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LEAF ANALYSIS AS A DIAGNOSIS OF NUTRITIONAL DEFICIENCY OR EXCESS IN THE SOILLESS CULTURE OF LETTUCE

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SUMMARY

The results are given of experiments to test wether leaf analyses can be used for diagnostic determinations of deficiency and excess in mineral nutrition of lettuce in soilless culture.

INTRODUCTION

In gravel culture, using lava as a substrate, lettuce develops quickly and a clean crop can be continuously produced with minimum labour.

The nutrient solution used in this culture was the universal solution used by Steiner[8] for the culture of horticultural plants. The solution was calculated for an osmotic pressure of 0.7 atm. (Table 1). This solution permits a certain variation in the mutual relation between the individual ions (Table 1), without any visible influence on the production or quality of the plants[8].

The object of the present paper is to determine the value of leaf analysis as a diagnosis for a deficiency or excess of elements by varying the concentration of individual nutrients beyond the limits given by Steiner but still without giving visual symptoms of defi-

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ciency or excess[9]. Under these conditions plants can complete their biological cycle, but their production will be decreased according to the level of deficiency or excess[3].

TABLE 1

Steiner's universal solution and its variations[8]

	NO_3^-	$H_2PO_4^-$	SO_4^{--}	K^+	Ca^{++}	Mg^{++}
Percentage of meq anions						
Universal solution	60	5	35			
Variations	50–70	3–10	25–45			
Percentage of meq cations						
Universal solution				35	45	20
Variations				30–40	35–55	15–30
Meq/l at 0,72 atm. osm. press.						
Universal solution	12	1	7	7	9	4
Variations	10–14	0.6–2	5–9	6–8	7–11	3–6

MATERIALS AND METHODS

Experimental

For this test beds with a surface of 2.88 m^2 (2.4 × 1.2 m) and a depth of 20 cm were used. The substrate was a porous lava, locally called 'picon', with particles of 5–10 mm diameter[1 6].

Plants were sown in a seedbed with a finer picon, diameter 2–5 mm, on the 15th of February and transplanted into the soilless culture on the 20th of March. The culture ended on the 3rd of May.

Table 2 shows the composition of the solution used in each treatment[7]. In all treatments the mutual ion relations are based on Steiner's universal solution, but the percentage of the variable ion is always beyond Steiner's limits given in the introduction, because it was considered that within these limits there would be no significant difference in crop production.

For studying the influence of a certain element in two or more nutrient solutions, it is necessary that all other factors in these nutrient solutions remain constant. This is not completely possible if extremely high or low levels of a certain element have to be compared; this enevitably gives changes in the total ion concentration. However, the differences in the total ion concentration are relatively small for most of the solutions (see atm. osmotic pressure in table 2), viz. 0.6 to 1.0 atm. Only the series with marked excess of nitrogen and the series with marked excess of potassium, have a rather high osmotic pressure, respectively 1.2 and 1.1 atm.

TABLE 2

Composition of the nutrient solutions (meq per litre, and mutual ratio) w = minor deficiency or excess, s = marked deficiency or excess

Meq per litre	NO_3^-	$H_2PO_4^-$	SO_4^{--}	K^+	Ca^{++}	Mg^{++}	Atm. osm. press.
Universal solution	12.0	1.0	7.0	7.0	9.0	4.0	0.7
s Mg excess	15.6	1.3	9.1	7.0	9.0	*10.0*	0.9
w Ca deficiency	12.0	1.0	7.0	10.2	*4.0*	5.8	0.8
s Ca deficiency	12.0	1.0	7.0	12.1	*1.0*	6.9	0.8
w N deficiency	*8.0*	1.5	10.5	7.0	9.0	4.0	0.7
s N deficiency	*4.0*	2.0	14.0	7.0	9.0	4.0	0.6
w N excess	*18.0*	1.0	7.0	9.1	11.7	5.2	1.0
s N excess	*24.0*	1.0	7.0	11.2	14.4	6.4	1.2
w K deficiency	12.0	1.0	7.0	*3.0*	11.8	5.2	0.7
s K deficiency	12.0	1.0	7.0	*0.5*	13.5	6.0	0.6
w K excess	14.4	1.2	8.4	*11.0*	9.0	4.0	0.9
s K excess	16.8	1.4	9.8	*15.0*	9.0	4.0	1.1
s S deficiency	17.1	1.4	*1.5*	7.0	9.0	4.0	0.8
s P deficiency	12.6	*0.0*	7.4	7.0	9.0	4.0	0.7
Universal solution + 20 meq NaCl/l	12.0	1.0	7.0	7.0	9.0	4.0	1.2
Mutual ratio	NO_3^-	$H_2PO_4^-$	SO_4^{--}	K^+	Ca^{++}	Mg^{++}	
Universal solution	60	5	35	35	45	20	
s Mg excess	60	5	35	35	45	*50*	
w Ca deficiency	60	5	35	35	*14*	20	
s Ca deficiency	60	5	35	35	3	20	
w N deficiency	*27*	5	35	35	45	20	
s N deficiency	*10*	5	35	35	45	20	
w N excess	*90*	5	35	35	45	20	
s N excess	*120*	5	35	35	45	20	
w K deficiency	60	5	35	*11*	45	20	
s K deficiency	60	5	35	*3*	45	20	
w K excess	60	5	35	*55*	45	20	
s K excess	60	5	35	*75*	45	20	
s S deficiency	60	5	*5*	35	45	20	
s P deficiency	60	*0*	35	35	45	20	
Universal solution + 20 meq NaCl/l	60	5	35	35	45	20	

