Early diagnosis of mineral deficiencies by means of plant analysis

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Summary

The effect of the development stage on the chemical composition of oats was determined under conditions of constant temperature, humidity and light. The changes in composition as a function of age were found to be small as regards K, Na, Ca and Mg but considerable in the case of the N and P contents.
In addition a study was made of early diagnosis of mineral deficiencies by means of chemical plant analysis, oats being used as the test crop. The data was obtained from 18 and 25 day-old plants growing in sand cultures from which varying amounts of N, P, K or Mg were omitted. The characteristic trends observed for each deficiency may constitute a basis for diagnosis.
The various aspects of the experimental results are discussed and it is concluded that early diagnosis is possible provided the fluctuation in chemical composition of normal plants is known. The rapid changes in chemical composition of crops in the field are most probably due to fluctuating concentrations of ions in the soil solution and not to small differences in the stage of development.

1. Introduction

The diagnosis of mineral deficiencies of crops is an important problem in agricultural and horticultural practice. Although the appearance of mineral deficiency symptoms may be of help, experience has shown that they usually appear when the deficiencies are already severe. Sometimes the symptoms are not characteristic, or else they may be masked when there are multiple deficiencies.
Leaf analysis of perennial crops has been successfully employed for diagnostic purposes, particularly in the tropics. It is possible to standardize the sampling technique as regards the time of year, morphological position of the leaves and physiological age. In this case analysis can be used as a diagnostic tool and it affords a useful check on any fertilizer policy adopted (cf. BROESHART, 1956; CHAPMAN and GRAY, 1949; EVANS, 1955; HALAIS, 1947; LOUÉ, 1953; PRÉVOT and OLAGNIER, 1951, 1953; SCHEIDECKER and PRÉVOT, 1954; DU TOIT, 1953).
Where annual crops are concerned the possibilities of leaf analysis are much more restricted. Sampling and diagnosis has to be done at a stage of development which is early enough to enable nutritional disorders to be corrected.
The chemical composition of annual crops may change during the growing season as a result of climatic conditions, fluctuations in the composition of the soil solution and the stage of development of the crop. In making leaf analyses of annual crops

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we are therefore faced with the problem of obtaining comparable samples of rapidly growing crops.
Two experiments were performed as a contribution to the study of leaf analysis of annual crops at early stages of development as a diagnostic tool.

2. Description of the experiments

The first experiment was designed to investigate the relation between the age of the plant and its chemical composition under constant conditions and at an early stage of development.
Oats were grown in a culture solution (TABLE 1 : complete solution) in a room at constant temperature (25 °C) at a relative humidity of 70 %. Light was provided for 15 hours a day by a set of 24 T.L. tubes (Philips 40W/55). In order to reduce changes in the chemical composition of the culture solution due to nutrient uptake an excess of solution was applied (10 litres for 144 plants) and renewed every 24 hours. After germination 4 bulk samples, each consisting of the shoots of 6 plants, were removed every 3 to 4 days and analysed for their N, P, K, Ca, Mg and Na contents.
The second experiment was designed to determine the changes in chemical composition of oats growing in a sand culture under normal and deficient conditions of N, P, K and Mg.
This experiment was carried out in a greenhouse on an 8 m diameter concrete disk rotating at a speed of 10 revolutions per hour. Oats were grown in 8-litre pots filled with quartz sand and supplied daily with nutrient solutions. Excess solution was able to drain from an outlet in the bottom of the pot. The treatments included the application of nutrient solutions from which various amounts of N, P, K and Mg were omitted in the deficiency range. Each series consisted of 5 levels with 6 replications. The complete nutrient solution was one recommended by HEWITT (TABLE 1).

