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UPTAKE OF NITROGEN AND PHOSPHORUS IN RELATION TO SOIL STRUCTURE AND NUTRIENT MOBILITY

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INTRODUCTION

It is an established fact that poor soil structure impedes the growth of plants. This inhibited growth must be the result of restricted uptake of water and nutrients, unless toxic substances are involved.

Closer study of this general relationship, however, reveals that poor soil structure cannot be considered as an individual value, but is better broken down to a number of single factors, some of which are interrelated. These single factors, which may impede root growth and function, may be partly compensated by other soil factors, such as a high content of mineral nutrients. It is no wonder, that on account of this latter fact, many investigations have not resulted in definite conclusions.

Physiological research has laid the basis for explaining poor uptake and growth of plants in so far as poor structure results in a lack of aeration, a surplus of carbon dioxide, *etc.* It seems worthwhile to consider the possibilities of a more direct influence of certain aspects of soil structure on growth or nutrient uptake.

Being involved in physiological and ecological research on root–soil relationships a study of two seemingly unrelated factors was undertaken. Previous experience had taught us that nutrient uptake is the result of the manner in which the available soil is being utilized by the roots. It seemed logical to assume that soil exploitation is mainly governed by two factors: – a) density of roots in the soil, and b) mobility of the stock of nutrients.

The experiments performed aimed at demonstrating a more or less direct influence of coarseness of soil structure on uptake of two nutrients of contrary behaviour.

Literature

Numerous observations on the influence of factors relating to soil structure on the habit of the root system are encountered in the literature.

Restriction of root growth may be the result of mechanical impedance caused by a high density of the soil. Veihmeyer and Hendrikson [14] found that no penetration occurred in sand with a density of more than 1.75, while in clay soils the limiting value was 1.46 to 1.63. However, density influence may be modified in relation to plasticity or to rigidity. Visser and Goedewaagen [15] noticed that a certain layer of clay only inhibited root growth after becoming hard by loss of water. Previous experiments in this laboratory demonstrated the influence of rigidity next to pore size [18].

Besides soil layers restricting root growth to only shallow depths another type of restriction may occur. In this case density of branching and thorough permeation of the soil by roots is impeded by a cloddy structure, often consisting of prismatic soil blocks. Rooting is then restricted to the fissures and thin layers of more friable soil in between the dense units [5 6 7 17]. Figure 1 shows roots of young apple stocks as they developed in a friable and in a cloddy soil.

The mobility of the stock of available nutrients in the soil is correlated with the degree to which they are dissolved in the soil solution. In recent times Tepe and Leidenfrost [13] have investigated the distance over which nutrients are extracted from the soil. The average distance over which phosphate is extracted from a water-saturated soil is 2.5 mm. Ca, Mg, and Mn are extracted over 5 mm, K and Na over 7.5 mm and the ions mainly occuring in the soil solution over still larger distances, ab. 20 mm. Letey and Klute [8] also stress the difference in mobility between adsorbed and non-adsorbed ions.

Supply of nutrients to the roots is, however, not only dependent on diffusion. The plant continually draws on the water in the soil. All ions in solution will thus be carried along with the extracted water. That this process implies a difference in volume of soil contributing to the supply of the plant was put forward by Bray [2]. For the adsorbed ions only thin mantles of soil around the roots are exploited as desorption is only induced near the absorbing root surface. For the nutrients mainly in solution all soil from which water is extracted, *viz* more or less the total soil volume occupied by the roots, is being utilized. An illustration of this concept can be found in an investigation on NH_4 and NO_3 uptake in citrus by Wallace [16]. Administering $N^{15}H_4NO_3$ the uptake rate of $N^{15}H_4$ and NO_3 was the same from both solution and sand culture. From soil, however, the coarse-rooted citrus plants absorbed far more NO_3 than $N^{15}H_4$. The latter ion was now rendered immobile by adsorption. Also the results of the experiments of Shapiro, Armiger, and Fried [12] stress the same points.

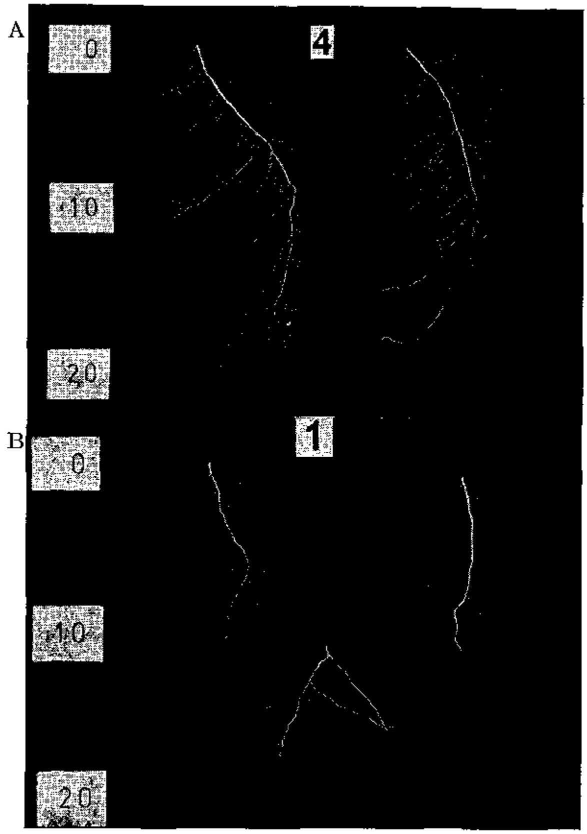

Fig. 1. Roots of young apple stocks in two types of soil,

A, in friable soil of loose and spongy structure
B, in soil consisting of prismatic coarse clods.

