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YIELD CURVES AND CHEMICAL PLANT ANALYSES

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Questions relating to the relative contents of plant nutrients in a crop are, in various ways, closely connected with questions of fundamental importance concerning the fertilizing technique as, for instance, the relationship between applied and absorbed quantities of the plant nutrient in question, the relationship between the absorbed quantity of the plant nutrient and the production of dry matter, and finally the relationship between the applied quantity of the same plant nutrient and the production of dry matter.

With a more comprehensive knowledge of these relationships, many problems associated with fertilizing may be solved in principle e.g. problems connected with the interpretation of chemical plant analyses.

The use of plant analyses as a means of determining the nutrient status of plants is well known. During the last few decades, however, a great deal of work has been directed exclusively towards the application of chemical plant analyses as a means of diagnosing the nutrient requirements of plants and soils [1]).

It is not considered necessary to include in this paper, details as to (*a*) the rapid chemical methods used (*b*) the particular plant organs chosen for analysis and (*c*) the calculation of the analytical results etc. Such details may be obtained from the review by Goodall & Gregory [1]).

The interpretation or evaluation of the analytical results, however, is of decisive importance in the application of the chemical plant analysis. What for instance, does a certain percentage nutrient content in barley leaves mean? Just as we must interpret the results of chemical soil analysis or the results of field trials, so must we interpret the results of chemical plant analyses if these results are to throw any light on other special cases.

In general three different methods have been used in the interpretation of chemical plant analyses, of which two are of particular importance.

Interpretation I: Figure 1 *) illustrates for a given crop (or part of the crop) the relationship between increase in yield (dry matter) after the application of a certain quantity of a plant nutrient, and the percentage content of this nutrient in the unfertilized crop. The evaluation of the analytical results may also be made as

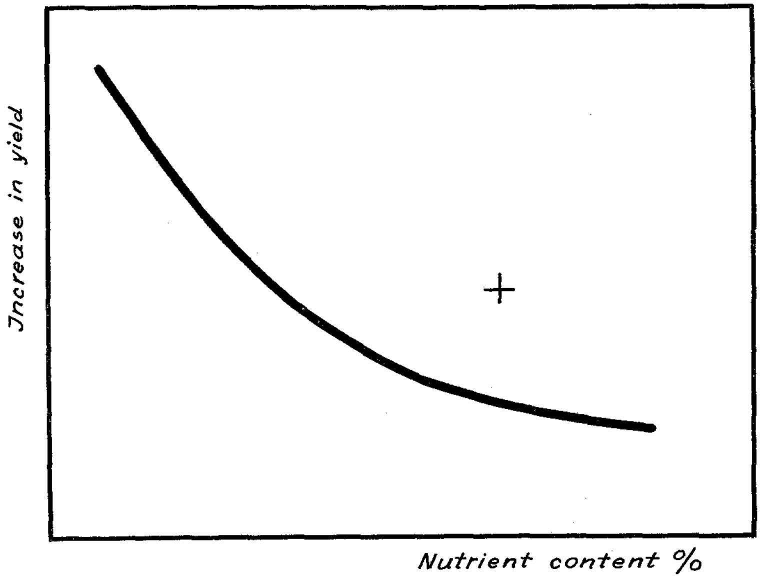

Fig. 1. Interpretation I

follows: standard values for the plant nutrients in the crop are found, these standard values (limiting or basic values) being determined for three or more levels e.g. high, medium and low content, due attention being paid to the time during the growing season at which the samples are taken i.e. the stage of development of the crop.

Interpretation II: Figure 2 illustrates the relationship between the dry matter production (total yield or a particular fraction of the yield) and the percentage nutrient content of the dry matter (yield).

*) Except for figure 4, the figures referred to in the text are all schematic.

It will be observed that with increasing yield, the percentage nutrient content normally rises (full line).

Thus in both methods of interpretation, the percentage nutrient content may be used for diagnosis. The question arises however — on what principles or laws are such interpretations based? Before enlarging upon this point it is necessary to bear in mind that there are four groups of factors which influence the nutrient content of a plant.

These are:

(1) Soil factors in the most comprehensive sense (including also the ability of the soil to supply the crop with water).

