Conclusions

The effects of N, P, and K on citrus fruit quality are important commercially. Problems of fruit yield, size, and quality should not be approached independently; in some cases tradeoffs are necessary for best overall results. Leaf analysis guides calibrated against fruit yield, size and quality have practical value in improving fruit quality. To use leaf analysis results most effectively one should know, for the orchard in question, what specific problems can be influenced by nutrition. One should also have a continuing record of fertilizer applications and leaf analyses. With this information a nutritional program can be planned for the specific orchard in question.

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ORGANIC VS. INORGANIC NUTRITION AND HORTICULTURAL CROP QUALITY[1]

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Until the development of modern chemical fertilizers began in about 1840, natural and organic materials supplied virtually all the plant nutrients to the soil. The use of chemical fertilizers increased gradually until about 1940. Since then the total consumption of chemical fertilizers in the United States has increased nearly fivefold to about 40,000,000 tons annually (28). The development and use of modern chemical fertilizers has decreased the relative importance of organic fertilizers. Today, organic materials account for less than 1% of the N fertilizers sold in this country (27). Phosphate rock materials account for about 20% of the present P fertilizer consumption in the United States, and over 85% of these materials are consumed in Illinois and Missouri (4). Natural potassic fertilizers, such as seaweed, greensand, and granite dust, apparently account for an insignificant fraction of the K fertilizer materials sold in this country, since muriate of potash alone accounts for nearly 90% of the commercial K fertilizers consumed here (4).

Composts and farm manures are important fertilizers to the present-day organic or home gardener, but these materials are of much lesser importance on a national scale. If all of the farm manure in this country were equally distributed and spread without loss, nearly 5 tons of this waste could be applied per acre of cropland. This amount is enough to provide about 25% of the primary nutrient requirement by crops. However, due to the concentration of the livestock industry in specific regions of the country and due to losses of manure during storage and handling, only a fraction of the farm manure may actually reach commercial cropland. Probably no more than 2 to 4% of the manure is used on vegetable crops, assuming that its use is proportional to the consumption of commercial fertilizers on vegetable crops (18).

Impact of organic fertilizers

When one considers the above statistics, it is obvious that the impact of the use of organic fertilizers in the vegetable crop industry is insignificant with respect to the total consumption of fertilizers on vegetable crops in this country. Organic gardening gains potential importance, however, when the statement is made that crops grow better, taste better, and are more nutritious when grown organically than when grown chemically. The advocates of organic gardening have been successful in taking their case to consumers and have gained their confidence. They have presented their case in a language which the layman understands by simply stating that nature knows best and that chemicals merely stimulate the plant and poison the soil (7, 22, 30). Foods are said to lose their wholeness if they are grown in soils enriched with chemical fertilizers (13).

Influence of fertilizers on nutritional quality of plants

Undoubtedly, a relationship exists between crop husbandry (30) or soil fertility (14) and the nutrient content of vegetables. It is clear that varying the mineral content of a nutritional medium for plants will have an effect on their mineral contents (1, 9). Often, however, this relationship is never simple and direct, and other environmental factors may override the effects of nutrient supply (26). The effect of mineral nutrition on the vitamin, protein, and carbohydrate content of vegetables is very complex and few generalizations can be made (10, 26). It has been difficult to associate fertilization practices with nutritional value of vegetables. The general conclusion has been that field and climatic conditions and plant species or cultivar may have more marked and more practical effects on nutritional quality than fertilization practices (10, 12, 15, 16). Another general conclusion is that well-nourished, green plants will have a higher total vitamin content than undernourished chlorotic ones but that contents of specific vitamins will vary (26).

The validity of the hypothesis that organic farming yields vegetables of superior nutritional value has never been adequately tested in human or animal feeding trials. Such a study would be

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prohibitive in cost because of all of the variables needed to be controlled and because of all of the tests needed to be made (11). Most of the studies to evaluate the hypothesis for the superiority of organically-grown vegetables for human nutrition have dealt with the effect of organic or chemical fertilizers on a specific plant constituent of known nutritional significance for human health. A few examples follow.

Brandt and Beeson (11) found that the ascorbic acid and carotene concentrations in carrots, snap beans, potato tubers, and rye seedlings fertilized with manures, composts, mineral fertilizers, or combinations of manures and mineral fertilizers were not significantly different. They also found no significant differences in Fe and Cu concentrations in potato tubers from plants fertilized with manures or chemical fertilizers. Vitamin B_{12}, not normally found in plants, was detected in turnip greens grown in soil with organic matter added, but the amount of B_{12} was not sufficient to meet human nutritional needs (3). Composts and manures are known to contain vitamin B_{12} and other vitamins and have been reported to affect vitamin synthesis in corn leaves and kernels (19).

