NOG, were not amended, as they were recommended by the manufacturers as 'stand-alone' fertilizers. Rates of application of these two organic fertilizers were set to match the nitrogen (N) concentration of the CV fertilizer. Since NCS was comprised of various products, it could be formulated to match the NPK concentrations of the CV fertilizer. All fertilizers were applied through a drip irrigation system (Photo 3).

The experiment was conducted in one, 20 ft. (6.1 m) x 17 ft. (5.2 m) [340 sq. ft. (31.7 m^2)] greenhouse equipped with a Modine gas heater and vented by a two-speed fan. Cooling was achieved with an evaporative pad system. Plants were staked (Photo 4) when they were about 2 ft. (0.7 m) tall using twine suspended from overhead pipes. They were attached to the twine using 1 in. (2.54 cm) circular, plastic clips approximately every 1 ft. (0.3 m) to 1 1/2 ft. (0.46 m) of stem. Plants were topped after development of the sixth cluster. Suckers were pruned on a weekly basis or as necessary. Plants were pollinated every day between 11:00 am and 2:00 pm with a mechanical vibrator. Heating, cooling, and venting were controlled with thermostats. Fertigation was controlled by time clocks. Cards containing pupae of *Encarsia formosa* were added regularly for whitefly control.

Four fertilizer treatments were assigned in a randomized complete block design (RCBD) with four plants per treatment and four treatments in each of three blocks, for a total of 48 plants. Plant development rate was measured by examining the plants daily and recording the number of days from seeding to the appearance of the first fully reflexed flower on each of the first five clusters. Soil and tissue samples were submitted to the North Carolina Department of Agriculture, Agronomic Division (NCDA) for evaluation of nutrient content and media properties on 27 Feb 2001 and 23 March 2001, representing 1 week and 1 month after the beginning of treatments, respectively. Additional soil samples were taken after the end of the experiment (May 25, 2001). Tomatoes were harvested twice weekly. Harvest data were collected on all fruit from the first two clusters of each plant, and consisted of total yields per treatment, average weight of fruit per plant, weight per plant of No. 1 grade fruit (fruit weighing more than 70.0 g and without visible defects) , and incidence of visible defects such as blossom-end rot (BER), cracking (C), russeting (R), open locule (OL), small fruit (SF), anther scar (AS), and cat-facing (CF). Harvest dates were April 10, 18, and 24, May 1, 4, and 9, 2001. Data were analyzed by a simple analysis of variance (ANOVA) method using GLM (SAS Institute, Cary, N.C.).

5. Project Results:

a. Plant Development

1. Days to Flower and plant vigor: The number of days from seeding to the first fully reflexed flower of each cluster is shown in Figure 1. Fertilizer treatments did not result in any significant differences in the rate of tomato plant development ($p = 0.6603$). However, by the end of the experiment, vegetative growth was excessive in OM-fertilized plants, which displayed thick stems, dark green leaves, lush foliar

growth and poor fruitset. These plants were several feet taller than the plants in the other treatment. On the other hand, in NOG-fertilized plants, vigor was low, and plants showed signs of severe potassium deficiency (Photo 5) and no fruit set in the upper clusters. Harvests were discontinued after the second cluster because there was little or no fruit to harvest in the NOG and OM treatments. Plant vigor in NCS-fertilized plants was similar to that in the conventionally fertilized plants, although initial problems with solubilizing bloodmeal (Photo 6) may have slowed growth.

2. Nutrient Content of Tissue: Nutrient concentrations of tomato leaf tissue, collected 1 week (27-Feb) and one month (23-Mar) after the start of treatments are listed in Table 2. Specific treatment effects are described in Appendix 1. Only minor differences between treatments were noted in initial tissue samples and none were outside the range of adequate values. After 1 month, tissue levels in all treatments were adequate, but not excessive, according to NCDA guidelines (also shown on Table 2) with the following exceptions.

   N concentrations in OM-fertilized plants (>5%) were significantly higher than in the other treatments (<3.5). Excess N in the OM treatment increased growth rate, which increases the risk that tissue calcium content falls below critical levels (Kleeman and Metspalu, 2000). Although initial N levels were not significantly different between treatments, N levels declined in all treatments, but declined much less in the OM treatments. Some decline is normal in mature tomato plants and all treatments were above the deficiency level of 2%, although (except for the OM treatment) below the NCDA adequate level of 3.5%.

   Potassium levels, an important nutrient for tomato fruit quality, were initially highest in the NOG-fertilized plants (3.63%) and slightly below the adequate range (3.5-5%) in the other 3 treatments. However after a month of treatment, potassium levels increased in the other treatments to well within the adequate range, but declined in the NOG treatment to the deficiency level of 2.5% at fruiting (Jones, 1999). Deficiency symptoms were apparent in the leaves by the time the second cluster was harvested, and plant vigor was very low (Photo 5).

   N:K ratios are also critical. In conventional greenhouse tomato feed recommendations (OMAF, 1985-86), N concentrations are gradually decreased from week 1 to 5, to steer growth from vegetative to fruiting, then increased again to balance growth. Potassium, on the other hand, is increased steadily until almost the end of production in conventional production. Suggested K:N ratios are 1.7 for the first 3 weeks after transplanting, then increased to 1.4 and finally to 1.2 by week 9 after transplanting. In our fertilizers (Table 1), K:N was lowest in the NOG fertilizer (0.083) and highest in the stage 1 conventional fertilizer (2.17). The OM and NCS blend were intermediate, with K:N ratios of 0.83 and 0.71, respectively. Actual K:N may have been higher in the NCS blend, since not all the bloodmeal was initially in solution.

