The Effects of Leaf Position and Time of Sampling on Nutrient Concentration in the Petiole Sap from Tomato Plants Cultured Hydroponically

Yiqing He, Satoshi Terabayashi and Takakazu Namiki
Faculty of Agriculture, Kyoto Prefectural University, Sakyō-ku, Kyoto 606-8522

Summary

Tomato plants (Lycopersicon esculentum Mill. cv. Momotaro) were cultured hydroponically. The effects, under different weather conditions, of leaf position and sampling time of day on the concentration of nutrient elements in the petiole sap from leaves under the fruit truss at two growth stages were investigated.

At the flowering stage of the second truss, the NO₃-N, P, and K concentrations in the petiole sap did not differ among the three leaves under the first truss. At the fruit growth stage of the second truss, no difference in the P and K concentrations existed among the three leaves under the second truss. The concentration of NO₃-N in the petiole sap collected from the leaf just below the second truss, however, was clearly lower than those of the other two adjacent leaves. At both growth stages, the higher the leaf position among the three leaves under the fruit truss, the lower were the Ca and Mg concentrations in the petiole sap.

Variations in the concentrations of nutrient elements in the petiole sap were minimal at different times of day and under differing weather conditions.

Key Words: hydroponic, tomato, diagnosis, sap analysis.

Introduction

The nutrient concentrations in fresh plant sap have been used to diagnose nutrient deficiencies and excesses and provide information for adjusting fertilization programs for many years. Plant sap analysis was developed by the Guernsey Horticultural Advisory Service, and is now being actively assessed in several countries, including the Netherlands, France, the UK, and the USA. The technique has been considerably expanded to provide a routine monitoring service specifically for rockwool-grown crops (Smith, 1987).

In Japan, plant sap analysis as a diagnostic tool of plant nutrient status was not established until recently. The climate, variety, and cultural methods of growing horticultural crops in Japan are different from those of the United States and Europe. The most popular variety of tomato in Japan is different from those in the Europe and USA in the absorption rate of nutrient and the ratio of fruit to vegetative growth. Therefore, we expect that similar techniques would not apply to the tomato grown hydroponically in Japan. Recent hydroponic culture of horticultural crops has advanced significantly, so that it holds an important position under protected horticulture in Japan. To promote wider use of the technique and to take advantage of its simple application to achieve high, stable production, it will be necessary to establish a quick and easy diagnostic technique for analyzing plant sap.

Plant sap analysis techniques include sampling the crop and laboratory procedures, such as sample preparation, its extraction, and extract analysis. The laboratory procedures of plant sap analysis were reported by He et al. (1996). In this study, we measured the concentration of nutrient elements in the petiole sap from the three successive leaves under the fruit truss of tomato plants cultured hydroponically, to understand the influence of leaf position on nutrient status in the petiole sap. Furthermore, we investigated the influence of sampling time of day under different weather conditions on the nutrient status of the petiole sap.

Materials and Methods

Experiment 1. The influence of leaf position under the truss on nutrient concentration in the petiole sap

Tomato seeds (Lycopersicon esculentum Mill. cv. Momotaro) were sown in trays containing an equal volume of nursery soil (Kureha, Co., Ltd.) and vermiculite on March 1992. At the 5-leaf stage, the seedlings were transplanted into beds containing a half-strength Enshi solution (Hori, 1966). The nutrient solution was aerated continuously with an air pump. Plants were topped above the third truss and 2.5 g of the main petioles, including their rachis, of each leaf under the first or second truss were collected from 6 plants at the flowering or fruit growth stage of the second truss. Samples were immediately packed into plastic bags, and
frozen until analyzed.

Samples were chopped into small pieces and homogenized by adding distilled water at a 1:10 ratio of sample (g) to water (ml). The mixture was filtered through No. 2 filter paper (Toyo Roshi, Co., Ltd.). Fifteen ml of the filtrate and 1.5 ml of 2M ammonium sulfate (ionic strength adjustor) were made up to 30 ml with distilled water. \( \text{NO}_3^-\text{N} \) concentration was monitored with a nitrate electrode (Orion Research, Co., Ltd., Model 701A), whereas those of K, Ca, and Mg were determined with an atomic absorption spectrophotometer (Shimadzu, Co., Ltd., AA-630-01).

Concentration of P in the petiole sap was measured on August 1996. The cultivar, culture system, sampling stage and sampling method were the same as in 1992 except that, 1) a small amount of activated carbon powder was added to the homogenate and 2) the homogenate was diluted at a 1:5 ratio with distilled water and then filtered through No. 2 filter paper. One ml of filtrate was mixed with 10 ml ammonium vanadomoly-

date solution acidified with nitric acid and diluted 50 times with distilled water; the P concentration was determined with a spectrophotometer (Hitachi, Co., Ltd., Model 100-50) set at 400 nm.