TABLE 1. Composition of the nutrient solutions (m.e./litre)

Complete solution :					
K^+	2	Fe^{+++}			0,33
Ca^{++}	8	Mn^{++}			0,02
Mg^{++}	3	Cu^{++}			0,002
Na^+	1,33	Zn^{++}			0,002
NO_3^-	10				
$H_2PO_4^-$	1,33	B			0,033 mmol/l
SO_4^{--}	3	Mo			0,0002 „
Deficient solutions :					
N-series NO_3^- resp.	0,1	0,25	0,5	1	10 m.e./l
P-series $H_2PO_4^-$ resp.	0,013	0,032	0,065	0,131	1,33 „
K-series K^+ resp.	0,02	0,05	0,1	0,2	2 „
Mg-series Mg^{++} resp.	0,03	0,075	0,15	0,3	3 „

In the K and Mg series Na was used as the replacing cation; SO_4 replaced anions in the N and P series. The pH of the nutrient solution varied from 5 to 5,5.
The oats was sown at the end of April 1959. The first sampling was carried out 18 days later by removing a number of plants, leaving 15 plants to a pot. The second sampling took place 26 days after sowing by harvesting half the replicates

(no distinction being made between stems and leaves). The parts above the soil were kept for analysis. The final yield, i.e. dry matter and grain yield at maturity, was determined 3 months after sowing.
After drying at 70 °C the two series were ground and stored in air tight bottles. The N, P, K, Ca, Na and Mg contents were analysed by methods developed by the Laboratory of Soils and Fertilizers (SCHUFFELEN, MULLER and VAN SCHOUWENBURG, 1961).

3. Results

3.1. *Chemical composition and stage of development* (first experiment)

TABLE 2 shows the dry matter production and the changes in chemical composition at intervals of 3 to 4 days.

TABLE 2. Chemical composition of oats grown in complete solution at various stages of development

Sampling time in days after germination	Dry matter production	Moisture %	N	P	K	Na	Ca	Mg	N/P
			as a percentage of dry matter						
4	0,09	89,8	5,4	1,50	9,26	0,12	0,66	0,20	3,6
8	0,16	89,9	5,5	1,38	8,10	0,14	0,68	0,26	4,0
11	0,24	90,7	5,3	1,26	8,26	0,12	0,62	0,23	4,8
15	0,36	90,7	5,0	1,04	8,32	0,17	0,59	0,28	4,8
18	0,48	90,9	5,1	0,96	8,36	0,19	0,53	0,26	5,3
22	0,82	88,8	4,6	0,79	7,96	0,12	0,52	0,24	5,8
25	1,20		4,4	0,70	7,87	0,16	0,52	0,26	6,3
29	1,70		3,9	0,64	7,60	0,19	0,50	0,25	6,1

It can be seen that the N and P contents decrease with increasing age. The fall in P content is relatively more rapid than that of the N content (cf. the increase in the N/P ratio).
The K and Ca contents decrease very little, whereas no changes can be observed in the Na and Mg contents. The relatively high contents of N, P, K and Ca in the youngest samples may be partly due to the influence of the seed.
Moreover, the decrease in content of the elements might be due to a slight extent to an insufficient supply from the nutrient solution. It can be seen, however (TABLE 3) that usually only small quantities of the total supply had been adsorbed by the plants.

3.2. *Deficiency symptoms* (second experiment)

Two weeks after planting all series of the second experiment showed differences in growth. Characteristic deficiency symptoms of oats were observed at the lowest levels of N, P, K and Mg. In the case of K deficiency the leaves turned light green, the veins remaining dark. Plants with extreme Mg deficiency showed mottling of the intervenal area. The lowest N levels caused a reduction in growth and produced light-green leaves with a yellowish-brown tinge at the leaf tips. At this stage P deficiency had no effect on growth but the plants were dark green. At a later stage the oldest leaves of P-deficient plants were coloured brown.