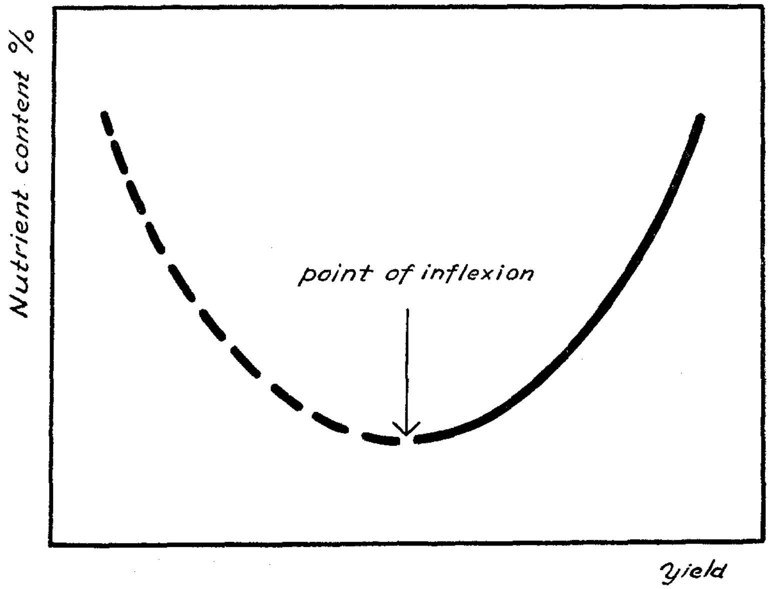

Fig. 2. Interpretation II

(2) The nature of the crop.

(3) Climatic conditions including factors like light and temperature.

(4) The time during the growing season at which the plants are sampled i.e. the stage of development of the crop.

According to interpretation I, variations occur from place to place and from one year to another, in (1) the soil factors and (3) the climatic conditions. On the other hand (2) the nature of the crop and often (4) the time of sampling (stage of development of the crop) are kept constant.

According to interpretation II, variations in (1) the soil factors, are reduced to a minimum (e.g. by sampling from as small an area as possible) whilst the remaining factors grouped under (2), (3), and (4) are kept constant or as nearly so as possible.

We can now discuss the basic principles underlying the interpretation of chemical plant analyses according to figures 1 and 2.

For these interpretations to be valid, the presupposition is that the law of diminishing returns holds in all cases concerned. The argument would be further simplified if the relationship between applied and absorbed quantities of a plant nutrient was

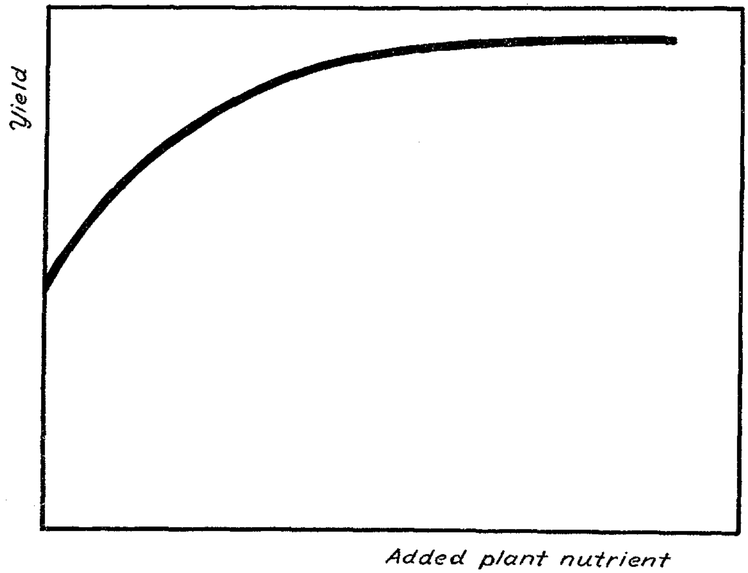

Fig. 3a

linear but even if the line is not straight i.e. if the rate of absorption steadily decreases with increasing applications of the particular nutrient, this does not alter the fundamental considerations.

From figures 3*a* and 3*b* it follows that normally, a high yield is associated with a high percentage content of the nutrient and with small increases in yield.