   Another important difference between treatments was in tissue calcium levels. Initially, all were slightly below the NCDA adequate range (1-3%), although

differences were not significant. After a month of treatment, calcium levels increased in all treatment except OM, where they decreased to 0.38%, well below the deficiency level of 1% (Jones, 1999), and significantly lower than the other treatments, which did not differ. Blossom-end rot, a calcium-related disorder was evident in about 20% of fruit from the OM treatment, giving it the lowest percentage of marketable fruit of all the treatments (55.85%, Fig. 2). Magnesium was also significantly lower in the OM treatments by the second sampling date, and at 0.31% was below the adequate level of 0.35-1.0%. For magnesium, highest levels were found in the NOG and NCS treatments and intermediate levels in the conventional feed. For the micronutrients, although there were significant differences between treatments (Table 2 and Appendix 1), none fell outside the adequate zone except for boron which was above 75 ppm in all treatments except OM, and Zn which was below 18 pm in the CV plants.

Comparing all the fertilizers tested on overall plant nutritional levels, the most striking differences were with the OM formulation, which led to excessive N levels and low calcium and magnesium levels, and with the NOG formulation, which was potassium deficient. The NCS formulation and the conventional formulation were generally similar, except for significantly lower levels of N, Fe, and Cu and significantly higher levels of Mg, Na, Mn and B in the NCS formulation. These differences should not have greatly affected growth, since tissue nutrient levels were all at or above the adequate range, except for N at 2.46, which was lower than the recommended minimum of 3.5, presumably because of problems in dissolving the bloodmeal. Higher levels of Na (0.22 vs. 0.07%) and B (100.8 vs. 77.67 ppm) in the NCS compared to CV feed did not appear to cause problems in this experiment, but would be potential sources of salinity and boron toxicity, respectively.

3. Substrate pH, CEC, and Nutrient Content: Substrate properties and substrate nutrient concentrations are listed in Table 3. Differences between treatments are discussed in detail in Appendix 2.

   Throughout the experiment, substrate pH values were somewhat lower (5.1-6.1) than recommended for tomato production (5.5-6.5). Of all the fertilizers, tested, the NCS blend maintained pH nearest to optimal values, ending at a pH of 6.10, which was significantly higher than in the other treatments. Cation exchange capacity was also good in the NCS blend with significantly higher CEC than the OM-fertilized substrates, and not significantly lower CEC than in the conventional and NOG treatments. Soluble salt index values (data not shown) were low-medium, ranging from 9 to 31, where 11-25 is considered in the low range.

   As with the tissue nutrient levels, the most striking difference between the fertilizers was in nitrate-N, where OM-fertilized substrates had nitrate levels 4-9 times higher than those in the other treatments at the second and final sampling dates. This represents significant excess nitrate availability to the plant, especially during early harvest. In the other treatments, substrate nitrate levels declined from initial values, but in the OM-fertilized substrates, they almost doubled. Substrate calcium % was also low in OM-fertilized substrates compared to NSC and conventionally fertilized

substrates and substrate magnesium was lower than in any of the other treatments. Another cation, sodium, which can indicate excess salinity, increased in all the treatments, but the increase was much higher in the NOG and NCS formulations.

Large differences between treatments were also seen in potassium values. Initial substrate potassium values were high or medium in all treatments, with the NOG treatment being significantly lower than the other three treatments and OM significantly higher than the NCS, but not the conventional treatment. By the end of the experiment, substrate potassium index levels remained high in the OM and NCS treatments, but declined in the conventional and NOG treatments to levels considered low (19 and 13%, respectively where 25-50 is considered medium).

Phosphorus values were low in all treatments, according to NCDA index values, although they increased over the growing season in the NOG and NCS treatments to reach the medium range (25-50) by the end of the experiment.

By the final sampling date (end of experiment), levels of substrate micronutrients (S, Mn, Zn, and Cu), did not differ in most cases between treatments. All the treatments were high in Zn, had high or medium levels of sulfur and were low in manganese and copper. Sodium, however, did differ significantly between treatments throughout the season. NCS had significantly higher levels than any of the other treatments and sodium in the conventional treatment was significantly higher than in the two remaining organic treatments.

Comparing the NCS and conventional treatment, pH was nearer optimal in the NCS treatment, as were P and Mg. For the other substrate characteristics measured, the NCS and conventional treatments did not differ significantly, with the exception of sodium levels, which were consistently higher in the NCS treatment.

4. Harvest Yields: Harvest yields are presented in Figure 2. as a stacked bar chart with marketable fruit, as well as the incidence of various defects expressed as a percentage of total yields. Tomato plants grown with NCS produced the highest percentage of marketable fruit ($p < 0.0001$). OM resulted in the lowest percentage of marketable fruit ($p < 0.0001$) because of a high incidence of blossom-end rot (BER) and cracking (C), both defects associated with calcium deficiency. Incidence of fruit with BER also accounted for a large percentage of the defects in the NOG and CV treatments. Tomatoes grown with NCS had a higher incidence of small fruit (SF) and open locule (OL) than the other treatments, but little BER.

   Actual yields for the first and second cluster are shown in Table 4. CV produced significantly greater total and No. 1 yields than any of the organic treatments ($p < 0.0001$), averaging 39 and 41% more total fruit than organic treatments for the first and second cluster, respectively. Differences in marketable fruit were similar for the first cluster (38%), but by the time of harvest of the second cluster, differences between the organic treatments in marketable fruit were much greater. The conventional treatment produced 75, 33 and 52% more marketable fruit than the OM, NOG and NCS treatments, respectively. Had harvest been continued beyond the

second cluster, treatment differences would undoubtedly have been even greater in the OM and NOG treatments as there was little fruitset in the third and subsequent cluster in either the NOG or OM treatments. Yields in the NCS treatment might have caught up with conventional, and tissue nutrient levels and substrate characteristics were similar by the end of the experiment.