TABLE 3. Quantity of elements accumulated in the plants expressed as a percentage of the total amount supplied

Sampling time in days after germination	N	P	K	Ca	Mg	Na
4	4,4	4,1	13,4	0,5	0,6	0,4
8	1,4	1,0	3,0	0,2	0,3	0,2
11	2,9	2,0	9,0	0,4	0,4	0,2
15	1,7	0,8	5,8	0,2	0,6	0,4
18	3,7	1,5	10,4	0,2	0,5	0,8
22	3,3	1,6	11,2	0,4	0,7	0,1
25	6,5	2,8	22,4	0,7	2,0	1,9
29	2,4	1,5	11,1	0,4	0,8	1,8

TABLE 4. Effect of deficiency level on total dry matter and grain production (grams per pot)

Deficient element	Deficiency level					Sign. diff. at P= 0,05	Date yield
	I	II	III	IV	Com-plete		
N	0,85	1,09	1,26	2,78		0,71	Total dry matter after 25 days
P	1,84	1,85	2,86	6,77	10,26	1,04	
K	2,54	3,32	3,95	6,38		0,72	
Mg	4,55	5,26	8,43	9,20		1,49	
N	4,3	8,2	19,8	37,0		6,4	Total dry matter after 3 months
P	8,1	10,0	31,4	90,2	151,5	17,1	
K	35,3	50,5	67,8	93,7		22,4	
Mg	45,3	84,6	120,3	139,9		10,8	
N	1,3	2,7	8,5	16,3		1,6	Grain yield
P	2,7	3,5	13,5	34,9	44,8	7,3	
K	10,0	16,9	21,3	28,5		10,0	
Mg	4,0	29,3	29,3	36,2		4,9	

3.3. *Effect of mineral deficiencies on dry matter and grain production*

TABLE 4 shows the dry matter production after 25 days and 3 months, together with the final grain yield for each of the treatments. Column I corresponds to lowest and "complete" with the highest level of application.

It can be seen that each deficiency had a distinct effect on the dry matter and grain production and that very extreme levels of deficiency were reached. The greatest reduction in growth was found in the case of N deficiency, followed by P, K and Mg in that order.

3.4. *Effect of mineral deficiencies on plant composition*

TABLES 5 and 6 illustrate the chemical composition of the plants at various deficiency levels after 18 and 25 days respectively. Comparison of the two tables shows that the chemical composition of the plants altered between the two sampling periods.

TABLE 5. Chemical composition of oats after 18 days; data expressed as percentage of dry matter

Treatment	K	Na	Ca	Mg	N	P
N 1	4,17	0,08	0,68	0,20	3,3	1,46
N 2	4,40	0,07	0,65	0,18	3,0	1,28
N 3	4,65	0,07	0,62	0,18	3,2	1,36
N 4	4,36	0,05	0,59	0,17	3,0	1,02
Complete	5,96	0,12	0,75	0,26	5,9	1,02
D(0,05)	0,62	0,03	—	0,03	0,6	0,37
P 1	4,78	0,12	0,52	0,13	3,7	0,13
P 2	4,73	0,10	0,51	0,13	3,8	0,11
P 3	4,54	0,12	0,49	0,13	3,8	0,16
P 4	5,42	0,14	0,62	0,18	5,1	0,28
Complete	5,96	0,12	0,75	0,26	5,9	1,02
D(0,05)	—	0,03	0,08	0,03	0,8	0,15
K 1	0,54	3,45	0,61	0,40	5,2	1,84
K 2	0,55	3,59	0,64	0,41	5,3	1,69
K 3	0,58	3,44	0,66	0,41	5,5	1,46
K 4	1,10	2,93	0,78	0,40	5,7	1,27
Complete	5,96	0,12	0,75	0,26	5,9	1,02
D(0,05)	0,18	0,44	0,09	0,07	0,3	0,29
Mg 1	6,87	0,20	0,83	0,06	5,1	1,43
Mg 2	6,54	0,22	0,84	0,07	5,3	1,24
Mg 3	6,69	0,20	0,81	0,10	5,8	1,22
Mg 4	6,30	0,32	0,83	0,12	6,1	1,01
Complete	5,96	0,12	0,75	0,26	5,9	1,02
D(0,05)	—	0,09	—	0,01	0,6	—

D(0,05) significant difference when P = 0,05.