Where, however, the law of diminishing returns does not apply, serious errors may arise in the interpretation unless the utmost care is taken; cf. figures 3*c* and 3*d*. In figure 3*d*, the relationship between dry matter production and quantity of nutrient absorbed is expressed by an *S*-shaped curve i.e. with first increasing then decreasing returns. This means that the relationship between dry matter production and quantity of nutrient applied must also be represented by an *S*-shaped curve, irrespective of whether the rate of absorption is constant or steadily decreases with increasing applications of that nutrient (fig. 3*c*). The relationship between dry matter production (yield) and *percentage* nutrient content must therefore be expressed by a curve of the form given in figure 2 (dotted line + full line).

In other words we may find that a high percentage content of a

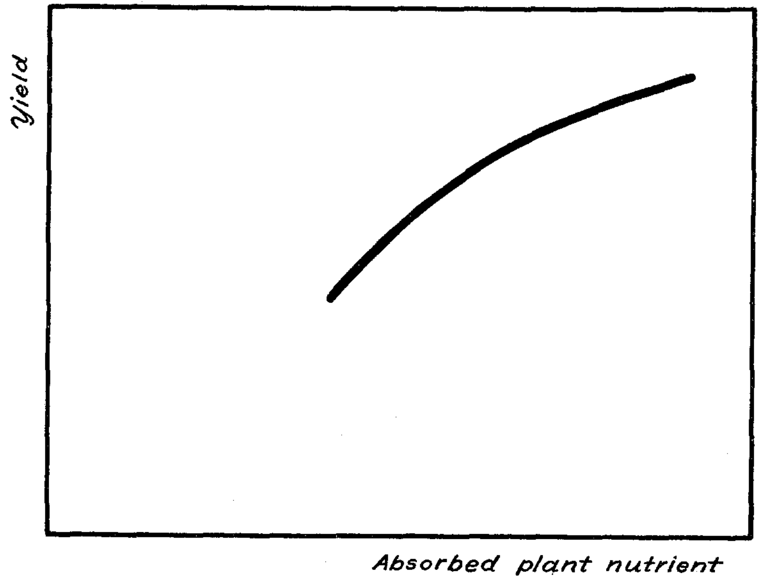

Fig. 3b

particular nutrient is associated with a low production of dry matter, in which case there is still the possibility of a large increase in yield (cf. cross in fig. 1). This would mean serious errors in the interpretation according to both methods I and II (see dotted parts of the curves given in figs. 2 and 3*d*).

Therefore, in order to be able to use chemical plant analyses successfully it is important to know as much as possible about the influence exerted by the group of yield factors mentioned above (1, 2, 3 and 4) on the shape of the yield curve, its flexibility and its position in the coordinate system.