6. **Conclusions and Discussion:**

By using the same substrate in all the treatments (as opposed to the different substrates used in Miles (2000), it was possible to separate the effects on pH and EC of organic fertilizers from the effects of organic additions to the substrate in the previous experiments (vermicompost, bloodmeal, bonemeal, potassium sulfate, limestone, gypsum). Conventional fertilizers used for tomato production generally drive down substrate pH, while Miles (2000), suggested that organic fertilizers may have the opposite effect on soil pH. Thus, instead of adding lime at the generally recommended rate for conventional fertilizers of 10 lbs $\cdot$ yd^{-3}. (6 kg $\cdot$ m^{-3}), the rate of limestone used was less than that recommended for conventional practices, but more than was reported to be optimal for organic production (Miles, 2000). In the present experiment, we therefore expected below-optimal pH in the conventional treatments and above-optimal pH in the organic treatments.

However, without organic additions to the peat/perlite substrate, and with these three fertilizers, pH was slightly below-optimal in all treatments, with no significant differences between treatments in substrate pH after 1 month. In fact, by the end of the experiment, pH was closest to optimal (6.1) in the NCS blend. Low pH may have somewhat reduced availability of Ca and K, although changes in availability over this range are fairly small, and pH levels did not seem related to differences in tissue concentrations (Tables 2,3). In future experiments, we would somewhat increase the level of lime addition to the substrates, but it seems unlikely that higher lime levels would significantly change the results of this experiment. This suggests that substrate additions are a more important factor contributing to the high pH and initial EC values seen in our earlier study. Different fertilizers were used in that study, however, so it may have been a combination of fertilizers and substrate additions. In one experiment in the previous study, the vermicompost was omitted from the media without reducing the pH or EC, so the other additions were the most likely source of these high values. Overall, combining the results from all our work with organic production practices, we would recommend careful testing of all substrate/fertilizer combination for effects on substrate pH and EC and adjusting substrate pH with lime or sulfur as necessary. We recommend a minimal number of substrate additions to increase fertility. Overall fertility was easier to control with drip irrigation than with substrate additions, however. Even in our final study, where substrate additions were much lower, initial EC was high (4), then declined. This can lead to burning, then subsequent nutrient stress. For tomatoes grown in soilless media, constant feed with drip irrigation, or minor adjustments to control plant growth seem to work better.

In comparing the specific fertilizers, we were surprised not to see more and earlier evidence of potassium deficiency in the NOG treatment. Substrates did not receive any nutritional amendments and this fertilizer contained almost no K (0.3%). NOG had not been previously tested on tomatoes, but the manufacturer recommended it as a stand-alone fertilizer on the

basis of more potassium and micronutrients becoming available over time. Tissue K levels after 1 month of treatments were significantly lower in NOG than in plants from any of the other treatments, and these plants were the only treatments in the deficiency range (2.5%). NOG substrate K was also the lowest in any treatment, although most of the differences from the conventional treatments were not significant. In spite of what would seem to be inadequate K fertilization, plants grown with this fertilizer had percentages of marketable fruit that were similar to the NCS and CV treatments, and higher than the OM treatment. Yields were as good or better than in the other organic treatments, although significantly lower than in the conventional treatment. The relatively good performance of the NOG fertilizer was probably associated with the discontinuation of harvests after the second cluster. As shown in Photo 5, plants were severely deficient at this stage, and no fruit set in upper clusters. However this fertilizer worked well in the drip irrigation system, and if combined with a soluble, organically soluble source of K, such as the Maxicrop 1-0.11-12 fertilizer used in the NCS blend, should perform well over an extended cropping period.

Plants grown with OM had the poorest yields, both in actual amounts (Table 4) and in % marketable, although they grew the most vigorously, and looked to be the healthiest. These plants had large, dark green leaves and thick stalks, and were several feet taller than any of the other plants. Although the N amount in this fertilizers were matched with that of the conventional feed, plants appeared to be taking up luxury amounts of nitrogen, causing excessive vegetative growth. By the end of harvest of the second cluster (May 9) plants in this treatment had little fruitset above the second cluster. Leaf tissue had high concentrations of N and low concentrations of Ca. Low Ca in the tissue can explain the high incidence of BER in this treatment. High levels of N fertilization stimulate rapid vegetative growth in tomatoes, which can deplete calcium in rapidly growing organs, such as fruit (Kleeman and Metspalu, 2000). High levels also increase shoot growth at the expense of root growth, which can make calcium uptake by root tips more difficlt. OM fertilizer might be useful for transplants, but should be discontinued for tomato production after flowering. Tomatoes are generally fertilized at a ratio of 1-2-2, or a K:N ratio of 1.5 after transplanting. It would be difficult to add enough K to the feed to maintain this ratio without burning the plants.

Plants in the NCS and conventional treatments were in good shape in terms of balanced vegetative and generative growth, but were compromised by shading from the OM plants, and a whitefly infestation, which was hard to control because of the excessive vegetative growth of plants in the OM treatments. Although most characteristics of tissue and substrate nutrition were similar to the conventionally fertilized plants, and marketable yields similar, total yields were significantly lower. This may have been caused by the difficulties in getting bloodmeal into solution, reducing nitrogen, and causing clogging in the weeks after transplanting. Substituting NOG for bloodmeal and microphos in the NCS blend might be a good combination. The fertilizer blend had relatively low levels of calcium and magnesium, but no evidence of deficiency was found in either tissue content or substrates. Levels of substrate sodium and tissue boron in the NCS treatment were higher than in the other treatments, and should be monitored in future development of this fertilizer. No evidence of problems from boron toxicity or salt accumulation was seen in this study, however.