They, too, come to the conclusion that in regard to phosphate only part of the soil in between the roots is being sampled and that soil-water movement accounts for part of the supply.

In regard to the above mentioned facts and their implications on the problem of uptake of nutrients and utilization of the soil volume available for rooting a tentative calculation has been made of the net soil volume contributing to supply of the plant with immobile nutrients [19]. Under field conditions only about 2 to 5% of the soil can be fully utilized by the plant in regard to the immobile nutrients.

EXPERIMENTS

Experiments were made to test the expectation that a coarse structure in the soil would result in sparse rooting and that, in relation to differences in mobility this should result in a shift in the ratio N/P in the plant. The plants were only analyzed for N and P as the phosphate and nitrate are extremes in relation to their mobility.

Technique

Young seedlings of various plants were planted in small jars, which were filled with aggregates of different sizes. As it was considered necessary to have indestructible and impenetrable aggregates most experiments were carried out using gravel, *i.e.* pieces of tile drainpipes or flowerpots fractioned

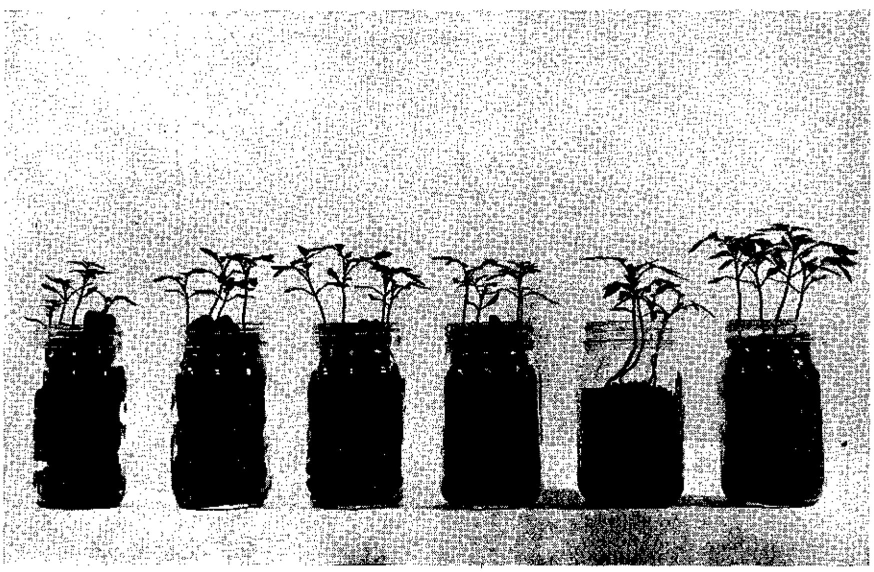

Fig. 2. Young tomato plants being cultivated on soil aggregates of different size. Note better growth of the plants on the fine substrate.

into different sizes. Natural soil aggregates usually fell apart when re-moistened or were too soft to prevent penetration by roots. In Fig. 2 such an experiment is shown.

The gravel fractions were first thoroughly soaked with a concentrated Hoagland solution. The very coarse aggregates had sizes in excess of 1 cm, while the very fine fraction was smaller than 1 mm. During the experiment only water was added to the pots. Water was added as required, usualy only when the plants were near to wilting. This was done to achieve a intermittent soaking and extraction of the water absorbed in the aggregates. The plants were grown in the greenhouse and harvested after 2–5 weeks of growth. The percentage content of total N and P in the shoot was then determined.

Results

The results of a series experiments are given in Table 1.

TABLE 1

Influence of size of aggregates on N- and P-content of the plant

Aggregate size	% P	% N	N/P
Rye			
Very coarse	0.93	1.81	2.0
Coarse	1.04	1.60	1.5
Intermediate	0.99	1.78	1.8
Fine	1.13	1.59	1.4
Very fine	1.20	1.65	1.4
Tomatoes			
Very coarse	0.12	3.3	27.5
Coarse	—	—	—
Intermediate	0.15	3.3	22.0
Fine	—	—	—
Very fine	0.32	3.1	9.7
Sunflower			
Very coarse	0.04	2.35	57.3
Coarse	0.05	2.20	44.0
Intermediate	0.08	1.94	23.1
Fine	0.06	2.14	34.5
Very fine	0.11	1.55	14.3
Wheat			
Very coarse	0.12	2.96	24.7
Coarse	0.07	3.11	44.0
Intermediate	0.17	2.88	17.0
Fine	0.17	3.22	19.0
Very fine	—	—	—

As a rule the plants grown on the finer aggregates showed better growth. From the data obtained it becomes clear that the percentage nitrogen in the plants is variable to some extent, but no clear tendency to vary in correlation with aggregate size is evident. The percentage P in the dry matter, however, shows a distinct rise as the aggregate size becomes smaller. So the N/P ratio is high in the coarse substrate and low in the fine substrate.

