NUTRIENT DEFICIENCIES IN THE STRAWBERRY LEAF
AND FRUIT

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(WITH SEVEN FIGURES)

Introduction

Previous investigational work on the nutrition on the strawberry has been concerned largely with the relationship of soil and fertilizer treatment to growth and yield (5). While these studies have increased greatly the knowledge of the fertilizer requirements of the strawberry, they did not describe the symptoms of mineral deficiencies nor show the mineral composition of the plant and fruit. It would appear that foliar symptoms and mineral composition of the plant might be correlated with nutritional needs. In this connection the most notable contribution has been made by DAVIS, HILL, and JOHNSON (4). They found that foliar symptoms could be correlated with nutritional needs and that certain positive and negative correlations existed between pairs of elements in the ash of the plant. These relationships were established for the Parson Beauty variety grown under outdoor conditions in Canada. Water color illustrations of potassium-, phosphate-, and nitrogen-deficient strawberry leaves (variety not mentioned) have been published by DAVIS and HILL (3). HOAGLAND and SNYDER (6) have reported on the effects of potassium, phosphate, chloride, and boron on the growth of the strawberry plant in water cultures in California.

The effect of certain mineral deficiencies on leaf characteristics and associated mineral composition of the foliage and fruit of the strawberry is reported herein. The Klondike and the Blakemore were used as these are the two leading commercial varieties grown in North Carolina.

Materials and methods

In this study, dormant plants of Blakemore and Klondike, with fruit buds well formed, were removed from uniformly fertilized fields to the greenhouse early in January. The roots were washed free from soil, the old leaves were removed, and the plants were set in washed quartz sand in two-gallon glazed earthenware containers which were provided with drainage. Two plants were set in each container and twenty plants of each variety were included in each treatment. The mineral content of dormant field-grown Klondike strawberry plants was determined at the beginning of the experiment. The composition of the respective nutrient solutions employed is shown in table I. These solutions were buffered at pH 5.6 and were applied daily, using the sand-culture technique. Preliminary studies of the

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growth of strawberry plants in sand cultures indicated that the presence of chlorides in the nutrient solutions was objectionable except at very low concentrations. High concentrations of sulphate ions also proved objectionable. The chloride ion was, therefore, omitted from all nutrient solutions and sulphate concentrations were kept low (table I).

**TABLE I**

**Composition of nutrient solutions**

<table>
<thead>
<tr>
<th>Series</th>
<th>Partial volume molecular concentration of salts</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ca(NO₃)₂</td>
</tr>
<tr>
<td>Complete</td>
<td>0.004</td>
</tr>
<tr>
<td>Minus-Ca</td>
<td>0.004</td>
</tr>
<tr>
<td>Minus-K</td>
<td>0.004</td>
</tr>
<tr>
<td>Minus-Mg</td>
<td>0.004</td>
</tr>
<tr>
<td>Minus-P</td>
<td>0.004</td>
</tr>
<tr>
<td>Minus-S</td>
<td>0.004</td>
</tr>
</tbody>
</table>

* Boron at the rate of 0.5 p.p.m. and manganese, iron, zinc, and copper at the rate of 0.25 p.p.m. were added to all nutrient solutions.

The studies were made during the fruiting stage of development in January and February. Mature leaves showing deficiency symptoms were sampled for chemical analysis and ripe fruits from the plants receiving the various treatments were sampled at the time the leaf deficiency symptoms appeared. The fresh leaves and fruit were extracted and analyzed by the procedure described by Burkhart and Page (1).

**Results**

**Nutrients in foliage and fruit**

At the beginning of the experiment, samples of dormant field-grown Klondike plants were taken for the determination of the soluble minerals present in the leaf blades, petioles, crowns, and roots (table II). In the dormant state, there was a considerable accumulation of potassium in the roots as compared with that in leaves and crowns. Soluble calcium, mag-
nesium, and phosphate were somewhat localized in the leaf blades. Petioles were low in soluble calcium and sulphate and the crowns were relatively very low in soluble calcium.