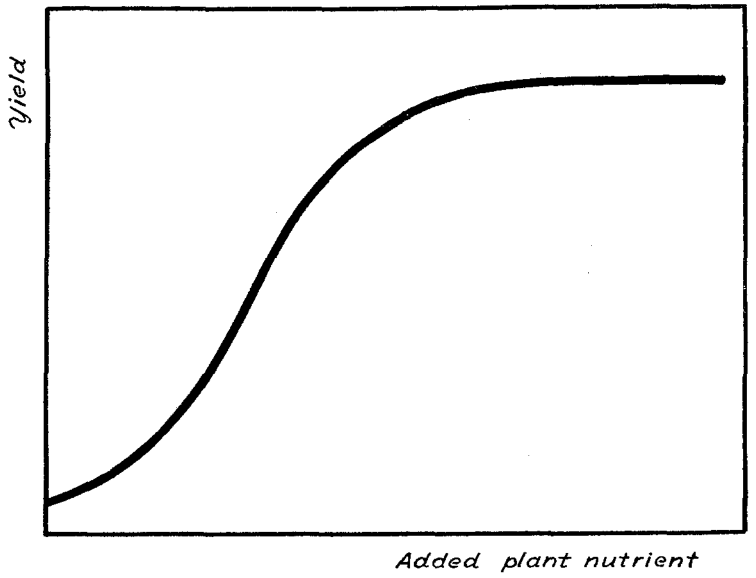
Yield
Added plant nutrient

Fig. 3c

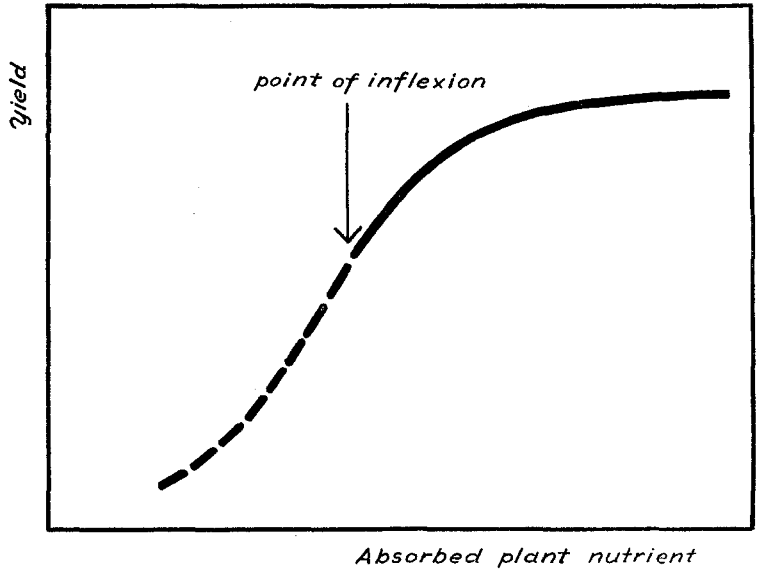
Yield
point of inflexion
Absorbed plant nutrient

Fig. 3d

Before commenting further on the value of such increased knowledge of the form of the yield curve, it would be appropriate to give a concrete example in which one can go into further detail about the points arising out of the discussion on fundamentals. This will be done first by describing some of our typical experimental results and then by discussing their interpretation (method II).

Over a period of 3 years (1939–41) pot experiments were carried out with the same soil to which had been added increasing quantities of various copper fertilizers. These, applied in the first year, were as follows:

1. Copper pyrites or chalcopyrite, $CuFeS_2$
2. Purple copper ore or bornite, Cu_3FeS_3 or Cu_5FeS_4
2a. Copper glance or chalcocite, Cu_2S
3. Malachite, $CuCO_3.Cu(OH)_2$
4. Red copper ore or cuprite, Cu_2O
5. Copper sulphate, $CuSO_4.5H_2O$.

Each of these minerals was applied in two degrees of fineness. The soil in all pots was otherwise treated alike and heavily fertilized with nitrogen, phosphorus and potassium. Check analyses showed that the pH values varied between 6 and 7 approximately (increasing slightly with time) whilst the contents of phosphorus and potassium in the soil were high and fairly constant in all treatments. The water supply was maintained at a constant level during all three years. Total contents of nitrogen, phosphorus, potassium, copper and manganese were determined in the ripe crops (barley); (cf. tables Ia, Ib, Ic).

In the treatments without copper, symptoms of copper deficiency were typical and very severe; the severity of the symptoms gradually decreased with increasing yields (and increasing copper applications) disappearing at a dry matter production of about 80 g per pot. The amount of copper applied varied greatly, causing a considerable variation in production of dry matter (cf. abcissa values, fig. 4). The fully drawn curves show, for all three years, the average relationship between relative copper content and production of dry matter per pot, for grain, straw and grain + straw. For the individual years, the main course of the curves is the same as that for the average curves.

The curves obtained after the application of greatly varying quantities of copper sulphate were also found to follow the same

TABLE Ia

Copper additions and percentage contents of various plant nutrients, average 1939–41
Grain