In conclusion, as in our previous work, organic fertilizers did not differ greatly from conventional fertilizers in their effect on plant growth rates, percentage marketable fruit, and

tissue nutrient content. Unlike the previous study, actual yields were 38-54% lower than plants given conventional fertilizers and we found few differences in substrate pH and EC. We attribute lower yields to not matching as many of the components of the conventional mix as we did in the previous study with the commercial mixes.

We were fairly satisfied with our 'in-house' blend in terms of plant growth, but yields were still lower than in the conventional treatment, possibly because the bloodmeal was difficult to get into solution. We would not recommend using bloodmeal in a drip irrigation system, although we did eventually develop satisfactory extraction procedures. All the commercial formulations used this time (OM, NOG, Maxicrop and Micro Phos) dissolved well and did not clog the emitters, suggesting they could be combined into a balanced formulation. However blending them into a complete fertilizer, with N-P-K and secondary nutrients matched to conventional mixes is not as simple as with high-analysis fertilizers. The most promising combination would be to blend NOG and Maxicrop, and add more calcium to the substrate.

As more OMRI-certified soluble commercial fertilizers are available in bulk, we suggest combining them based on approximating conventional nutrient solutions as closely as possible and limiting substrate additions to the amount required for pH correction. This should allow greater stability of EC and pH and increased control of rootzone conditions throughout development. Both tissue and substrates should be monitored regularly during the development process to ensure that pH, EC, and nutrients remain in the optimal range.

7. **Outreach** This data has been presented by Peet at the 44th Annual Horticulture Growers' Short Course & Trade Show, Feb. 8, 2002 sponsored by the Lower Mainland Horticultural Improvement Association in Abbotsford, BC. It will also be incorporated into a video on cultural practices for greenhouse vegetable production. Data on levels of vitamins and anti-oxidants in the various treatments are still being analyzed and will be published along with the production data as in the near future. Miles also presented data on organic fertilizers at the 2001 meeting of the American Society for Horticultural Science in Sacramento, CA.

8. **References:**

Campbell, C.R. ed. Reference sufficiency ranges: vegetable crops: greenhouse tomato. In Reference sufficiency ranges for plant analysis in the southern region of the United States (Southern cooperative Series Bulletin #394). http://www.agr.state.nc.us/agronomi/saaesd/s394.htm

Drews, M. and B. Rennert. 1992. Investigations into the combining of intensive fish farming with NFT methods in the greenhouse production of cucumbers and tomatoes. Gartenbauwissenschaft 57:44-48.

El-Shinawy, M.A. E. M. Abd-Elmonien, and A.F. Abou-Hadid. The use of organic manure for lettuce plants grown under NFT conditions. Proc. Of the Int. Symp. On Greenhouse Mange for Better Yield and Quality in Mild Winter Climates. E. Y. Tuzel. Acta Horticulturae 486 ISHS 1999. P. 315-318.

Flynn, R.P. Wood, C.V. Guertal, E.A. 1995. Lettuce response to composted broiler litter as a potting substrate component. J. Am. Soc. Hort. Sci. 120:964-970.

Ingram, E.R. and M. Alms. 1999. Compost Tea Manual 1.1. Soil Foodweb, Inc. Growing Solution, Inc. Eugene, Oregon. Copies obtainable from Organic Farming Research Foundation, Santa Cruz, CA telephone 831-426-6670.

Jones, J.B., Jr. 1999. Tomato Plant Culture. Pp. 58 and 170-171.CRC Press, Boca Raton. 199 p.

Kleeman, M and L. Metspalu. 2000. Factors affecting calcium deficiency related disorders in vegetables. In Proceedings of the international conference: Development of environmentally friendly plant protection in the Baltic Region 2000. Ed. S. Mitt. Transactions of the Estonian Agricultural University, Agronomy No. 209 67-69.

Kraus, H.T. and S.L. Warren. 2000. Performance of turkey litter compost as a slow-release fertilizer in containerized plant production. HortScience 35:19-21.

Kraus, H.T., R. L. Mikkelsen and S.L Warren. 2000. Container substrate temperatures affect mineralization of composts. HortScience 35:16-18.

Miles, J. F. 2000. Organic, biorational and conventional growing systems for greenhouse tomatoes. M..S. Thesis North Carolina State University, Raleigh, NC. (additional references cited in thesis)

Ontario Ministry of Agriculture and Food. 1985-1986. Greenhouse Vegetable Production Recommendations. Publication 365.AGDEX 290/21.

Smith, M. 1994. The Real Dirt. Farmers Tell about Organic and Low-Input Practices in the Northeast. Northeast Organic Farming Association. Burlington, VT. P. 116, 264 p.

Appendix 1: Discussion of treatment differences in nutrient content of tomato leaves (Table 2).

Leaf tissue of plants grown with OM fertilizer contained significantly greater concentrations of N, Fe, and Zn, and significantly lower concentrations of Ca, Mn and B than all other treatments. Additionally, OM plants had significantly less Mg and Na than the other organic treatments, but these nutrient levels were not significantly different than those from CV. According to the NCDA ratings, the N levels in OM plants were acceptable for plant growth, but the amounts were approaching toxicity. The Mg levels in tissue for OM was low and the OM plants were deficient in Ca. It is possible that, due to luxury consumption of N, plants in the OM treatment were growing faster than Ca and Mg could be taken up. The significant differences in micronutrient levels between the OM plants and plants from other treatments can be attributed to the low substrate pH resulting from the OM fertilizer treatment.

Plants grown with NOG contained significantly more P and significantly less K than all other treatments. Tissue concentrations in these plants did not differ significantly form those in NCS in levels of MG and Na, which were significantly greater, or in levels of Fe and Cu which were significantly less than in those from the other two treatments. The deficient levels of K were not surprising considering that this fertilizer supplied only minute amounts of K.

