PROBLEMS INVOLVED IN CONTROLLING PLANT NUTRITION

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SUMMARY

In a short treatise it is attempted to point out some of the problems encountered in obtaining definite relationships between either plant analysis or soil analysis and nutrient supplying power of the soil and its conversion to fertilizer requirement. A few indications are given of modern approaches offering ways to solve these problems and of integrating knowledge.

INTRODUCTION

As an optimal yield can only be achieved if the plant or crop is adequately supplied with nutrients we need ways of measuring this adequate supply. Our problem thus is of finding ways to define this adequate supply in parameters of mineral contents in the substrate and the need for application of fertilizers.

Ultimately this adequate supply can only be measured on the plant itself and through its performance in yield or by signs of deficiency. But it can be done more in details by plant analysis. In our very simple approach all secondary factors, which may influence mineral supply - such as poor root development or drought - are left out of our consideration. Also the fact that plant mineral content may be modified through climatic conditions, such as temperature and light, or varies with age.

In our attempts to control plant nutrition one line of approach is to try to relate plant analysis data to data on soil analysis and converting the latter knowledge into amounts of fertilizer needed to achieve the optimal soil nutrient status. Quite often little effort is made to obtain precise data on the nutrient supplying capacity of the soil and only a direct relationship between plant analysis and fertilization is studied. Although this latter type of study can be quite useful - if accompanied by sufficient experience and a lot of secondary information on climate and soil - it lacks a certain universality.

The other line of approach could be to try to relate data on soil analysis to nutrient supplying power of the soil and again convert this knowledge into required amounts of fertilizer. But as this nutrient supplying power of the soil is not easily determined, much work also evades the precise determination and aims at obtaining reliable correlations between soil analytical data and yield.

Essentially both approaches ultimately need thorough and exact information on the essentials of the nutrient supplying capacity of the soil.

1. RELATING MINERAL PLANT COMPOSITION TO NUTRIENT SUPPLYING CAPACITY

If one has to obtain a well defined relationship between plant analysis data and nutrient supply it will be necessary to know how this supply is best characterized. If we accept the fact that the ions absorbed by the plant root are nearly all obtained from the soil solution, it means that the ionic concentrations and ionic equilibria in this solution at the root surface are the data we need. Here we encounter a first problem as we have as yet hardly any means of measuring ionic activities at this boundary layer in situ.

To some extent this difficulty can be overcome. To do this we can utilize a lot of information that has been obtained in plant nutrition research by means of waterculture experiments.

These studies have elucidated the uptake versus concentration relationships for many plants, and under varied conditions. One of the parameters that is needed is the lowest concentration of an ion, that will allow for adequate uptake. Only those experiments in which very well stirred or fast circulating solutions have been used can give us the required information. This constant movement of the solution is essential to evade the occurrence of stagnant water films at the root surface and in the root mass, which occurrence would induce diffusion phenomena in these layers. Too high concentration values will be obtained as a result, unless intensive movement makes complete regulation of concentration at root surface possible.

In table 1 a number of data have been compiled, which give an idea of the low actual concentration needed and which is in the range we could expect in the soil solution or even lower. If concentrations are below those required, data on plant mineral composition will demonstrate this and correlations can be obtained and formulated. But can we utilize these formulated correlations the other way around, i.e. decide on an absolute insufficiency of supply on account of a too low content for a certain nutrient?

This question can not be answered positively. And here we encounter our second problem. This situation arises from the fact that uptake of ions is not only related to absolute concentrations, but that in many cases interactions between ions (competitive uptake) disturb these relationships. Plant analysis will then show low mineral contents, which may be caused by another competing ion being present in a very high concentration, i.e. we have a case of imbalance or relative deficiency.

A large amount of research has been carried out to establish the best composition of a nutrient solution to obtain optimal growth. In general this ionic balance required will stay about the same throughout a reasonable range of concentrations. We are thus more or less in the position to establish the minimum requirements in concentration and ionic balance. This type of information is now being further obtained in some of the research in hydroponics and could be quite useful.

If one makes a rough estimate it would seem that the requirements of many plants could be met if the concentrations of the main nutrient ions at their root surface could be maintained at about 1/20th of those encountered in most nutrient solution recipes.

