

study also showed that cuttings taken early in the season were less vegetative than those taken in August and September.

The light intensity and light duration to completely keep the standard cultivars vegetative is 10 to 20 foot-candles for one hour in the middle of the night. A recent experiment on 'Paul Mikkelsen' grown at 70° F revealed that lighting for four hours (10 p.m. to 2 a.m.) with a minimum of 10 foot-candles is necessary to prevent flower bud initiation. This points out that this new introduction is relatively less sensitive to artificial light when compared to standard cultivars.

This series of experiments has resulted in the following recommendations to reduce the amount of premature budding in 'Paul Mikkelsen': (1) Keep the stock plants vegetative all year by lighting the plants each night with a minimum of 10 foot-candles for four hours in the middle of the night. (2) Grow the stock plants at minimum night temperatures of 70° F. (3) Do not allow the shoots of the stock plants to exceed 10 inches at the time the cuttings are made. If the cuttings are not required at that time, the plants should be pruned to keep the shoots below the minimum length.

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Photo 2. 'Paul Mikkelsen' plant about two months after Christmas. Note that it retains its leaves and bracts. No support was required for this multiple stem plant.

# EXCESS PHOSPHORUS and IRON CHLOROSIS

P. C. DE KOCK • A. WALLACE

High concentrations of phosphate in plants cause a typical iron deficiency chlorosis with characteristic mineral and biochemical patterns. Studies show that organic acids in leaves are involved in the absorption and distribution of minerals, particularly calcium and potassium, and that their behavior is controlled by an iron-phosphate balance.

**T**HE METABOLISM of iron in living organisms is known to be required for the synthesis of chlorophyll, although the exact location of this function is still unknown.

Iron-deficient plant tissues are often found to contain higher quantities of citric acid than green plant tissues. Since it has been demonstrated in animal tissues that the enzyme responsible for the breakdown of citric acid requires iron in the ferrous or reduced form for its activity, lack of ferrous iron leads to reduced activity of the enzyme and to accumulation of citric acid in the tissues. Addition of ferrous iron restores activity of the enzyme and causes the level of citric acid in the tissues to fall. Studies of this aconitase enzyme in plant leaves show that its activity is much less in iron-deficient leaves than in green leaves containing adequate iron. Although addition

of iron to the surface of chlorotic leaves causes a rapid increase in enzyme activity, it has not been possible to isolate this action in a particular system.

Iron-deficient leaf tissues also contain less malic acid than the green leaf tissue, which is compatible with the theory that these acids are metabolized in a cycle—the so-called Krebs or citric acid cycle. This difference is highlighted when the ratio of citric acid to malic acid is considered. These acids are now quantitatively estimated by techniques of column chromatography on silica gel, using a gradient elution system of mixed solvents with increased solubility for various acids. The amount of malic acid contained in a leaf is often equal to the amount of calcium it contains; hence, the genesis of malic acid would appear to be connected with calcium accumulation. Blockage of the formation of malic acid by iron deficiency thus leads to a lower calcium content of the leaf.

An almost perfect relationship between the amount of calcium in a leaf and the oxalic acid content has long been known in plants which contain large amounts of this acid; and, in fact, crystals of calcium oxalate can be observed in many plant tissues. In the past, oxalic acid was considered poisonous and a waste product of metabolism, the plant eliminating it by precipitation with calcium. Recent studies indicate, however, that oxalic acid may arise via a "shunt" or side re-

ANALYSIS OF HEALTHY LEAVES AND CHLOROTIC LEAVES OF RASPBERRY VARIETY, MALLING JEWEL—SOIL ANALYSIS SHOWED HIGH PHOSPHATE CONTENT TO BE ASSOCIATED WITH THE CHLOROSIS

Leaves	Per cent in dry matter						Ratio	
	P	Fe	K	Ca	Na	Mg	P/Fe	K/Ca
Healthy	.22	.015	2.42	1.34	.03	.27	14.4:1	1.8:1
Chlorotic	.66	.005	2.96	0.30	.06	.29	130.2:1	10.0:1

action of the citric acid cycle. The genesis of oxalic acid is similarly linked to the activity of the enzyme aconitase, and its formation would be suppressed under conditions of iron deficiency.

The only other major nutrient cation which can compensate for this loss is potassium, since in most plants sodium and magnesium are taken up in much smaller amounts. Hence, differences in iron nutrition are also shown in the relationships between potassium and calcium, the iron-deficient tissues being characterized by higher ratios of potassium to calcium than the green tissues.

Investigators have repeatedly found that iron-deficient leaf tissues contain as much or more iron than the green tissues, and that so-called absolute iron content is not a valid criterion of iron deficiency. Very often the phosphorus content of such deficient tissues is greater; so it appears that it is really the ratio of phosphorus to iron which determines whether a tissue will appear chlorotic or healthy. Although the exact distribution of iron between the various structures in the cell is not known with certainty, attachment to phosphoproteins such as nucleic acids has been inferred and certain iron proteins containing phosphorus such as phytoferritin have been identified. Hence, addition of excessive amounts of phosphate to plants can be expected to induce a chlorosis which can be corrected by addition of iron—phosphorus toxicity, therefore, becoming equivalent to iron deficiency.

Although such toxicity effects are easily reproduced in the laboratory, they are rarely observed in the field. Such effects were discovered recently, however, in a raspberry plantation in which the new canes showed typical iron deficiency chlorosis. The soil contained abnormally high amounts of phosphate, although other factors were normal. The table shows that the chlorotic leaves contained more phosphorus and less calcium than the green leaves, so that the phosphorus-iron and potassium-calcium ratios were higher in the chlorotic than in the green leaves. Analyses of the organic acids of these leaves showed again that the chlorotic leaves contained greater amounts of citric acid and less malic than the green leaves (see graph), and the citric-malic ratio followed the trend of the phosphorus-iron and potassium-calcium ratios. Hence, excess phosphate in the soil caused changes in leaf composition which are characteristics of iron deficiency.

The amounts of nutrients as well as the relation of those amounts to each other are crucial in plant nutrition, and an excess of one nutrient may cause a deficiency of another. Moreover, such deficiencies or excesses can alter characteristic metabolic patterns.

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Training or shaping trees for easier harvesting must take into account yield reduction from pruning operations. Reshaping mature Valencia trees by slab pruning resulted in 80% less fruit, according to this report of a two-year trial conducted by the Citrus Research Center and the Agricultural Extension Service.

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J. E. PEHRSON

Valencia orange tree pruned as a 5-ft-thick hedge. The fruit-producing canopy has become a wall. Such a bearing surface offers easy picking. An inexpensive rolling scaffold with fruit-handling system could be utilized for greater harvesting efficiency. This pruning and training was too severe for mature orchards, and yield was reduced 80% over two years. Training young trees with closer spacings appears more feasible.



Iron-deficient leaf tissues contain more citric acid and less malic acid than healthy leaf tissues of the Malling Jewel raspberry. (Figures inside graph refer to milliequivalents per kilogram of fresh leaf tissue.)