The pH of all experiments was kept between 6 and 7. The following micronutrient concentrations were used in all treatments[4].

element	Fe	Mn	B	Zn	Mo	Cu
ppm	2	0.7	0.5	0.09	0.04	0.02

The variety of lettuce used was 'Blanca Romana'. This variety was chosen because it has smooth, separated leaves which permit easy observation of

any deficiency or excess symptom that might appear. The planting density was 25 plants per square meter.

Analytical determinations

The nutrient solutions were analyzed weekly for determining the additions of salts in order to maintain the nutrient concentrations in the solution more or less constant. Leaf analysis was carried out twice during the experiment, *viz* after 25 days of cultivation and at the end of the cultivation (43 days of cultivation).

For the leaf analysis three types of mineralization were made.

1. Destruction with sulphuric acid and oxygenated water for the determination of nitrogen and potassium. The nitrogen was determined using Lachica's method by semi-automatic valuation [5]. The potassium was determined by flame spectrophotometry.

2. Incineration at 550°C to obtain ash. This was diluted in hydrochloric acid to determine calcium and magnesium by atomic absorption spectrophotometry, sodium by flame spectrophotometry, sulphate by precipitation with barium chloride and phosphate colorometricly with ammonium metavanadate [2].

3. Incineration with magnesium nitrate at 350°C and diluting the ash in hydrochloric acid in which the phosphate was determined following the method mentioned sub 1.

The phosphate determination was carried out by two calcination methods because there could be a phosphorus loss with acid plants incinerated at 550°C [2]. As no differences between the values was found, the phosphorous for the second series only has been determined after incineration at 550°C.

RESULTS AND DISCUSSION

Magnesium excess

During the first four weeks growth on the magnesium excess solution was very vigorous, even stronger than on the universal solution. However, thereafter a reduction in growth occurred and, although the plants did not show external symptoms of toxicity, the weight was significantly lower for the plants growing on the high magnesium solution, with a decrease in yield of 26% compared with plants growing on the universal solution (see Table 4).

According to the results shown in Table 3 it may be concluded that when finding excessive magnesium values in the lettuce leaves, it is necessary to think more in terms of a possible potassium, calcium or phosphate deficiency than of a magnesium excess, as these treatments give higher magnesium values than the magnesium

excess treatment. For this reason it may be concluded that an excess of magnesium cannot be diagnosed by leaf analyses.

TABLE 3

Results of the leaf analysis

A = After 25 days of cultivation
B = At the end of the cultivation
w = minor deficiency or excess
s = marked deficiency or excess