Table 1. Some data on minimum required ion concentrations at the root surface.

nutrient	plant	concentration in ppm	reference
NO_3	sugar beet	2 - 500	16
	sugar beet	6 - 2000	16
	potato	30 - 50	8
	chrysanthemum	140	14
P	grasses	0.3 - 30	3
	sugar beet	0.6	16
	onions	1	1
	chrysanthemum	15	14
K	grasses, leguminous species	± 0.1	17
	potatoes, vegetables	8 - 15	13
	sugar beet	24 - 220	16
	rye grass	80	11
	chrysanthemum	95	14
	rice	10	6

Table 2. Some rates of ion uptake per unit root surface.

nutrient	plant	rate in $ug.10^{-4}/cm^2/hr.$	reference
NO_3	corn	0.1 - 0.8	5
	corn	0.5 - 15	10
	corn	± 7.5	12
	barley	2.5 - 4	4
	beans	± 11	15
	Brussels sprouts	0.8 - 6.2	15
P	rape	± 0.6	2
K	corn	0.2 - 2.2	10
	corn	1 - 3	7
	beans	± 4.8	15
	Brussels sprouts	± 1.5	15
Mg	onion	± 15	9

It must be concluded that although definite correlations between either concentration of ions at the root surface or balance of ions and plant composition can be established, it is in essential extremely difficult to convert plant composition data into the exact supply situation at the root surface. But the more nutrients are involved in the analysis, the more there is known about soil and climatic conditions and the more experience there is available the better the usefulness becomes. The practice of crop-logging can demonstrate this.

2. THE RELATIONS BETWEEN NUTRIENT SUPPLYING CAPACITY TO DATA OBTAINED BY SOIL ANALYSIS

In the previous part, where for the sake of simplicity we have assumed stationary conditions to exist, the nutrient supplying capacity of the soil could be characterized by a condition (concentration and balance of ions) only. But as the plant absorbs it detracts nutrients from the root-surface solution layer and disturbs the concentrations. If a steady state is to be maintained the rate of supply by the soil should be the same as the flux of ions through the root surface. In the soil it is this rate of replenishment that becomes the more important soil fertility characteristic.

This dynamic approach in soil fertility research has been more and more developed in recent times. But in order to know what is required from the soil the rate of intake by the root system per unit of length or surface should be known, because we need a universal transport parameter. On account of the labour involved in root measurements only a restricted amount of data is available, a number of which have been compiled in table 2. Considering all the difficulties involved in obtaining these data they show reasonable agreement. More work in this field will be needed so as to characterize the nutritional requirements of our cultivated plants in data, which can be converted to soil chemical and physical characteristics.

Establishing clear cut relationship between nutrient supplying capacity of the soil and data obtained by soil analysis (bulk soil fertility level) should ultimately be possible, although much difficult research will have to be carried out. But the advantage of this knowledge will be that the established relationship can more often be used in both ways and will be of equal usefulness whether they serve the interpretation of plant or soil analysis.

As a certain rate of supply has to be maintained the study of transport phenomena becomes our main concern. This field of research has developed more and more during the last two decades. Except for the generally unimportant contact exchange, supply towards the root surface either comes about by diffusion or by mass-flow along with the soil water drawn towards the roots.

If mass-flow is the dominating contribution in the supply, it would seem that all we would need to know is the amount of nutrient dissolved in the available water within reach of the root system. This amount can be determined and its adequacy calculated. The problems that arise in establishing the seemingly simple relationships are those that up till now in this discussion the dynamics have been neglected. Variations in soil water content will alter the soil solution concentrations, resulting in situations where mass-flow may carry along insufficient or superfluous amounts. In the case of nitrate additions to the available stock through variable rates of mineralization have to be considered and losses through leaching may occur. Relating nutrient supplying capacity of the soil to its fertility level as characterized by soil analysis has to take these difficulties into account. But if we try to work the other way around - starting from the soil fertility level - an approach using a dynamic model does indeed open up possibilities of simulating the supply conditions and the plant response to be expected. Recently such an approach has been published for the growth of lettuce.

In other cases, however, diffusion is the main mode of supply. In order to be able to establish a relationship between supplying capacity and soil characteristics information on a number of aspects is needed. To cope with a certain supply rate a definite concentration gradient will be needed. This means that concentration of the equilibrium soil solution should be a certain amount higher than the situation required at the root surface (intensity). But as ions are detracted by uptake the rate of replenishment to the equilibrium solution should keep pace, requiring sufficient amounts that are easily desorbed (capacity). So both parameters have to be known. Again a static approach can not cope with the large variations in rate of diffusive supply that will be the result of variations in soil water content. Dynamic simulation of the whole process by means of a computer and utilizing the data obtained in soil analysis, knowledge on soil chemistry and soil physics, offer a solution. A number of attempts in this field have already been published.

3. CALCULATING THE REQUIRED AMENDMENTS

In our discussion the last topic should be how to convert our data on soil fertility into the required amount of fertilizer to be applied. In many instances the ad hoc relationship as established between plant or soil analysis in regard to fertilizer requirement is used. But it has been the purpose of this discussion to show the possibilities of a more fundamental and universal approach. Ultimately in this approach information on general fertility level of the soil is needed. And we also need to know in what manner the fertilizer added affects this fertility status, if we are to calculate the amounts needed.

Soil analysis is needed to obtain information on its fertility status. But all problems involved in what methods are to be used and how to convert the data into the required information will for this paper be accepted as more or less common knowledge or left to others for further discussion.

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