As regards the N and K contents the difference is considerable and more pronounced in the complete treatment than in the deficient plants. These results seem to be inconsistent with the findings of the growth chamber experiment (see discussion).

In TABLE 7 the deviations in chemical composition of the deficient plants as against the complete treatment are compared for the two series of samples. The trends are obviously similar.

N deficiency reduces the K, Na, Ca, Mg and N contents and increases P.

P deficiency results in a decrease of N, P, Ca and Mg contents. After 25 days a significant increase in K was observed and a decrease in Na.

K deficiency reduces the K and N contents but increases Na, Mg and P.

Mg deficiency increases K, Ca and P but decreases Mg and N.

TABLES 8, 9 and 10 show the effect of the deficiencies on the relative proportions of the elements in both samplings.

TABLE 8 shows that the N/P ratios of the two series of samples are not identical in each treatment, but the deviations from the complete treatment show similar trends in both samplings. N and K, and to a lesser extent Mg, reduce the N/P ratio, whereas a great increase is observed when there is a P deficiency.

In TABLES 9 and 10 the K, Ca, Na and Mg contents are expressed as a percentage of their sum. It can be seen that there is comparatively little difference between the two series of samples under conditions of extreme deficiency. The greatest differences were found in the complete treatment. But the trends in the deviation from the complete treatment are similar in both samplings.

TABLE 6. Chemical composition of oats after 25 days; data expressed as percentage of dry matter

Treatment	K	Na	Ca	Mg	N	P
N 1	4,24	0,08	0,63	0,25	1,9	1,51
N 2	4,14	0,07	0,56	0,22	1,7	1,33
N 3	4,57	0,13	0,56	0,22	1,9	1,32
N 4	3,87	0,39	0,49	0,20	2,0	0,97
Complete	4,73	0,77	0,70	0,38	6,1	0,91
D(0,05)	—	—	—	0,10	0,6	—
P 1	5,78	0,13	0,53	0,15	3,5	0,10
P 2	5,80	0,13	0,51	0,17	3,6	0,11
P 3	5,66	0,20	0,56	0,16	4,1	0,16
P 4	6,05	0,30	0,61	0,18	5,0	0,21
Complete	4,73	0,77	0,70	0,38	6,1	0,91
D(0,05)	0,48	0,26	0,08	0,05	0,4	0,04
K 1	0,40	3,78	0,70	0,49	5,0	1,93
K 2	0,48	3,61	0,61	0,46	5,1	1,76
K 3	0,59	3,47	0,58	0,46	5,1	1,58
K 4	0,66	3,48	0,68	0,50	5,2	1,27
Complete	4,73	0,77	0,70	0,38	6,1	0,91
D(0,05)	0,09	0,50	—	—	0,4	0,32
Mg 1	7,86	0,56	0,87	0,05	4,9	1,30
Mg 2	7,34	0,79	0,72	0,05	5,0	1,11
Mg 3	6,03	1,24	0,72	0,07	5,6	1,98
Mg 4	5,32	1,28	0,72	0,12	6,2	0,89
Complete	4,73	0,77	0,70	0,38	6,1	0,91
D(0,05)	0,82	0,40	0,10	0,04	0,7	0,14

TABLE 7. Difference in chemical composition after 18 and 25 days as compared to complete treatment

Deficiency	Sampling time in days	K	Na	Ca	Mg	N	P
N	18	—	—	(—)	—	—	+
	25	(—)	(—)	(—)	—	—	(+)
P	18	(—)	0	—	—	—	—
	25	+	—	—	—	—	—
K	18	—	+	—	+	—	+
	25	—	+	0	(+)	—	+
Mg	18	(+)	+	+	—	—	(+)
	25	+	0	+	—	—	+

— decrease as compared to complete treatment
\+ increase as compared to complete treatment
0 no change in chemical composition
( ) not significant when P = 0,05