DISCUSSION

In these experiments it has been possible to demonstrate one way in which differences in soil structure may affect plant growth. The substrate consisting of large, impenetrable clods, has the effect of restricting thorough permeation of the roots in the available volume. This results in that large volumes of soil being at longer distances from the root surface. Only those nutrients which are highly mobile on account of being mainly dissolved in the soil solution will be displaced towards the surface of the clods as water is being extracted from them (Fig. 3). Thus the interplay of coarse

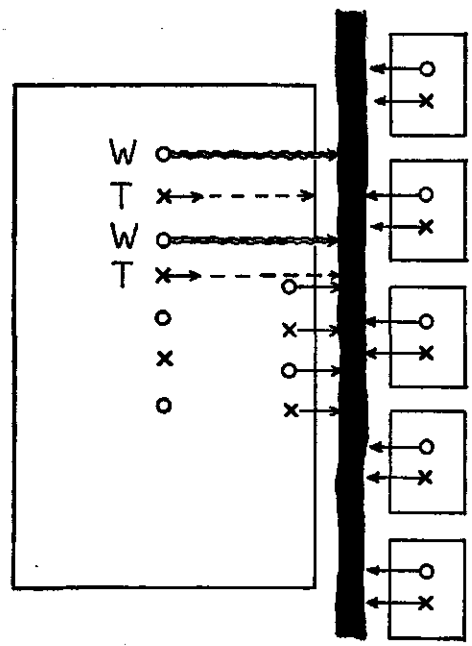

Fig. 3. Utilization of coarse and fine aggregates.

Arrows Diffusion and desorption

T Transport of the small dissolved fraction of an immobile element along with water

W Mass transport along with water of an element mainly in solution

$\circ = NO_3^-$ $\times = H_2PO_4^-$

rooting and mobility of nutrients will result in a shift in the relative amounts of nutrients absorbed. Uptake of the highly immobile ions, such as phosphate, is most severely affected. In a fine substrate the extensive permeation by roots enhances the uptake of the immobile nutrients.

That the principles demonstrated in this experiment also hold in the field is borne out by a number of observations by other workers. The deleterious effect of poor soil structure on the phosphate nutrition of a crop has been mentioned by van der Paauw [10] and by Murdock and Seay [9]. Cleveringa [3] also noticed poor phosphate nutrition of the crop on a soil where the root system was restricted to the friable soil in between large, impenetrated clods. In research on the growth of *Pinus radiata* in New Zealand Atkinson [1] also comes to the conclusion that restricted root growth mainly impairs uptake of nutrients of low mobility such as phosphate. Here restriction of root development to structural joints and cracks between aggregates was sometimes noticed.

Some data given by Rennie and Clayton [11] also seem to be better understood in the light of these principles. The percent fertilizer-P utilization is highest on a soil type containing prismatic blocks. In this case there has been noticed a large difference in the field "A" value and greenhouse "A" value as determined by means of tagged phosphate. A possible explanation of this discrepancy might be that in the greenhouse tests the soil has been broken to finer pieces before filling the pots, thus allowing more intense rooting and a better phosphate utilization.

Domsch [4], who performed experiments on the influence of various-sized aggregates on the growth of young plants by means of a modified Neubauer technique noticed that both rooting and uptake of P and K was less on the coarse substrate.

If the demonstrated principles are generally valid, they have some implications for practical purposes. Firstly restriction of the total volume available for rooting – whatever may be the cause – will result in a diminished stock of nutrients. The supply of mobile nutrients will be less and may become limiting at low fertility level. Uptake of the more immobile nutrients need not be impaired as long as a more dense rooting can occur. This results in a better utilization of the soil.

Secondly the development of a root system densely permeating the soil may be restricted. Uptake of the immobile nutrients is mainly impaired, unless this can be compensated for by a vast total volume of soil available for widely spaced roots. The mobile nutrients will still be mainly available.

The consequence is that on a soil allowing only shallow rooting, nitrogen is liable to be the first element becoming limiting, while on a deep soil with a bad structure the possibility is that phosphate starvation will appear first. However, at a high nutrient level these effects will be hardly evident.

SUMMARY

Nitrogen and phosphate uptake by young plants was studied in experiments, mainly using artificial aggregates of different sizes. Large impenetrable aggregates brought about coarse rooting, while in the finer substrates dense root growth was possible. Coarse rooting resulted diminished uptake of the mainly immobile stock of phosphate. Nitrate uptake, however, was hardly influenced by rooting density on account of its high mobility and transport along with the extracted water. On the finer substrates the plants absorbed more phosphate and therefore the N/P ratio was lower.

Implications of this effect of soil structure on uptake are indicated.

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