Schuphan (24) found that chemical N, P, and K fertilizers in relation to farm manures gave a slight decrease in total protein content of potato tubers but gave an increase in the nutritional value of the protein. As the N application from both fertilizers increased to the point of yield depression, crude protein increased, but the biological value of the protein decreased. The effects of N fertilization on the total N or protein content of agronomic crops have been fairly well-documented. Typically, the results have been similar to those of Shah and Mehta (25) who reported that farm manure and peanut meal were less effective than synthetic N fertilizers for increasing yields of millet grain and straw, but none of the fertilizers had any significantly different effects from the others on the crude protein content of the grain or straw.

Nitrogen nutrition of spinach with organic N fertilizers

In our organic gardening course, we have compared for three years the effects of various organic and chemical N sources on the growth and total N and nitrate concns in spinach leaves. The results of last year's studies are reported here. In these studies, which were conducted in pots in the greenhouse, the various N fertilizers were supplied by mixing them into the potting soil (7 parts loam: 3 parts peat moss: 2 parts sand by volume) in which the spinach was seeded. Equivalent amounts of P and K were supplied to all treatments as bone meal and wood ashes, respectively. The plant population was thinned to 3 plants/pot, and the spinach was grown for about 50 days from seeding to an apparent market maturity stage of development. Dried cow manure produced lower yields than any of the other fertilizers with highly significant differences occurring with 'Hybrid 424' (Table 1). The diminished yields with cow manure are apparently due to its low mineralization rate (5, 23). None of the other treatments were significantly different from one another. When organic N carriers as a group were compared to NH_4NO_3, no significant differences in yields occurred at any level of N application (Table 2). At the highest application of fertilizer N, we noted slight NH_4 toxicity (8) with the plants receiving NH_4NO_3. On the other hand, seed germination was severely inhibited by the organic N fertilizers at all N fertilization rates. The average seed germination for all treatment levels was 36% for the organic N treatments against 53% for the NH_4NO_3 treatments and 74% for the control.

Table 1. Growth and appearance of spinach plants grown with various organic and chemical N fertilizers.

	Fresh wt (g/pot)		Appearance rating[z]	
Fertilizer	Hybrid 424	America	Hybrid 424	America
None	13a[y]	18a	3.0c	2.0c
Dried blood	31cd	26a	0.5a	0.5a
Castor pomace	34cd	22a	0.6a	0.5a
Cottonseed meal	37d	26a	0.9a	0.5a
Sewage sludge	32cd	22a	0.9a	0.4a
Dried cow manure	21ab	18a	2.1b	1.4b
Ammonium nitrate	26b	21a	0.8a	0.2a

[z]0 = No N deficiency; 3 = severe N deficiency.
[y]Means separation within columns by Duncan's multiple range test, 1% level.

Table 2. Average yields of 'America' and 'Hybrid 424' spinach grown with organic or chemical N fertilizers applied in varying amounts.

	Fresh wt of leaves (g/pot)				
	N added, mg/pot				
Fertilizer	0	100	200	400	800
Avg of 5 organic	16a[z]	20ab	27bc	31bc	29bc
Ammonium nitrate	16a	21abc	26abc	30bc	24abc

[z]Mean separation by Duncan's multiple range test, 1% level.

No significant differences were detected for total N concns between 'America' and 'Hybrid 424'. Total N concns generally increased as the amount of N applied increased, and except for the highest rate of N application, the total N concn in the plants grown with NH_4NO_3 exceeded that in the plants grown with the organic fertilizers (Table 3). This difference was due primarily to the depressing effect of cow manure on the average total N concn of the plants grown on the organic fertilizers (Table 4).

Nitrate-N concns in the leaves increased as the amount of N applied increased, and except for the 200 mg/pot N application, the amount of NO_3-N in the leaves was not associated with whether the fertilizer was organic or chemical (Table 5). Among the different fertilizers (Table 4), cow manure gave the lowest concn of NO_3-N; however, it was significantly lower only with 'America' spinach. None of the other organic fertilizers or NH_4NO_3 produced NO_3-N concns in the leaves significantly different from one another. The amount of NO_3-N which accumulated in the spinach leaves (Table 4) is clearly a function of the rate of mineralization of the organic N from the various carriers (Table 6), for all of the organic fertilizers except cow manure are mineralized rapidly, and these produced significantly greater NO_3-N concns in the spinach than did the cow manure.