Tissue levels of S did not differ between NCS and CV and were significantly greater than those in tissue from the other two treatments. The NCS plants contained greater levels of Mn and B than other treatments. Again, this was probably due to the higher substrate pH resulting from this treatment. The NCS treatment resulted in significantly less N in leaf tissue than all other treatments. These levels were low, but not deficient. About the time these samples were taken, it was discovered that the blood meal was not dissolving adequately. It follows that the plants were not receiving adequate amounts of N. This problem was ameliorated by extracting the N from the blood meal and adding the supernatant liquid to the fertilizer stock tank. The extraction procedure is described in Table 1.

Plants grown conventionally had significantly lower accumulation of P and higher accumulation of Cu than the other treatments. These plants did not differ from plants grown in NOG or NCS in tissue concentrations of Ca, which was higher than that in OM plants, or Zn, which was lower than in OM plants.

Appendix 2. Discussion of treatment differences in substrate pH, CEC and nutrient levels (Table 3) measured one week and one month after the start of treatments, and the end of the experiment.

The OM treatment resulted in significantly lower cation exchange capacity (CEC) than other treatments. Substrates from the OM treatment contained significantly less Mg and significantly more NO_3 than all other treatments. OM substrates did not differ significantly from NOG substrates in levels of Ca, Na, and S. All these nutrient levels were significantly lower than those from the other two treatments.

The NCS treatment resulted in significantly higher substrate pH, as well as levels of Ca, Mg, and Na than all other treatments. Also, NCS substrates had greater levels of P than substrates from all other treatments except NOG, and greater levels of S than substrates from all other treatments except CV.

Substrate levels of K did not differ significantly between OM and NCS, or between NOG and CV. The former substrates had significantly more K than the latter pair. NOG and CV substrates also did not differ in Mg content.

The CV substrates contained significantly less P than substrates of any other treatment. NOG substrates contained the greatest amounts of P. The CV substrate had the highest CEC, although this was not significantly higher than CEC in the NOG or NCS substrates. There were no significant differences in substrate concentrations of Cu, Mn, or Zn among any treatments.

Appendix 3: Photos showing activities on this project and previous work.

Photo 1. Mixing fertilizers using 5 different sources in previous study (Miles, 2000).

Photo 2. Mixing substrates.

Photo 3. Drip irrigation system with Dosatro injectors and stock tanks.

Photo 4. Potassium-deficient plant from NOG treatment in left foreground. Note plant with normal light green foliage from conventional treatment immediately to the right, and plant from OM treatment with dark green foliage slightly in background and to the right. Another plant from the OM treatment is in the extreme right, and can be seen to be much taller than plants from the other treatments. Note also cards for biological control of whiteflies.

Organic Farming Research Foundation
Greenhouse Tomatoes Grown with
Organic and Conventional Fertilizers

Table 1. Organic fertilizer rates and formulas.

Conventional N-P-K rates for each growth stage[z]		
Stage 1	**Stage 2**	**Stage 3**
90 ppm N	125 ppm N	165 ppm N
45 ppm P	45 ppm P	45 ppm P
195 ppm K	195 ppm K	310 ppm K

Fertilizer Formulas			
Fertilizer	**Stage 1**	**Stage 2**	**Stage 3**
Omega (OM) [y]	9.99 fl. oz. (299.7 mL)	13.88 fl. oz. (416.3 mL)	18.32 fl. oz. (549.6 mL)
Natural Organic-Grow (NOG)[x]	27.97 fl. oz. (839.0 mL)	38.85 fl. oz. (1165.4 mL)	51.63 fl. oz. (1540.8 mL)
NCSU Blend (NCS)[w, v]	1.34 oz. (38.0 g) Blood Meal	2.00 oz. (56.9 g) Blood Meal	2.55 oz. (72.3 g) Blood Meal
	13.33 oz. (377.8 g) Micro Phos	13.33 oz. (377.8 g) Micro Phos	13.16 oz. (373.1 g) Micro Phos
	5.19 oz. (147.3 g) Maxicrop	5.19 oz. (147.3 g) Maxicrop	8.25 oz. (234.1 g) Maxicrop

[z] Stage 1: the period from transplanting to the first fruit set; Stage 2: the period of fruit set from first through sixth clusters; Stage 3: the period from fruit set on the sixth cluster until the end of the crop.

[y] Omega (OM). Analysis: 6-6-6 (6N-2.64P-4.98K). For 1 gallon (3.79 L) of stock injected at a rate of 50:1

[x] Natural Organic-Grow (NOG). Analysis: 3-2-0.3 (3N-0.88P-0.25K). For 1 gallon (3.79 L) of stock injected at a rate of 70:1

[w] NCSU Blend (NCS) is comprised of three products: Blood Meal – Analysis: 14-0-0 (14N-0P-0K); Micro Phos – Analysis: 0-2-0 (0N-0.88P-0K); and Maxicrop – Analysis: 1-0.11-12 (1N-0.05P-10K). Additional nutrients: 12,000 ppm Ca; 8,000 ppm Mg; 37,000 ppm S; 80 ppm B; 5 ppm copper; 1200 ppm Fe; 12 ppm Mn; 100 ppm Zn. Formulated for 1 gallon (3.79 L) of stock injected at a rate of 20:1

[v] Since blood meal is insoluble, the nitrogen was extracted by soaking overnight the amount required in 1 gal. (3.79 L) of hot water to which 1 oz. (28.3 g) of citric acid was added. The supernatant was then strained into the stock tank and the remaining ingredients were added.

Table 2. Nutrient content of tomato leaves analyzed by The NCDA. Each sample consisted of the fifth leaf from the apex of each plant in each treatment.