Copper added in g:		In dry matter % N	% P	% K	p.p.m. Mn	p.p.m. Cu	g dry matter per pot
No treatment		2.90	—	0.60	—	3.2	0.1
Chalcopyrite I *)	0.56	3.57	0.53	0.67	33	5.4	4.6
,, I	2.79	2.58	0.54	0.77	31	3.2	48.4
Chalcocite and bornite II †)	0.52	—	—	—	—	0.7	0.1
Chalcocite and bornite II	2.59	—	—	—	—	6.9	0.3
Chalcocite and bornite I	0.52	3.00	0.52	0.72	30	3.0	29.3
Chalcocite and bornite I	2.58	2.21	0.43	0.60	29	4.5	50.7
Malachite II	2.50	3.55	0.60	0.78	30	4.2	6.8
,, I	0.47	2.13	0.40	0.60	25	4.4	51.5
,, I	2.34	2.03	0.39	0.57	19	5.4	53.2
$CuSO_4.5H_2O$	0.03	3.77	0.62	0.77	38	4.3	2.4
,, ,,	0.13	2.76	0.49	0.64	23	2.5	34.7
,, ,,	1.02	2.14	0.42	0.56	26	4.7	54.4

*) I refers to very finely ground mineral (see [3])).
†) II refers to coarsely ground mineral (see [3])).

TABLE Ib

Copper additions and percentage contents of various plant nutrients, average 1939–41
Straw

Copper added in g:		In dry matter % N	% P	% K	p.p.m. Mn	p.p.m. Cu	g dry matter per pot
No treatment		2.93	0.33	0.60	189	16.6	8.3
Chalcopyrite I *)	0.56	2.07	0.37	1.52	129	8.5	47.8
,, I	2.79	0.81	0.09	1.50	98	12.5	49.5
Chalcocite and bornite II †)	0.52	2.59	0.49	1.16	225	14.4	10.4
Chalcocite and bornite II	2.59	2.83	0.54	1.57	163	11.0	24.1
Chalcocite and bornite I	0.52	1.22	0.19	1.46	85	9.4	50.6
Chalcocite and bornite I	2.58	0.85	0.07	1.51	87	13.1	45.9
Malachite II	2.50	1.90	0.37	1.51	102	8.3	51.6
,, I	0.47	0.77	0.07	1.33	93	11.0	47.3
,, I	2.34	0.79	0.07	1.30	81	13.4	50.0
$CuSO_4.5H_2O$	0.03	2.04	0.39	1.49	118	9.6	42.8
,, ,,	0.13	1.23	0.19	1.46	99	9.3	49.7
,, ,,	1.02	0.78	0.08	1.46	91	10.9	47.3

*) I refers to very finely ground mineral (see [3])).
†) II refers to coarsely ground mineral (see [3])).

TABLE Ic

Copper additions and percentage contents of various plant nutrients, average 1939–41
Grain + straw

Copper added in g:		In dry matter					g dry matter per pot
		% N	% P	% K	p.p.m. Mn	p.p.m. Cu	
No treatment		2.95	0.33	0.60	187	16.6	8.4
Chalcopyrite I *)	0.56	2.16	0.38	1.47	123	8.3	52.4
,, I	2.79	1.66	0.31	1.15	66	7.8	97.9
Chalcocite and bornite II †)	0.52	2.59	0.49	1.16	225	14.3	10.5
Chalcocite and bornite II	2.59	2.83	0.54	1.57	163	10.9	24.4
Chalcocite and bornite I	0.52	1.78	0.29	1.23	68	7.1	79.9
Chalcocite and bornite I	2.58	1.56	0.26	1.03	57	8.6	96.6
Malachite II	2.50	2.02	0.39	1.46	97	7.9	58.4
,, I	0.47	1.49	0.25	0.94	57	7.6	98.8
,, I	2.34	1.44	0.23	0.92	48	9.3	103.2
$CuSO_4.5H_2O$	0.03	2.09	0.40	1.47	116	9.2	45.2
,, ,,	0.13	1.78	0.30	1.16	71	6.4	84.4
,, ,,	1.02	1.51	0.26	0.98	56	7.2	101.7

*) I refers to very finely ground mineral (see [3])).
†) II refers to coarsely ground mineral (see [3])).

course both for the average values as well as for individual years.

The three dotted curves at the bottom of figure 4 (all curves are drawn freehand) show the average relationship between percentage content of nitrogen in grain in straw and in grain + straw, and the corresponding production of dry matter per pot. This relationship was repeatable for each of the three years. When grain formation sets in, the yield of straw is slightly reduced and at the same time the percentage nitrogen content in the straw is reduced. The same is found for phosphorus, both for the average and for individual years, but not so in the case of potassium or manganese. The relative content of these elements both in the total yield and the particular fractions of the yield gradually decreases with increasing yield for each of the three years.