TABLE 8. Effect of deficiency level on the N/P ratio after 18 and 25 days

Deficiency	Sampling time in days	Deficiency level I	II	III	IV	Complete
N	18	2,4	2,3	2,5	3,0	5,8
	25	1,3	1,3	1,4	2,1	6,7
P	18	28,5	34,6	23,8	18,2	5,8
	25	55,0	32,7	25,6	23,8	6,7
K	18	2,7	3,1	3,7	2,3	5,8
	25	2,6	2,9	3,2	4,1	6,7
Mg	18	3,6	4,4	4,8	6,1	5,8
	25	3,8	4,5	5,7	6,9	6,7

TABLE 9. Chemical composition of oats after 18 days; data expressed as percentage of K + Na + Ca + Mg (m.e.)

Treatment	K	Na	Ca	Mg
N 1	66,3	2,2	21,1	10,4
N 2	69,0	1,8	20,0	9,2
N 3	70,9	1,8	18,4	8,9
N 4	70,9	1,4	18,7	9,0
Complete	70,4	2,4	17,3	9,9
P 1	74,5	3,2	15,8	6,5
P 2	74,9	2,6	15,8	6,7
P 3	74,2	3,3	15,6	6,9
P 4	72,7	3,2	16,2	7,9
Complete	70,4	2,4	17,3	9,9
K 1	6,1	65,9	13,4	14,6
K 2	6,0	66,1	13,5	14,4
K 3	6,4	64,6	14,3	14,7
K 4	12,4	55,9	17,1	14,6
Complete	70,4	2,4	17,3	9,9
Mg 1	76,1	3,8	17,9	2,2
Mg 2	74,5	4,3	18,6	2,6
Mg 3	74,9	3,8	17,7	3,6
Mg 4	71,2	6,1	18,3	4,4
Complete	70,4	2,4	17,3	9,9

TABLE 10. Chemical composition of oats after 25 days; data expressed as percentage of K + Na + Ca + Mg (m.e.)

Treatment	K	Na	Ca	Mg
N 1	66,1	2,1	19,2	12,6
N 2	68,3	1,9	18,0	11,8
N 3	69,3	3,3	16,6	10,8
N 4	63,1	10,8	15,6	10,6
Complete	54,8	15,1	15,8	14,3
P 1	66,9	2,5	12,0	4,6
P 2	78,1	3,0	13,4	5,5
P 3	75,5	4,5	14,6	5,4
P 4	74,2	6,2	14,6	5,0
Complete	54,8	15,1	15,8	14,3
K 1	4,1	65,6	14,0	16,3
K 2	4,1	66,4	12,6	15,9
K 3	6,5	64,7	12,4	16,4
K 4	6,9	62,1	13,9	17,1
Complete	54,8	15,1	15,8	14,3
Mg 1	73,7	8,7	15,9	1,5
Mg 2	71,6	13,0	13,7	1,6
Mg 3	61,8	21,5	14,4	2,3
Mg 4	57,3	23,3	15,1	4,2
Complete	54,8	15,1	15,8	14,3

4. Discussion

Provided two conditions are complied with it would seem possible to employ plant analysis for the diagnosis of mineral deficiencies of annual crops at an early stage of development.

4.1. Even at a very early stage of growth the plant should indicate which elements in the soil will be insufficiently supplied during its future development. The results of the sand culture experiment show that only 18 days after germination the chemical composition of oats may give an indication of N, P, K or Mg deficiency provided a control is available, i.e. the chemical composition of a normal plant grown under the same climatic conditions as the deficient plants. In this case the diagnosis can be based on the deviations in chemical composition from the "normal" composition. Nitrogen deficiency causes a reduction in N content, but TABLES 5 and 6 show that in the case of P deficiency also the N contents are below the normal level. The P content may be used to distinguish between N and P deficiency. When N is deficient the P content is relatively high, whereas the P content falls when P becomes deficient. Consequently the N/P ratio in N deficient plants (TABLE 8) should be used as an additional criterion. When N is deficient this ratio is of the order of 1,5—3, and of 20—30 when P is deficient; in the complete treatment the N/P ratio is approximately 6.