Experiment 2. The influence of sampling time of day under different weather conditions on nutrient concentration in the petiole sap

Tomato seeds were sown in trays containing nursery soil on August 1994. At the 3-leaf stage, the seedlings were transplanted into beds containing the nutrient solution in which 50me \( \text{NO}_3^-\text{N} \) and 20me P per plant were supplied weekly. Other nutrient elements were maintained at half-strength Enshi solution. This feeding program had been tested for optimum nutrient supply for tomato fruit growth by Terabayashi et al. (1993, 1995, 1996). Plants were topped above the fourth truss. At the harvest stage of the first truss, 3 g of petiole from each leaf just below the second and the fourth trusses were sampled from 6 plants at 10:00, 13:00, and

![Graphs showing concentrations of elements in the petiole sap](image)

**Fig. 1.** Concentrations of elements in the petiole sap from the three leaves under the first truss at the flowering stage of the second truss (Mean±SE). The number of leaf position was counted from the leaf just below the first truss. The concentration of P was determined in 1996, the concentration of other elements were determined in 1992.
16:00 hr on a rainy day (Dec. 9) and a sunny day (Dec. 15). Air temperature, relative humidity, and photosynthetic photon flux (PPF) were recorded at each sampling time. Samples were immediately packed into plastic bags and frozen until analyzed.

The extraction method of petiole sap was similar to that described in Experiment 1. Electrical conductivity (EC) of the filtrate was determined with an EC meter (Horiba, Co., Ltd., Model C-173). A 0.1 ml aliquot of the filtrate was diluted 500 times with distilled water and the NO$_3$-N concentration determined with a spectrophotometer set at 210 nm. The P, K, Ca and Mg concentrations in the petiole sap were determined as in Experiment 1.

**Results**

**Experiment 1. The influence of leaf position under the truss on nutrient concentration in the petiole sap**

At the flowering stage of the second truss, there was no difference in the NO$_3$-N, P, and K concentrations in the petiole sap among the three leaves under the first truss. The higher the leaf position among the three leaves under the first truss, the lower were the Ca and Mg concentrations in the petiole sap (Fig. 1). At the fruit growth stage of the second truss, there was the same trend in the P, K, Ca, and Mg concentrations in the petiole sap among the three leaves under the second truss as those under the first truss at the flowering stage of the second truss. The concentration of NO$_3$-N in the petiole sap of the leaf just below the second truss, however, was clearly lower than those of the two adjacent leaves (Fig. 2).

**Experiment 2. The influence of sampling time of day under different weather conditions on nutrient concentration in the petiole sap**

Figure 3 shows the concentrations of nutrient ele-
ments and EC in the petiole sap from tomato plants collected under different weather conditions.

The concentrations of NO₃⁻N, P, Ca and Mg, and EC were higher in the leaves below the second than those below the fourth truss. The K concentration fluctuated considerably. The Ca and Mg concentrations on the rainy day were always higher than those on the sunny day, although no such trend was observed in other nutrient elements or EC. The EC value varied little between the rainy and the sunny days. The concentration of each element and EC value did not show any particular trend related to the sampling time of day.

Although air temperature, relative humidity and PPF varied considerably at different times of day on each sampling date (Table 1), variations in the concentrations of nutrient elements in the petiole sap were minimal (Fig. 3).

Fig. 3. Concentrations of elements and EC in the petiole sap from the leaf just below the second and the fourth trusses of tomato plants collected on the rainy (●) and the sunny (○) day (Mean±SE). Rainy weather conditions : Dec. 9, 1994. Fine weather conditions : Dec. 15, 1994.
Table 1. Air temperature, relative humidity and photosynthetic photon flux (PPF) under different weather conditions of the sampling days.

<table>
<thead>
<tr>
<th>Factors</th>
<th>Sampling time on rainy day</th>
<th>Sampling time on fine day</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>10:00 13:00 16:00</td>
<td>10:00 13:00 16:00</td>
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<tr>
<td>Air temperature (°C)</td>
<td>17 17 17 29 26 21</td>
<td></td>
</tr>
<tr>
<td>Relative humidity (%)</td>
<td>100 100 100 72 54 69</td>
<td></td>
</tr>
<tr>
<td>PPF ($\mu$E·m$^{-2}$·sec$^{-1}$)</td>
<td>45 33 6 260 205 31</td>
<td></td>
</tr>
</tbody>
</table>

Discussion

Experiment 1. The influence of leaf position under the truss on nutrient concentration in the petiole sap

Studies on photosynthesis, translocation, and distribution of assimilates in tomato plant by Shishido and Hori (1991) and Shishido et al. (1988, 1991) revealed that most assimilates distributed into the developing fruit were translocated from the leaves just below the respective fruit trusses. In our experiments, the concentration of NO$_3$-N in the petiole sap collected from the leaf just below the second truss was clearly lower than those of the other two leaves at the fruit growth stage of this truss. Larouche et al. (1989) reported that on a mature tomato plant, nitrate reductase was active mainly in leaves just below the developing fruit truss. Hageman et al. (1961) found that the peak of nitrate reductase activity in leaves corresponded with the depletion of leaf NO$_3$-N concentration. Shaner and Boyer (1976) reported that nitrate reductase activity was more closely related to the flux of nitrate rather than to the actual nitrate concentration in the leaf tissue. Consequently, the nitrate is metabolized rapidly in the petiole sap from the leaf just below the developing fruit truss during fruit development.