Nutrient/ Adequate range[y]	Unit	Date	Fertilizer: Omega	Natural Organic-Grow	NCSU	Conventional
N	%	27-Feb	6.47 a[z]	5.44 a	5.72 a	5.84 a
3.5-5%		23-Mar	5.10 a	3.48 b	2.46 c	3.18 b
P	%	27-Feb	1.11 a	1.08 a	0.92 b	1.03 a
0.3-.65%		23-Mar	0.72 b	0.83 a	0.68 b, c	0.59 c
K	%	27-Feb	3.41 a, b	3.63 a	2.93 b	3.10 a, b
3.5-4.5%		23-Mar	3.87 a	2.50 b	4.25 a	4.09 a
Ca	%	27-Feb	0.78 a	0.86 a	1.00 a	0.94 a
1-3%		23-Mar	0.38 b	1.06 a	1.17 a	1.09 a
Mg	%	27-Feb	0.56 b	0.63 a	0.60 a, b	0.61 a, b
0.35-1%		23-Mar	0.31 c	0.57 a	0.61 a	0.50 b
S	%	27-Feb	0.79 b	0.91 a, b	0.94 a	0.85 a, b
0.2-1%		23-Mar	0.40 b	0.53 b	0.89 a	0.78 a
Na	%	27-Feb	0.06 a	0.06 a	0.06 a	0.05 a
		23-Mar	0.10 b	0.20 a	0.22 a	0.07 b
Fe	ppm	27-Feb	101.65 b	99.20 b	93.00 b	121.33 a
50-300 ppm		23-Mar	94.80 a	53.57 c	51.32 c	77.43 b
Mn	ppm	27-Feb	116.17 a	121.30 a	125.00 a	122.17 a
25-200ppm		23-Mar	83.42 c	160.00 b	199.17 a	138.00 b
Zn	ppm	27-Feb	61.27 a	61.72 a	55.40 a, b	49.35 b
18-80 ppm		23-Mar	50.90 a	19.22 b	19.05 b	16.15 b
Cu	ppm	27-Feb	8.95 b	10.72 a, b	9.17 b	12.57 a
5-35 ppm		23-Mar	10.25 b	8.28 c	7.87 c	14.00 a
B	ppm	27-Feb	70.17 b	77.12 a, b	85.75 a	69.42 b
30-75 ppm		23-Mar	50.48 c	83.17 b	100.80 a	77.67 b

[y]Reference sufficiency ranges for greenhouse tomatoes. In sufficiency ranges for plant analysis (SCSB#394)

[z] Different letters denote significant differences (alpha=0.05) among treatments.

Table 3. Substrate pH, cation exchange capacity and nutrient content. Soil cores from four gro-bags of each treatment were combined for each analytical sample.

Soil Property or Nutrient	Type of Unit	Date	Fertilizer			
			Omega	Natural Organic-Grow	NCSU	Conventional
pH		27-Feb	5.53 a, b[y]	5.43 b	5.63 a	5.10 c
		23-Mar	5.53 a	5.37 a	5.57 a	5.33 a
		25-May	5.20 b	5.13 b	6.10 a	5.00 b
Cation Exchange Capacity (CEC)		27-Feb	7.13 b	6.90 b	7.30 b	8.07 a
		23-Mar	8.67 b	8.37 b	8.93 a, b	9.93 a
		25-May	6.43 b	7.60 a, b	7.43 a, b	8.83 a
Nitrate-N (NO_3)		27-Feb	9.00 b	3.67 b	8.00 b	25.67 a
		23-Mar	18.67 a	2.00 a	2.67 a	4.00 a
		25-May	16.33 a	3.33 b	2.33 b	2.00 b
Phosphorous (P)	Index[z]	27-Feb	16.00 a	16.67 a	12.00 a	16.33 a
		23-Mar	22.67 a	21.00 a, b	19.67 a, b	15.33 b
		25-May	18.00 b, c	30.00 a	26.00 a, b	9.33 c
Potassium (K)	Index	27-Feb	62.67 a	35.00 c	48.67 b	55.00 a, b
		23-Mar	61.00 a	8.33 b	52.67 a, b	31.67 a, b
		25-May	80.67 a	13.33 b	79.67 a, b	19.00 b
Calcium (Ca)	%	27-Feb	35.33 a	35.67 a	36.33 a	36.33 a
		23-Mar	33.00 b	32.33 b	34.33 b	41.00 a
		25-May	31.67 b	33.33 a, b	42.67 a	42.00 a
Magnesium (Mg)	%	27-Feb	27.33 a	27.33 a	25.67 a	25.33 a
		23-Mar	23.67 a	26.00 a	23.33 a	23.00 a
		25-May	13.67 c	21.33 b	24.67 a	20.00 b
Sulfur (S)	Index	27-Feb	23.00 b	36.67 b	27.00 b	113.00 a
		23-Mar	18.67 b	25.33 b	44.67 a	29.67 b
		25-May	27.67 b	32.67 b	74.33 a	91.67 a
Manganese (Mn)	Index	27-Feb	24.67 b	26.33 b	26.00 b	34.67 a
		23-Mar	25.67 b	27.33 b	25.00 b	40.33 a
		25-May	18.67 a	24.67 a	20.00 a	25.00 a
Zinc (Zn)	Index	27-Feb	87.33 a	86.67 a	77.67 a	79.67 a
		23-Mar	102.67 a	98.67 a	81.67 a	83.33 a
		25-May	91.67 a	87.67 a	90.33 a	81.33 a
Copper (Cu)	Index	27-Feb	15.00 a	15.67 a	16.00 a	14.33 a
		23-Mar	29.33 a	17.00 b	17.33 b	28.00 a
		25-May	23.67 a	15.67 a	16.00 a	18.00 a
Sodium (Na)	%	27-Feb	0.20 b	0.20 b	0.27 a	0.20 b
		23-Mar	0.33 b	0.33 b	0.67 a	0.27 b
		25-May	0.40 c	0.37 c	1.07 a	0.50 b

Table 4. Weight per cluster (g) of total and marketable (No. 1) tomato fruit harvested per plant using 3 organic fertilizers and a conventional fertilizer.