% of dry matter	N		P		S		K		Ca		Mg		Na	
	A	B	A	B	A	B	A	B	A	B	A	B	A	B
Universal solution	4.9	4.1	0.5	0.4	0.2	0.3	7.0	7.8	1.1	0.9	0.4	0.2	0.6	0.4
s Mg Excess	3.9	4.6	0.6	0.6	0.4	0.4	6.7	8.6	1.0	1.2	0.5	0.4	0.8	0.9
w Ca deficiency	4.8	4.1	0.6	0.7	0.4	0.3	8.0	9.2	0.9	0.9	0.5	0.4	0.9	0.8
s Ca deficiency	5.1	4.3	0.7	0.8	0.4	0.3	7.5	9.4	0.4	0.4	0.6	0.6	1.2	0.9
w N deficiency	4.8	3.6	0.5	0.6	0.3	0.3	7.4	9.4	0.9	1.0	0.3	0.3	0.6	0.7
s N deficiency	4.7	3.0	0.6	0.8	0.4	0.5	7.7	8.7	1.0	1.0	0.3	0.4	0.7	0.8
w N excess	4.5	4.1	0.5	0.5	0.3	0.2	7.7	8.1	1.2	1.2	0.3	0.3	0.6	0.7
s N excess	4.8	4.2	0.5	0.6	0.3	0.1	5.6	7.9	2.0	1.5	0.5	0.4	0.9	0.6
w K deficiency	5.2	4.6	0.4	0.6	0.2	0.2	6.3	7.2	1.3	1.4	0.5	0.5	0.7	0.6
s K deficiency	4.6	3.9	0.5	0.4	0.3	0.2	2.2	1.8	1.5	1.2	1.0	0.7	2.1	2.0
w K excess	5.5	4.3	0.5	0.5	0.3	0.2	7.7	9.1	1.0	1.0	0.4	0.3	0.7	0.7
s K excess	5.1	4.5	0.5	0.5	0.3	0.2	8.9	9.1	1.0	0.9	0.4	0.3	0.7	0.6
s S deficiency	4.4	3.9	0.5	0.4	0.1	0.2	6.5	7.9	1.2	1.0	0.5	0.2	0.7	0.5
s P deficiency	4.3	—	0.2	—	0.4	—	7.4	—	2.0	—	1.3	—	1.4	—
s NaCl excess	—	4.1	—	0.4	—	0.3	—	6.6	—	0.9	—	0.3	—	1.7

Calcium deficiency

From the second week after planting a slower development has been noticed in the plants with calcium deficiency than in the plants on the universal nutrient solution. As expected, the development on the marked calcium deficiency solution was slower than on the weak deficiency solution.

The weak calcium deficiency gave a yield diminishing of 14%, the marked deficiency 30% (see Table 4). Moreover the marked deficiency showed visual symptoms after the fourth week. It started with a wrinkling and browning, without actually necrosis, especially in the tops of the young leaves, which form the central head. Finally all the plant tops died. In the older leaves a wrinkling and a slight form of umbrella could be observed. The symptoms were similar to those described by Wallace[10].

The amount of calcium in the leaves of the minor calcium deficiency series (Table 3) was similar to the amount found in the universal solution series, therefore leaf analysis cannot be used to dis-

TABLE 4

Comparative yields

	Average weight g per plant	Significance 95 %	Significance 99 %	Weight percentage of universal solution
Universal solution	400			100
s Mg excess	297	+	+	74
w Ca deficiency	344	+	—	86
s Ca deficiency	278	+	+	69
w N deficiency	381	—	—	97
s N deficiency	322	+	+	80
w N excess	371	—	—	93
s N excess	278	+	+	70
w K deficiency	341	+	+	85
s K deficiency	282	+	+	70
w K excess	382	—	—	95
s K excess	323	+	+	81
s S deficiency	304	+	+	77
s P deficiency	—			—
s NaCl excess	318	+	+	79

cover a minor calcium deficiency. The marked calcium deficiency series produced a very low calcium content in the leaves in comparison with all the other series, but it cannot be used for diagnostic purposes as there were already marked visible deficiency symptoms. It may be noticed that the marked calcium deficiency gave a higher sodium content and possibly some higher content of phosphate and magnesium.

Nitrogen deficiency and excess

During the two first weeks the development on all nitrogen series seemed the same as on the universal solution. Later the minor deficiency and the minor excess series still seemed to be equal to the series on the universal solution; at the end of the experiment there only was a very small, insignificant reduction in growth (see Table 4).

The treatments with marked deficiency and marked excess showed less growth, but without any visual symptom of deficiency or excess. The yield reduction was 20% for the marked deficiency and 30% for the marked excess.

The leaf analysis after 25 days of cultivation (Table 3) did not

show differences in the nitrogen content between the series for deficiency and excess, which indicates that it cannot be used for diagnosis in the early stages of growth.

The leaf analysis at the end of the cultivation (Table 3) showed a decrease for the nitrogen content in the minor and marked deficiency series. Although the differences are rather small, leaf analysis may be used as a diagnosis for nitrogen deficiency. The minor excess series and even the marked excess series for nitrogen did not show any higher nitrogen content in the leaves than from the universal series, reason leaf analysis cannot be used as a diagnosis for a nitrogen excess.