Table 3. Total N concn in 'America' spinach grown with organic or chemical N fertilizers applied in varying amounts.

	Total N in leaves (% dry wt)				
	N applied, mg/pot				
Fertilizer	0	100	200	400	800
Avg of 5 organic	2.53a[z]	2.62a	3.41ab	4.15bc	4.92cd
Ammonium nitrate	2.53a	4.03bc	5.12cd	5.34d	4.76cd

[z]Mean separation by Duncan's multiple range test, 5% level.

Table 4. Total N and NO_3-N concn in spinach plants grown with various organic and chemical N fertilizers.

	% dry wt		
	Total N	Nitrate-N	
Fertilizer	America	Hybrid 424	America
None	2.53a[z]	0.03a	0.04a
Dried blood	4.11b	0.27a	0.47c
Castor pomace	4.08b	0.36a	0.51c
Sewage sludge	4.12b	0.28a	0.58c
Dried cow manure	2.85a	0.15a	0.19b
Ammonium nitrate	4.76b	0.20a	0.62c

[z]Mean separation within columns by Duncan's multiple range test, 1% level.

Table 5. Average nitrate concn in 'America' and 'Hybrid 424' spinach grown with organic or chemical N fertilizers supplied in varying amounts.

	NO_3-N in leaves (% dry wt)				
	N applied, mg/pot				
Fertilizer	0	100	200	400	800
Avg of 5 organic	0.06a[z]	0.11a	0.30b	0.52c	0.79d
Ammonium nitrate	0.06a	0.18ab	0.50b	0.60c	0.77d

[z]Mean separation by Duncan's multiple range test, 1% level.

Table 6. Mineralization of N in the organic fertilizers used in this study (23).

Fertilizer	N concn	Conversion of organic N to NO_3-N (% in 40 days)
Dried blood	13.8	66
Castor pomace	5.0	67
Cottonseed meal	7.2	54
Sewage sludge[z]	5.7	53
Dried cow manure[y]	2.0	7

[z]Milorganite.
[y]Bovung.

Response of tomato plants to organic P fertilizers

The effects of bone meal and colloidal rock phosphate on the growth of tomato plants were compared with the growth responses obtained with superphosphate. The tomato plants were 6-week old transplants which were placed in a sandy loam soil with a low P status and with a pH of 4.8. The soil was contained in 15-cm plastic flower pots, and 2 g of the P fertilizers, each of which was 8.8% P, were incorporated into the soil. One tomato plant was grown in each pot for about 6 weeks, after which the development of deficiency symptoms were evaluated, and the shoots were harvested and weighed. This study was made each spring for two years with nearly identical results. Colloidal rock phosphate did not improve growth and plant appearance relative to adding no P fertilizer, whereas good growth response and no P deficiency symptoms were observed with bone meal or superphosphate (Table 7). Although not reported in Table 7, liming the soil to pH 6.5, adding 100 g of peat moss per pot of soil, or using these two factors in combination slightly improved the effectiveness of all three fertilizers. However, under these conditions the colloidal rock phosphate remained wholly inadequate.

Response of tomato plants to natural K fertilizers

We have reported previously (8) that tomatoes growing on excessive NH_4-N nutrition form stem lesions but that the lesion formation can be prevented if adequate K is made available in the soil in which the plants are growing. Granite dust (5% total K, 0% available K), wood ashes (2% available K), and KCl (50% available K) were tested for two years for their effectiveness in meeting the K requirements of tomato plants receiving excessive NH_4-N nutrition. Six-week old tomato plants were transplanted into 15-cm flower pots, using the same kind of potting soil as described above for the spinach. Before potting, the K fertilizers were mixed into the soil to provide the amounts of K in the treatments shown in Table 8. The plants were allowed to grow for 1 week to overcome the transplanting shock. After this time, 100 ml of 0.04 N $(NH_4)_2SO_4$ was given 5 times weekly for 3 weeks; then the development of lesions was determined, and the shoots were harvested and weighed. For prevention of tomato stem lesions, granite dust was no better than no K fertilizer (Table 8). Wood ashes fully eliminated the formation of stem lesions at all levels of K application. On the other hand, lesion formation was depressed as the amount of KCl increased. The complete effectiveness of wood ashes at all levels of application was probably because the ash contained some Ca and Mg as well as K (8). Granite dust is insoluble and overapplication of this material was not evident (Table 9). However, growth depression was quite evident with excessive applications of wood ashes or KCl. The wood ashes were much more harmful to plant growth than the KCl at high quantities of K application.