Harvest Yields - Tomatoes Spring - 2001 By Cluster				
	Average Wt. (g) / Plant			
	Cluster 1		Cluster 2	
Treatment	All Fruit	No. 1 Fruit	All Fruit	No. 1 Fruit
OM [z]	742.59	505.46	559.78	212.55
NOG	884.19	670.94	610.49	558.67
NCS	766.38	708.79	476.03	396.43
CV	1300.93	1011.47	932.42	837.53

[z] OM = Omega; NOG = Natural Organic Grow; NCS = North Carolina State Formula; CV = Conventional

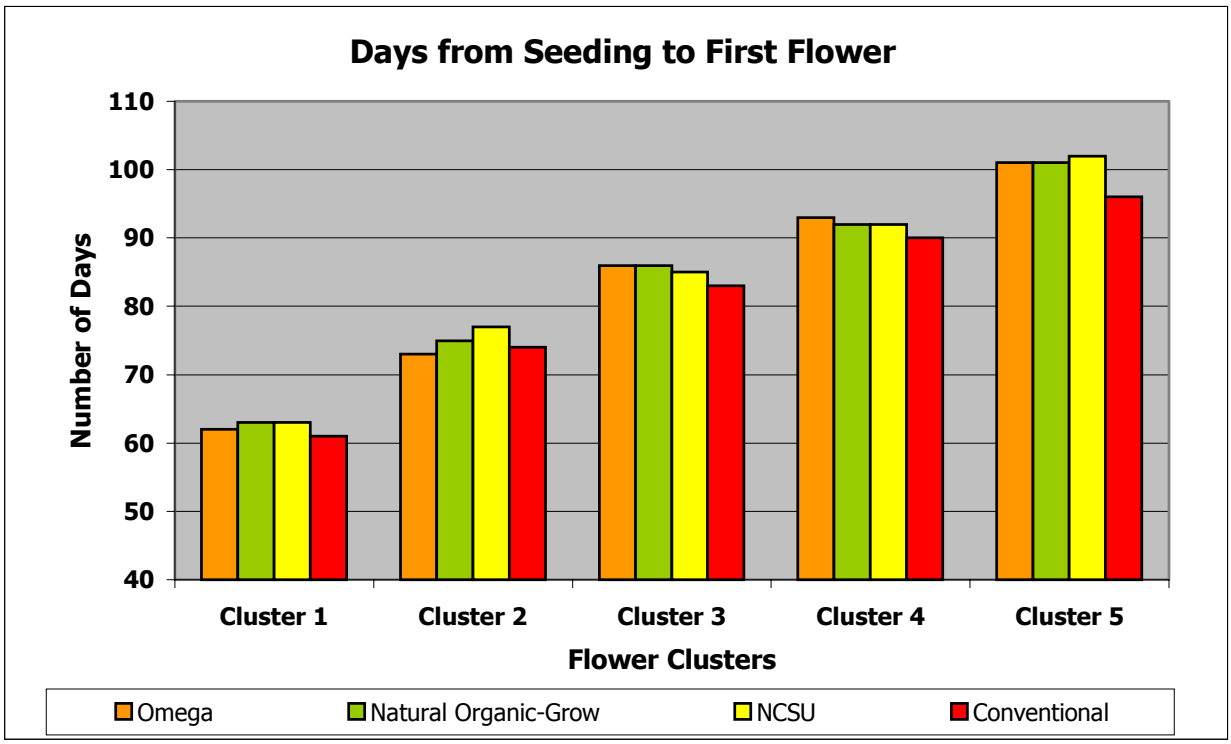

Figure 1. Number of days from seeding to the first fully reflexed flower on each of the first five clusters.