Potassium deficiency and excess

Without showing any visual symptoms of deficiency, the plants with minor and marked potassium deficiency, gave a reduction of respectively 15 and 30% in production. The weak potassium excess series only gave a small, insignificant decrease of 5% in the production, the marked excess series a decrease of 19% (Table 4).

Marked potassium deficiency can be diagnosed by leaf analyses, because it gives a potassium content in the leaves three times lower than in plants grown on the universal solution. It also showed very high values of magnesium and sodium. The weak potassium deficiency cannot be diagnosed, because it presents values similar to those of the universal solution (Table 3).

The minor and strong potassium excess series may give some higher potassium content, but it is still very doubtful if it can be used for diagnosis.

Sulphur deficiency

Without giving any visual symptoms, the marked sulphur deficiency gave 23% decrease in the production. (Table 4).

Leaf analysis after 25 days of cultivation showed lower values than in all other series. However, at the end of the cultivation the sulphur content was less conclusive, especially why the same sulphur contents were found in other series. This indicates that leaf analysis are not useful as a diagnostic method for sulphur deficiency.

Phosphorus deficiency

The marked phosphorus deficiency solution did not contain any

phosphorus. Consequently in this experiment the plants only obtained the phosphorus present in the seed. The plants were growing very slowly and showed the typical signs of phosphorus deficiency, *viz* the purple anthocyanin colour of the leaves. Due to the poor growth there was a yield diminution of nearly 100% at the end of the cultivation in comparison with the plants developed on the universal solution. For this reason leaf analysis could only be carried out after 25 days of cultivation, resulting in a real low phosphorus content; nevertheless it cannot be used for diagnostic purposes as there already were marked visible deficiency symptoms.

CONCLUSIONS

In all treatments with a deficiency or excess of a certain element the production of lettuce decreased in weight, *viz* only a relatively small decrease for minor nitrogen deficiency and excess and for minor potassium excess ($< 10\%$), a more important decrease for magnesium excess, calcium deficiency, strong nitrogen deficiency and excess, potassium deficiency and marked excess, marked sulphur and phosphorus deficiency ($> 10\%$).

Among all these treatments only the marked calcium and marked phosphorus deficiency series showed visible deficiency symptoms; no excess symptoms could be observed at all.

Based on the results of these experiments diagnosis of malnutrition may be based on leaf analysis for nitrogen deficiency and for marked potassium deficiency, not for a deficiency of calcium, a marked deficiency of sulphur and phosphate, and not for an excess of nitrogen and potassium and for a marked excess of magnesium.

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REFERENCES

1 Blesa, C. and Luque Escalona, A., Contribución al estudio de los materiales volcánicos de las Islas Canarias, para su utilización en cultivos hidropónicos. I Estudio de las propiedades físicas y químicas. Anal. Edaf. y Agrob. **7–8**, 583–599 (1972).

2 Chapman, H. D. and Pratt, P. F., Métodos de análisis para suelos, plantas y aguas. Ed Trillas, México (1973).

3 Hernando, V. and Sanchez Conde, M. P., Estudio de las deficiencias minerales en el cultivo de lechuga romana. Anal. Edaf. y Agrob. **11–12**, 769–776 (1964).

4 Hewitt, E. J., Sand and water culture methods used in the study of plant nutrition. Commonw. Agric. Bur., Techn. Comm. **22** (2nd Ed.) England (1966).

5 Lachica, M., Aguilar, A. and Yañez, J., Análisis foliar; métodos utilizados en la Estación Experimental del Zaidín. Anal. Edaf. y Agrob. **11–12**, 1033–1047 (1973).
6 Luque Escalona, A. and Pérez Melián, G., Materiales volcánicos como sustratos en hidroponía; propiedades físicas y químicas. *Unpublished* (1974).
7 Steiner, A. A., A universal method for preparing nutrient solutions of a certain desired composition. Plant and Soil **15**, 134–154 (1961).
8 Steiner, A. A., Principales diferencias entre cultivos en tierra y cultivos hidropónicos. Proc. 2nd Int. Congr. on Soilless Culture, IWOSC, Wageningen (1969).
9 Steiner, A. A., Curso sobre cultivos hidropónicos. Caja Insular de Ahorros de Gran Canaria, Las Palmas (1970).
10 Wallace, T., The diagnosis of mineral deficiencies in plants by visual symptoms. Her Majesty's Stationery Office, London (1961).