We found no difference in P and K concentrations in the petiole sap among the three leaves under the fruit truss at two growth stages. Thus, we conclude that leaf position was no effect on P and K concentrations during plant growth.

It was previously revealed that the higher the leaf position on the tomato plant, the lower were the Ca and Mg concentrations in the petiole sap (He et al., 1994a); we found the same tendency among the three leaves under the fruit truss at both growth stages.

Blossom-end rot (BER) of tomato fruit is a physiological disorder which is generally associated with Ca deficiency. El-Gizawy and Adams (1986) reported that very young fruit (7-14 days after anthesis) were most susceptible to this disorder which was reported earlier by Barke (1968) and Chiu and Bould (1976). Our data reveal that at the flowering stage of the second truss when the fruit of the first truss was setting, the concentration of Ca in the petiole sap from the leaf just below the first truss was clearly lower than those of the other two leaves under the same truss. He et al. (unpublished) postulated that it is possible to diagnose Ca deficiency based on the Ca concentration in the petiole sap from the leaf just below the fruit truss at the early flowering stage.

Experiment 2. The influence of sampling time of day under different weather conditions on nutrient concentration in the petiole sap

Temperature, humidity, and light intensity are important environmental factors for the growth and development of plants. In this study, the variation in the concentration of nutrient elements in the petiole sap from ‘Momotaro’ tomato plants was minimal, although air temperature, relative humidity, and light intensity varied significantly at sampling times on both sunny and rainy days. Ikeda et al. (1993) also reported that there was a slight diurnal variation of nutrients in the petiole sap from ‘TVR-2’ tomato plants cultured on nutrient solutions and that there was almost no change in the mineral status on account of the sampling time of day. Consequently, we believe that it is not particularly necessary to consider the sampling time of day for diagnosis on the nutrient status of tomato plants cultured hydroponically, but we agree with Colman (1987) that sampling at a fixed time of day should be an adequate precaution to minimize this potential variation.

We found little variance in the NO$_3$-N, P, and K concentrations and EC in the petiole sap attributable to collecting samples under different weather conditions, although Ca and Mg concentrations tended to be influenced. Ho (1989) assessed the effect of environmental factors on the diurnal accumulation of Ca by young fruit and leaves of tomato plants; he concluded that the accumulation of Ca by mature leaves and the shoot apex in the light was slightly affected by high humidity. However, the Ca and Mg concentrations in the petiole sap from tomato plants grown under shade for 7 or 25 days were lower than exposed plants (He et al., 1994b and unpublished data). In our study, rainy or cloudy weather conditions continued from Dec. 9 to 14 but cleared on Dec. 15. Therefore, we infer that the low concentrations of Ca and Mg in the petiole sap collected on Dec. 15 was a carry over effect of continuous low intensity light previous to the sampling day. We believe that sampling days of different weather conditions has no significant influence but that the continuous effect of weather conditions preceding the sampling day does have a significant influence on petiole sap nutrient status.

It should be noted that the high humidity conditions of rainy days favour the development of diseases and that wounds caused by petiole pruning often allow the entry of fungus (Watterson, 1986). Consequently, collecting samples under sunny day is preferable to rainy conditions to minimize the incidence of diseases.
Literature Cited


養液栽培されたトマトの葉柄汁液の無機養分濃度に及ぼす葉位、天候および採取時刻の影響

何 毅靖・寺林 敏・並木隆和

京都府立大学農学部 606-8522 京都市左京区下鴨半木町1

摘 要

トマト品種‘桃太郎’を養液栽培し、花房直下の3枚の葉につき、異なる生育段階、試料採取の時刻、天候が、葉柄汁液の無機養分濃度に及ぼす影響を調べた。

第2花房開花期に、第1花房直下の3枚の葉の間で、葉柄汁液の硝酸態窒素、リンとカリウムの濃度に違いは認められなかった。第2花房果実肥大期においては、第2花房直下の3枚の葉の間で、葉柄汁液のリンとカリウムの濃度に違いは生じなかったが、硝酸態窒素濃度は、花房直下の葉で著しく低くなった。いずれの生育段階においても、花房直下の3枚の葉の間で、葉柄汁液のカルシウムとマグネシウムの濃度は上位葉ほど明らかに低かった。

試料採取日の天候や時刻が異なっても、葉柄汁液の無機養分濃度の変動は小さかった。