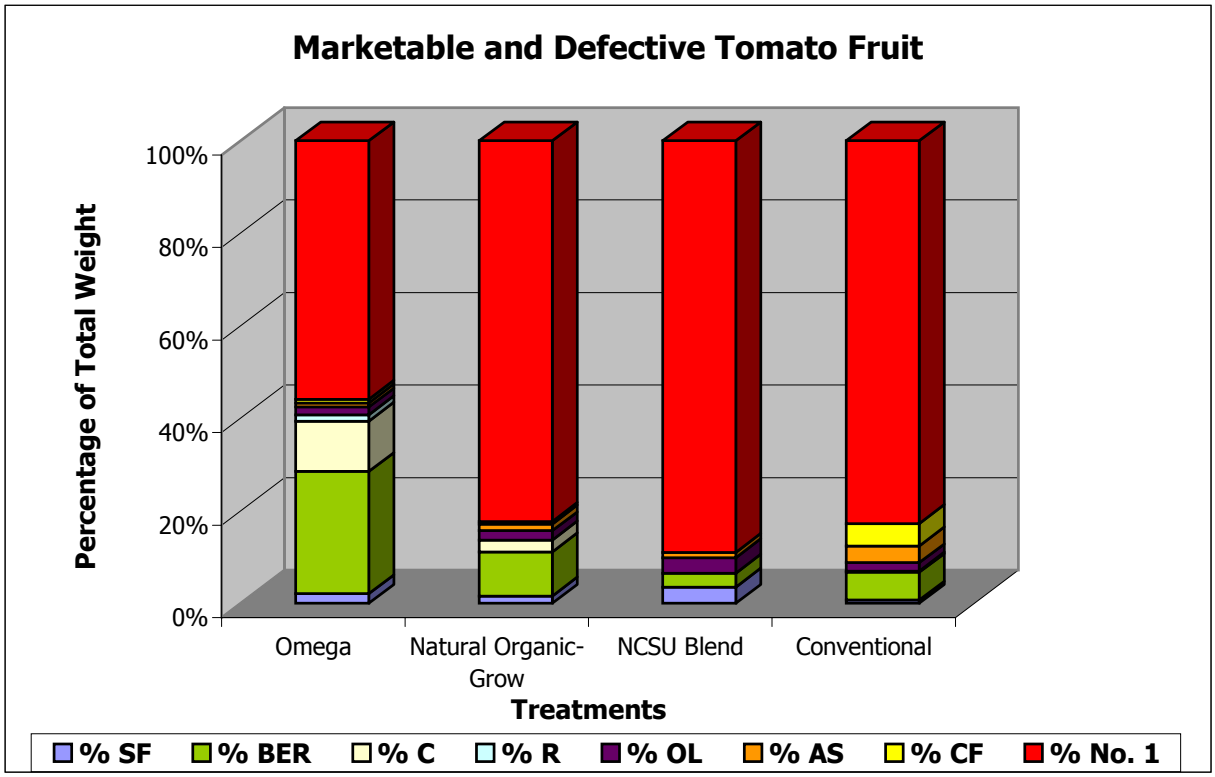

Figure 2. Marketable and defective fruit. Average weights are expressed as a percentage of the total yields for each treatment. SF=small fruit, BER=blossom-end rot, C=cracked, R=rough, OL=op AS=anther scarring, CF=cat-faced, % No. 1=fruit with no defects

Total and No.1 Yields
Treatment Means

	Total	No. 1
OM	1314.73	734.23
NOG	1494.68	1229.61
NCS	1242.4	1105.22
CV	2233.34	1848.99

Total and No.1 Yields
Treatment Means

Tmt	Total	No. 1
OM	1314.73 b	734.23 c
NOG	1494.68 b	1229.61 b
NCS	1242.4 b	1105.22 b
CV	2233.34 a	1848.99 a

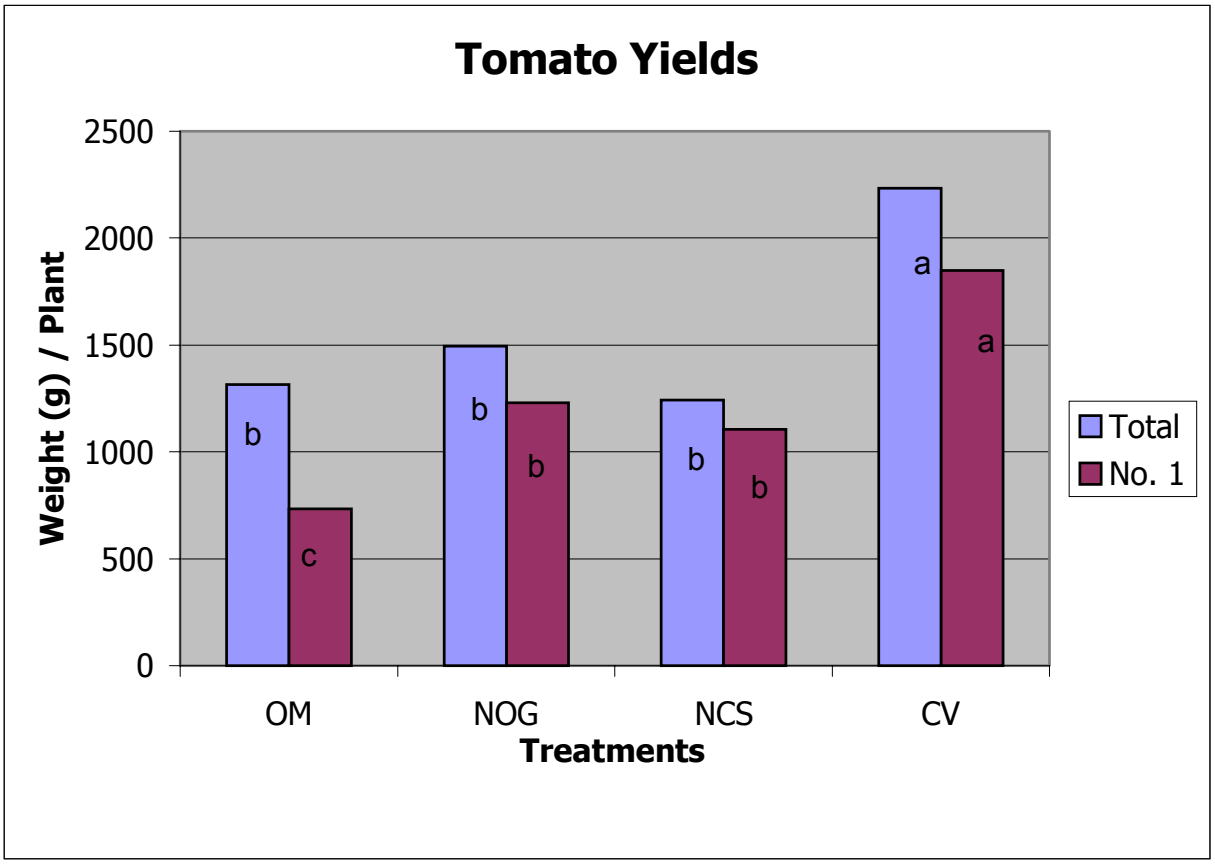

Figure 3. Total and No. 1 tomato yields. Letters designate significance of treatment differences.