For grain, as well as for straw and grain + straw, it will be seen that the relative copper content may be the same for very different yield values. If, in this case therefore, only a single sample was taken from a copper deficient crop and its relative copper content determined, a very high copper content might be found. If two samples were taken, one from a small copper deficient crop, the other from a somewhat bigger crop where the copper deficiency is not so marked, there would be a possibility of finding the latter crop having the lowest copper content.

If samples of such crops are handed in for chemical analysis, the

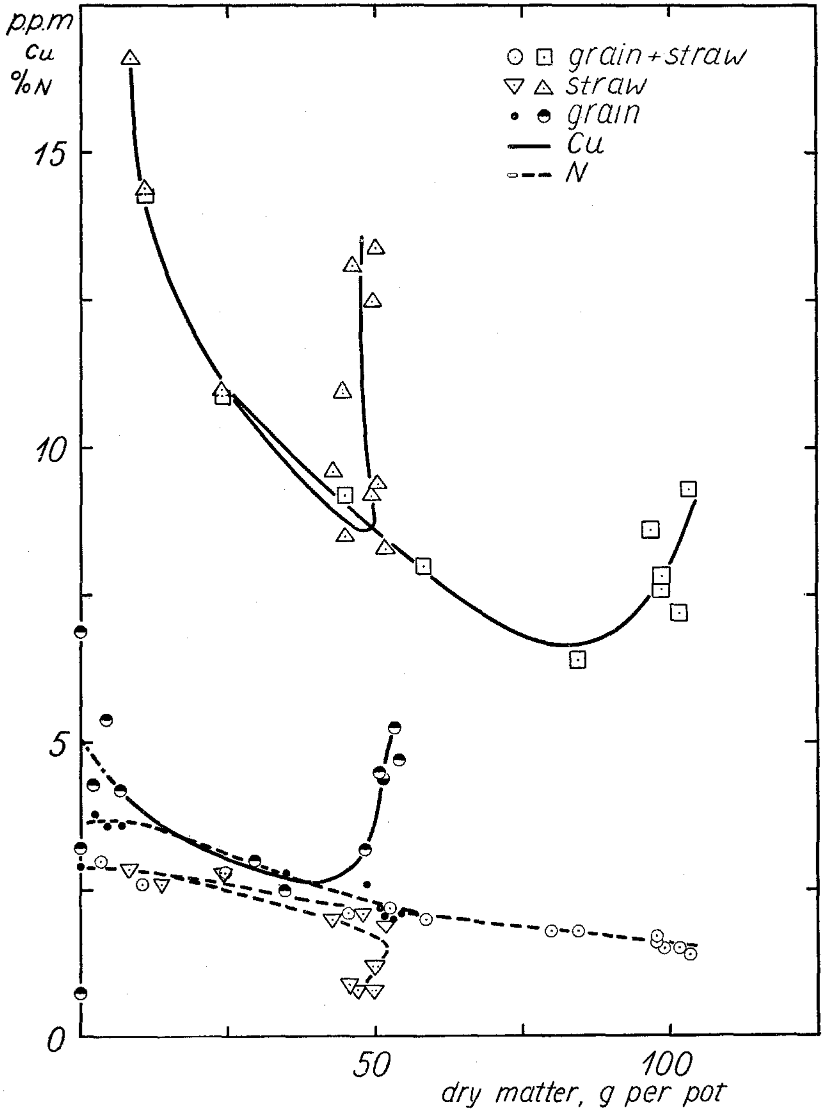

Fig. 4. Dry matter and the relative content of plant nutrients.

information on yield and the appearance of deficiency symptoms may be lacking or inaccurate — hence it may be necessary to analyse the crop not only for copper but also for a number of other plant nutrients.