K deficiency may be readily recognized by the low K content which was not observed in the case of any other deficiency. Additional characteristics of K deficiency are the very high P and Na, and increased Mg contents.

Mg deficiency causes a rapid decrease in Mg content. It should not be assumed that this decrease is the only characteristic, as it was shown that N and P deficiency may also induce a reduction in the Mg content. It is obvious, however, that the low N content in the case of N deficiency and the high N/P ratio in the case of the P deficiency are the additional characteristics required to distinguish Mg deficiency from N and P deficiency.

It should be emphasized once again that the diagnosis of deficiencies should be based on a comparison of the contents of all elements with a "normal" or reference composition. A diagnosis based on single values, i.e. on the content of one element only, will lead to erroneous results.

STEENBJERG (1951) observed that plants which are extremely deficient in one element have higher contents of this element than plants which are less deficient in it. Supplying a small amount of this element to the crop may stimulate vegetative growth to such an extent that the "diluting effect" of the rapid growth will result in a decrease of the content.

This trend was not observed in the samples taken at early stages of development. In order to see whether this phenomenon might occur in the mature crop the leaves were analysed (TABLE 11).

TABLE 11. Chemical composition of the leaves of the mature crop at different deficiency levels; data expressed as a percentage of dry matter

Deficiency	Deficiency level					D(0,05)
	I	II	III	IV	Complete	
N	0,59	0,38	0,44	0,48	2,29	0,28
P	0,02	0,01	0,00	0,07	0,24	0,04
K	0,14	0,16	0,27	0,18	3,31	0,16
Mg	0,03	0,02	0,03	0,06	0,45	0,03

N, P and Mg contents showed light increases at extreme deficiency levels, but these were not significant when $P = 0,05$. It can therefore be concluded that relatively high contents of elements at very extreme deficiency levels did not occur at any stage of development of oats.

4.2. The major problem in foliar diagnosis of annual crops is to establish the reference for comparison, i.e. the composition of normal plants for a particular set of climatic conditions. It may be concluded from the experiment in the constant temperature room that the age of the oats had little effect on the composition of the crop as regards the K, Na, Ca and Mg cations. Only a slight decrease in K and Ca contents was observed with increasing age of the plants. On the other hand, the fall in N and P content and the relatively rapid increase in the N/P ratio at later stages of development would seem to be a function of the age of the plant rather than of the nutrient supply. In this respect it is interesting to note that the N/P ratio of the oats that received a complete treatment in the sand culture had the same N/P ratio after 18 and 25 days as the oats grown in the constant temperature room. This would seem to suggest that the age of the plant should be taken into account when diagnosing the N or P deficiency. For K, Na, Ca and Mg deficiency it was shown that the changes in chemical composition of deficient plants are considerable and of a different order of magnitude than the possible changes in terms of age. Despite the small effect of the stage of development on the chemical composition of the oats, the two samplings of the sand culture experiment taken after 18 and 25 days showed considerable differences in chemical composition, particularly in the complete treatments. Taking into consideration the results of the constant temperature room, the differences in chemical composition of the two samplings of the sand culture experiment must be due to other factors than the age of the crop. It is quite possible that in the case of the sand culture experiment the K supply was inadequate and unable to cope with the rapid growth after 18 to 25 days.

It can be calculated from a daily supply of 0,5—1 litre of culture solution containing 2 m.e. of K/litre that the total supply of K in 25 days will be 1—2 g. In the complete treatment the oats absorbed 0,5 g of K (10 g of dry matter with a K content of 5 %). This amounts to at least a 25—50 % absorption of K from the solution.

This would explain why the differences between the two samplings are greatest in the case of the complete treatment and lessen as the deficiency progresses. Growth was extremely rapid in the case of the complete treatment but was greatly reduced with N, P and K deficiency.

In this connection the question arises as to what extent the chemical composition of a crop may vary without affecting its growth and yield. Once this reference range is known for each crop leaf analysis could be applied for diagnostic purposes.

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