After growing in sand culture for about two months, until they fruited and deficiency symptoms were apparent, determinations were made of the soluble-nutrient levels in both leaves and fruit of the Blakemore variety, with the results shown in figures 1 and 2. The potassium concentrations of

![Fig. 1. Soluble nutrients (expressed as parts per million in foliage and fruit) found in Blakemore strawberry plants, grown in nutrient solutions with the indicated deficiencies in certain elements, and in complete nutrient solution.](image1)

![Fig. 2. Soluble nutrients (expressed as parts per million in foliage and fruit) found in Blakemore strawberry plants, grown in nutrient solutions with the indicated deficiencies in certain elements, and in complete nutrient solution.](image2)

both leaves and fruit were greatly affected by the ionic nature of the nutrient. Lack of calcium, and especially of magnesium, resulted in a marked increase in potassium in the foliage and the fruit as compared with the effects of the complete nutrient treatment. Plants grown in the potassium-deficient nutrient solution produced foliage containing 1200 p.p.m. of potassium and fruit with 400 p.p.m. of this element, each value being about one-third of that for plants in the complete nutrient series. In the complete nutrient treatment the potassium concentration in relation to the other three soluble minerals was much less in the fruit than in the leaves. There was practically no soluble phosphate in either foliage or fruit at the time phosphorus deficiency symptoms were evident.
Fig. 3. Soluble nutrients found in Klondike strawberry plants grown in solutions with the indicated deficiencies in certain elements and in complete nutrient solution. Expressed in parts per million of fresh foliage and fruit.

In the Klondike variety (figs. 3 and 4) the concentration of soluble potassium and calcium in both leaves and fruit of plants that received complete nutrient solution were much higher than in the Blakemore variety. The ionic antagonistic effects of potassium and magnesium upon the concentrations of their ions in the foliage and fruit of Klondike were very much the same as in the Blakemore. The relatively high potassium concentration in the fruit of Klondike in relation to other soluble minerals was also evi-

Fig. 4. Soluble nutrients found in Klondike strawberry plants grown in solutions with the indicated deficiencies in certain elements and in complete nutrient solution. Expressed in parts per million of fresh foliage and fruit.
dent. Soluble phosphate also accumulated in potassium-deficient foliage and fruit. The accumulation of soluble phosphate was very marked in nitrogen-deficient leaves. In the fruit, potassium accumulation in high degree was associated with nitrogen deficiency.

Davis et al. (4) also found negative correlations in the leaf ash of the Parson Beauty variety of K₂O with CaO, MgO, P₂O₅, respectively, but a positive correlation of MgO with P₂O₅. Wallace (8) has reported a high nitrogen content of strawberry fruit when potassium was deficient in the nutrient medium.

DEFICIENCY SYMPTOMS

Potassium deficiency.—A distinct varietal difference was noted in the potassium deficiency symptoms on the leaves. In the Klondike variety, potassium deficiency was characterized by progressive necrosis of the petioles just below the leaflets as shown in figure 5, B and C. Concurrently the mid-

![Figure 5](https://www.plantphysiol.org)  
**Fig. 5.** Potassium deficiency symptoms in strawberry leaves. A, healthy leaf of the Klondike variety; B and C, progressive necrosis in petioles of this variety; D, marginal leaf scorched in the Blakemore variety.

ribs of the leaflets became purple. As a result of the breakdown of the conducting tissue in the petioles the leaflets wilted and soon dried up. In the Blakemore variety, though analysis showed the potassium level to be about the same as in the Klondike, this type of injury was not observed. In the Blakemore there was a marginal necrosis of the leaflets which gradually rolled upward and inward (fig. 5, D) and the younger leaflets became light green to yellow between the veins. In the early stages of potassium deficiency, the fruit of both varieties had a normal external appearance but many ripe Klondike fruits had dead calyces. In more advanced stages of potassium deficiency, the wilting and drying up of the pedicels and peduncles resulted in considerable shriveling of fruits.