If as in the present case, the total crop, the straw and the grain, were analysed for copper, nitrogen, phosphorus, potassium and manganese and if three crop samples were received — one from a crop with a very small dry matter production, another from a crop of about 80 g dry matter and the third from a crop of about 105 g dry matter per pot — the percentage contents as far as potassium and manganese were concerned would be found to decrease steadily from the smallest to the biggest crop. This, however, would not be the case for copper where we should find first a decrease and then an increase in its relative content as the yield of grain, straw or grain + straw increased. For nitrogen and phosphorus the results, as stated above, would be slightly different but only so far as the straw is concerned, where, for the same value of crop yield, slightly differing percentage contents *may* be found (see figure 4).

These results indicate that:

(1) If a series of results were obtained in which the relative nutrient content in the above-ground parts of the crop first decreased and then increased with increasing yield then according to interpretation II this would indicate severe deficiency in the particular plant nutrient concerned *where the dry matter production is lowest*. When the other plant nutrients (in this case N, P, K and Mn) are applied in sufficient and constant quantities, their percentage contents will on the whole progressively decrease with increasing yields. (The samples are taken close to each other in the field).

(2) A heavily declining percentage copper content with increasing yield and *slightly* decreasing percentage contents of nitrogen, phosphorus, potassium and manganese indicate a severe copper deficiency in the crop where the plants are smallest (lowest dry matter production). Other presuppositions as under (1).

(3) A greatly increasing percentage copper content with increasing yield and *slightly* decreasing percentage contents of nitrogen, phosphorus, potassium and manganese, indicate a copper deficiency in the crop where the plants are smallest (lowest dry matter production). Other presuppositions as under (1).

In previous works 3), 4) these problems have been dealt with for plant nutrients other than copper (see also Poulsen [2]). The form of the curve representing the relative nutrient content of the plants, as has been observed for copper (fig. 4), may be explained by the fact that the production of supporting tissue and starch by the plants, especially by grasses, increases more rapidly than the absorption of nutrients during the initial stages of uptake of copper from the soil until the point of inflexion is reached (cf. fig. 3*d*). From this point the formation of supporting tissue and starch cannot keep pace with the absorption of copper as the rate of application of this element is increased. The point of inflexion in fig. 3*d* corresponds with the three minima for relative copper content shown in fig. 4 (one for grain, one for straw and one for grain + straw).

SUMMARY AND CONCLUSIONS

According to experience gained in this laboratory, the observation of the *S*-shaped yield curve (fig. 3d) appears to depend upon the severity of the absolute deficiency of the nutrient in question, in this case copper. In those soils where this deficiency is not so pronounced, only that part of the curve to the right of the point of inflexion will presumably be observed which means that we shall find increasing relative nutrient contents with increase in dry matter production (increasing applications of the particular nutrient).

It is however possible that the observation of the *S*-shaped curve is influenced by other factors. A crop which has a high capacity for absorbing copper, even from soils deficient in this element, will, in such investigations, give the impression that we have a soil relatively rich in copper i.e. we shall only observe that part of the curve to the right of the point of inflexion (fig. 3d). Finally it is also possible that heavy and uniform applications of other plant nutrients (and water) might in some cases contribute towards the production of an *S*-shaped curve (relative deficiency of Cu).

Our knowledge of such problems is still incomplete. The present investigation indicates that in order to make the fullest use of chemical plant analyses for diagnostic purposes, these problems must be thoroughly investigated. To this end pot experiments carried out in the first instance according to a simple factorial plans, should prove useful. The proper design of such experiments, however, is of great importance.

As mentioned in the beginning, investigations of this kind will increase our knowledge of important fundamental problems relating to fertilizing techniques. The aim of these investigations should not be the establishment of new yield equations. These have always been of secondary importance being merely of an empirically descriptive nature, though it must be admitted they may not be without interest from the point of view of fertilizing technique.

The essential point is an increased knowledge of the flexibility and position of the yield curve in the co-ordinate system under different conditions, the conditions here being classed under four main groups of factors. In practice it becomes a question of determining interactions between factors affecting dry matter production or the flexibility of the yield curves under different growth conditions. From the point of view of fertilizing technique, it is extremely important to elucidate more thoroughly these interactions or this flexibility not only with regard to the interpretation of chemical plant analyses but also with regard to the interpretation of chemical soil analyses and for instance the distribution of fertilizers to the crops etc.

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