Table 7. Effects of P fertilizers on growth of 'Heinz 1350' tomato plants.

Fertilizer	Fresh (g/plant)	P deficiency rating[z]
None	15a[y]	2.7b
Colloidal Rock phosphate	16a	2.5b
Bone meal	30b	0a
Superphosphate	38b	0a

[z]0 = no P deficiency, 3 = severe P deficiency.
[y]Mean separation within columns by Duncan's multiple range test, 5% level.

Table 8. Effects of K fertilizers on the susceptibility of 'Heinz 1350' tomato plants to NH_4 toxicity.

Amount of K added (g/pot)	NH_4 injury rating[z]		
	Granite dust	Wood ashes	KCl
0	2.6b[y]	2.6b	2.6b
0.4	–	0a	0.8a
0.8	2.8b	0a	0.4a
1.6	2.8b	0a	0.2a
3.2	2.4b	0a	0a

[z]Visual rating of stem lesion formation, 0 = no injury, 3 = severe injury.
[y]Mean separation by Duncan's multiple range test, 1% level.

Table 9. Effects of K fertilizers on the fresh wt of 'Heinz 1350' tomato plants.

Amount of K added (g/pot)	Fresh wt (g/plant)		
	Granite dust	Wood ashes	KCl
0	88b[z]	88b	88b
0.4	–	113c	121c
0.8	94bc	75b	116c
1.6	99bc	40a	100bc
3.2	99bc	34a	76b

[z]Means separation by Duncan's multiple range test, 1% level.

Conclusions and summary

Fertilizers do have an effect on the mineral composition of vegetables, but their effects on the contents of vitamins, proteins, fats, carbohydrate, and other nutritional factors of vegetables are much more complex, undoubtedly because of the masking effects of environmental and genetic factors. No experimental results or surveys have ever shown any differences in nutritional quality of plants grown organically or conventionally with modern fertilizers. Actual data making these comparisons, however, are scarce, and unavoidable deficiencies in the experiments or results often prevent unequivocal conclusions.

It is clear that equivalent yields of crops can be produced organically or chemically, if the availabilities of nutrients are equivalent and if no toxicological properties are inherent in the fertilizer materials. Fertilizers which are very insoluble such as granite dust or rock phosphate and fertilizers which mineralize slowly such as dried cow manure (23) may not provide N, P, and K rapidly enough to meet crop needs unless application rates are very high. With granite dust, even increased quantities of application appear to be inadequate to meet the K requirements of crops.

Agronomic research has clearly shown that the organic matter content of soils can be maintained by either organic or conventional chemical farming (2, 14, 17, 20, 21), and, hence, none of the beneficial effects of organic matter on soil properties are lost by either means of agriculture. Either organic or chemical fertilizer when used properly will not have any adverse effect on environmental pollution, but if used improperly, either form can have deleterious effects on the environment.

Economics is a major consideration when evaluating organic fertilizers with respect to chemical fertilizers. The cost of organic fertilizers is a major contributor to the price differential between organically-grown vegetables and regular vegetables. On the basis of their primary nutrient contents, organic fertilizers cost from 10 to 100 or more times as much as modern chemical fertilizers. Therefore, although one can grow vegetables of equal quality by either means of culture, costs of producing organic vegetables are much greater. As a result, the consumer pays at least twice as much for organic foods as for those which do not bear the organic label (6).

Emotional factors undoubtedly are important in the choosing of organic farming over conventional methods or, on the other hand, aside from the costs, choosing of conventional methods over organic farming. If one leaves out any emotional factors, he must reach two conclusions. One conclusion is that he must agree with the organic farmer who says that if some people are willing to work hard and to bear the expense of producing food organically and if some people are willing to buy the food, then one should not be concerned, particularly if organic farming keeps some farmers in business. Obviously, organic farmers are not major competitors with the farmers who produce the bulk of our food. Additionally, one must conclude that much of the increase in productivity of agriculture in the past 30 years has been through the development and use of modern chemical fertilizers. All of the large farms which produce almost all of our vegetables make full use of chemical fertilizers.

It seems reasonable to conclude that both organic and chemical fertilizers have a role in agriculture. Organic farming apparently keeps some people on the farm and satisfies the demands of certain consumers as well as providing recreation to gardeners and recycling wastes and returning their nutrients to the soil. On the other hand, chemical fertilizers help to maintain high crop yields (29) and to provide us with cheap, abundant, and diversified foods. Neither organic nor chemical farming should be banned, but the good points of each should be recognized and emphasized, and the advocates of each method should live in peace with one another.

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