Davis and Hill (3) described potassium deficiency symptoms (variety not mentioned) in the following manner: “In early stages the plants were dark green in color which lasted well into the fruiting season; however, they were smaller and less vigorous than those receiving complete nutrients.
The leaves gradually lost their luster and by the end of the fruiting season began to curl. A bronzing and considerable purpling was observed on the under surface of the leaflets by late summer."

Hoagland and Snyder (6) in studying potassium deficiency of the Marshall, Ohmer, and Klondike strawberries did not find marginal scorch prominent in any of these varieties, but reported bronzing and necrosis of the petiole and base of the blade.

Calcium deficiency.—In both the Blakemore and Klondike varieties, symptoms of calcium deficiency first appeared as injury to the roots followed by injury to the leaves. A marked varietal difference in the appearance of calcium deficient leaves was evident. Calcium deficient Blakemore plants made much more growth than did the Klondike plants (figs. 6 and 7). Symptoms in the Blakemore foliage, however, were evident as in figure 4. The younger leaves were much deformed and crinkled, and exhibited tip burn. In contrast, the younger Klondike leaves were not crinkled but the older leaves lost their luster and became somewhat mottled. Later these older leaves became flaccid and internal breakdown of tissue was evident, suggesting that calcium had been translocated to some extent from them to the younger leaves. The fruits of calcium deficient plants of both varieties were very much deformed while still green and were still small when ripe.
The calyces of the ripe fruit of the Klondike variety all died, a condition also noted in potassium deficiency.

Davis et al. (4) reported that calcium deficient plants of the Parson Beauty strawberry grew vigorously during the summer and did not develop leaf blotch until early fall, after which leaf growth was restricted.

Magnesium Deficiency.—Early stages of magnesium deficiency in the Klondike foliage were characterized by the downward and inward rolling of the yellowish-green leaf margins. In later stages the upper surface of the leaf blades between the veins became a yellowish-orange color except in the region along the midrib. Brown necrotic areas appeared on the under surface of these leaves. These symptoms also appeared in magnesium deficient Blakemore foliage.

Davis et al. (4) reported that in summer the magnesium deficient series were the most vigorous of his experimental plants. The large leaves were of normal color until late August when characteristic brown patches, mostly confined to the leaf margins, developed. Abscession of these brown patches gave the leaves a ragged appearance. The petioles were always longer than those in the normal series.

Phosphate Deficiency.—Early stages of phosphate deficiency in both varieties were characterized by an intensified blue-green coloration of the foliage. This was accompanied by reddening of the leaf margins. In later stages the entire surface of the older leaf blades became bronzed and purpled due to the red pigments overlying the blue green. The petioles became red and brittle and the midribs and veins on the under surface of leaf blades showed the purple coloration that suggested a physiological nitrogen deficiency. The leaves were not as thick as the leaves of normal plants and the petioles were shorter. In more advanced stages of phosphate deficiency the plants were much dwarfed and the older leaves became brown and dry. Davis et al. (4) observed similar symptoms in the Parson Beauty variety in Canada.

Nitrogen Deficiency.—In early stages of nitrogen deficiency the serrations at the margins of older leaves became red. As nitrogen deficiency progressed, the younger leaves developed more slowly and appeared yellowish green. Later a reddening gradually extended over the entire leaf surface. The petioles, which were shorter than in the plants receiving complete nutrients, became red and brittle. In advanced stages of nitrogen deficiency the older leaves became light yellow with browning and necrosis of localized areas. The ripe fruit was small and the plants developed few feeding roots. In general, these nitrogen deficiency symptoms are in agreement with those described by Davis and Hill (2) and by Davis et al. (4). For the Aroma strawberry, Long and Murneek (7) found that the nitrogen content of leaves decreased rapidly during senescence, with a simultaneous increase in the roots and stems. They further reported that the roots accumulated 30 to 40 per cent. of the total amount of nitrogen found in the plant during the winter.
The mineral deficiency symptoms in the leaves of the Klondike and the Blakemore varieties as grown under the conditions reported herein are summarized in table III. Where there were differences in the symptoms between the young and old leaves such differences are listed. Varietal differences were greatest in the symptoms of calcium and potassium deficiencies. These differences were evident in the young leaves for calcium deficiency,

<table>
<thead>
<tr>
<th>Nutrient Deficiency</th>
<th>Variety</th>
<th>Symptoms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calcium</td>
<td>Klondike</td>
<td>Young leaves: dwarfed, with marginal scorch, followed by death of buds.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mature leaves*: loss of luster and turgor, followed by mottling.</td>
</tr>
<tr>
<td></td>
<td>Blakemore</td>
<td>Young leaves: dwarfed and wrinkled near tips.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mature leaves: loss of luster and turgor followed by yellowing.</td>
</tr>
<tr>
<td>Potassium</td>
<td>Klondike</td>
<td>Mature leaves: progressive purpling of midrib and petiole, followed by necrosis of petiole.</td>
</tr>
<tr>
<td></td>
<td>Blakemore</td>
<td>Mature leaves: margins of leaf blades scorched and rolled upward.</td>
</tr>
<tr>
<td>Magnesium</td>
<td>Klondike</td>
<td>Mature leaves: chlorosis of outer portion, followed by downward rolling of leaf margin.</td>
</tr>
<tr>
<td></td>
<td>Blakemore</td>
<td>Midribs and veins on under surface of leaf becoming purpled.</td>
</tr>
<tr>
<td>Phosphate</td>
<td>Klondike</td>
<td>Young leaves: dark blue-green, and retarded in growth.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mature leaves: intensified blue-green accompanied by reddening of the leaf margins, the leaf blades later becoming bronzed and purple and petioles bright red.</td>
</tr>
<tr>
<td></td>
<td>Blakemore</td>
<td>Midribs and veins on under surface of leaf becoming purpled.</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>Klondike</td>
<td>Young leaves: in more advanced stages, light green to yellow; growth restricted.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mature leaves: in early stages, the serrations of older leaves reddened. Later the entire leaf surface reddens, the older leaves finally becoming bright yellow accompanied by necrosis and browning of localized areas.</td>
</tr>
<tr>
<td></td>
<td>Blakemore</td>
<td></td>
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</tbody>
</table>

* A mature leaf as used herein refers to fully expanded turgid leaves.

and in the mature leaves for potassium deficiency. No varietal difference in symptoms was observed for magnesium, phosphorus, or nitrogen deficiency. Hoagland and Snyder (6) found Nick Ohmer strawberry to be less susceptible than Marshall to nutrient deficiencies, and Klondike to be the variety least susceptible to boron deficiency.

**Discussion**

The composition of the leaves of plants given a complete nutrient solution for about 2 months differed from that of dormant plants at the beginning of the experiment chiefly in the greater content of potassium. Analysis of
the leaves of plants in the deficiency tests after symptoms were evident indicates that their calcium, magnesium, and phosphorus content, as well as potassium content, may vary greatly depending on the supply. It would seem, therefore, that foliar analysis as an index to the nutrient condition of the plant might be practical.

In general, the nutrient content of the strawberry fruit followed that of the leaves but was not so high. Characteristic foliage symptoms of nutrient deficiencies were observed. For the most part they correspond to those observed in the strawberry by other investigators but additional symptoms were recorded. Particularly evident were the differences in the calcium and potassium deficiency symptoms for the Klondike variety as compared with the Blakemore. This indicates the need for a study of the symptoms for different varieties in order to make a correct diagnosis of deficiencies.

**Summary**

1. Foliar symptoms of potassium, calcium, magnesium, phosphate, and nitrogen deficiencies are described for both Blakemore and Klondike strawberry varieties during the fruiting stage of growth.

2. Marked varietal differences in potassium and calcium deficiency symptoms are noted and illustrated.

3. Soluble minerals were determined in the foliage and fruit of plants receiving the various nutrient treatments, and the results obtained are illustrated.

4. In the complete nutrient treatment of each variety the potassium concentration in relation to other soluble minerals in the fruit was high as compared with the same relationship in the leaves.

5. There were only traces of soluble phosphate in the foliage and fruit at the time phosphate deficiency symptoms were evident.

**LITERATURE CITED**


