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THE RELATION BETWEEN PORE VOLUME AND THE FORMATION OF ROOT SYSTEMS IN SOILS WITH SANDY LAYERS

by

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INTRODUCTION

In the Netherlands, soils occur over extensive areas with a thin top layer of clay, or humus-rich sand, lying on sand with a low silt- and humus content. In this second layer plant roots are penetrating only a few cm. See fig. 1. Since the moisture storage in the shallow top layer can only be small, correspondingly low yields of arable crops occur.

Many soil improvement measures, like subsoiling and deep plowing, have been tried in cases like this, but the effect on crop yields has been inconclusive. An explanation of the negative or positive results is not possible, since in almost all literature on this subject, data on the physical properties of the profiles in question before and after the treatment is lacking. Because of this, it is neither possible to predict what the future effect of soil improvement measures, on still undisturbed soil profiles with such sandy layers, will be.

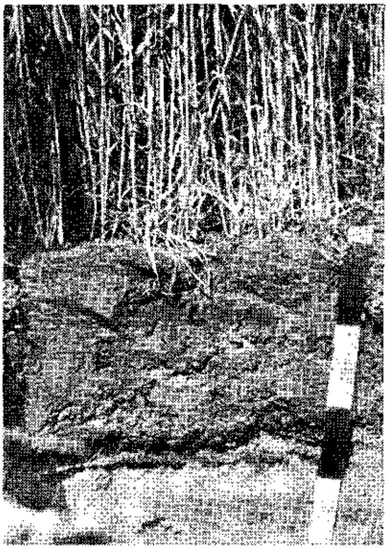

Fig. 1. Clay-on-sand profile. Pore volume of sand 38 %; ground-water level at 1.80 m. below surface; pH of sandy layer 7.0; pF 2.5, at 10 cm. below roots in the sandy layer. Crop: barley. Each scale division is 10 cm.

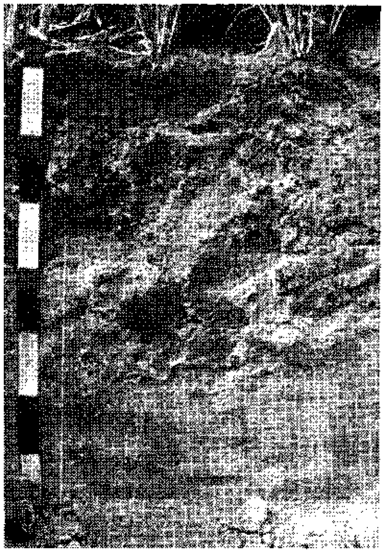

Fig. 2. Same field as in fig. 1, with the same crop. Deep ploughed to a depth of 55 cm. below surface. Dark colour in upper part of the profile: clay. At the bottom, the undisturbed part of the sandy layer.

Soil factors influencing root growth

The soil factors influencing root growth are nutrients and pH, water and air, and the soil texture.

It was found by Schuurman and Goedewaagen (5), in a pot experiment with spring wheat on artificial soils built up of sand of a dry volume weight of resp. 1.40, 1.55 and 1.75 and a clay top layer, that no correlation existed between rooting depth and the presence or absence of fertilizer in the sand layer. It may be said that although a nutrient deficiency may cause a less developed root system, it has not been observed that this factor alone is responsible for a complete absence of roots at a depth at which roots normally occur.

As regards the influence of the pH, it is well-known that root growth is possible inside a wide range of pH of the soil (Kramer, 3). The sandy layers of the soils in question all had a pH between 5.5 and 7.0, values that will not impede root growth.

It has already been made evident by experiments carried out by Hendrickson and Veihmeyer (2), that root growth can be impeded by water deficiency only at pF-values higher than approximately 4.0. Since in the sandy layers in question no roots were present, the pF did not reach higher values than approximately 2.7. This takes care of the water deficiency aspect.

An excess of moisture can decrease the exchange of carbondioxide and oxygen between the soil and the free atmosphere to such an extent, that roots are poisened. According to Van Duin (1), the permeability for air becomes approximately zero, when the air-filled pore volume is less than 10 % of the total soil volume, the air-filled pores being in that case no longer linked, forming the 'blocked' pore volume. Wesseling (7) gives values of 10 to 15 % for the 'blocked' pore volume. The top of the sandy layers in question is in all cases at least 50 cm. above the ground-water level. From the pF-curves made, it followed that at pF 2.0 the water-filled pore volume is less than 12 %, the air-filled pore volume was therefore much higher than 15 %. As the capillary conductivity for water at moisture tensions below pF 2.0 is rather high, the roots will be able to withdraw the moisture that is held at tensions lower than pF 2.0. from the pores, before entering them. From the above the conclusions can be made, that the water-air regime can in this case not be the cause of the absence of roots. There remains the impediment of root growth by mechanical resistance of the soil.

From the mechanical point of view, root growth will be governed by the pore size, making a penetration with primary roots possible, and by the movability of the soil particles under root pressure, allowing secondary growth if the original pore size does not allow this already. In general these two soil characteristics will be related. In soils with aggregate structure, pores are large and movability is high, so impediment of root growth due to mechanical resistance is not to be expected. Aggregate structures do not occur, however, in sandy soils with a low humus- and silt content.

Veihmeyer and Hendrickson (6) made a pot experiment with artificial soils of various volume weights. It appeared that with high volume weights the roots could not penetrate into the soil. Here also it was assumed that air deficiency could not be the cause of this.

In the already mentioned experiment of Schuurman and Goedewaagen (5) it was found that the roots penetrated deeper, the lower the dry volume weight of the packed sand. When the specific weight of the used sand is taken at 2.60, their given volume weights would correspond with a pore volume of respectively 46, 40 and 35 %. From their results it may then be inferred that pore volumes of 40 % and less impede root growth.

This would agree with the yield estimations in relation with various pore volumes given by Merbitz and Von Nitzsch (4) where a yield decrease of 8 to 17 % occurred when the pore volume dropped below 40 to 45 %.

A fundamental approach to the problem of mechanical resistance against root growth was made by Wiersum (8), who did experiments with glass pellets in which root growth appeared only possible when the pore size was larger than 150 μ. The pellets were in this case nearly immobile. He also investigated the influence of pore size in glass tubes of various sizes filled with pure sand. The wider the tubes the deeper the roots would go, apparently depending on the movability of the sand grains.

Experiments

Since for practical purposes, the determination of pore size and movability of the particles is too complicated, and it was thought that pore volume would be correlated with both, experiments were carried out to find a correlation between pore volume and root growth for the soils in question.

a. Some 270 soil samples were taken from sandy layers with (79) and without (191) roots, present in the profiles of fields under rye, oats, barley and potatoes. Determined were volume weight, specific weight, pH of the sandy layer, ground-water depth, the moisture characteristic and the presence or absence of root systems.

b. In pots with a depth of 80 cm., artificial profiles were made consisting of 60 cm. pure sand and a 20 cm. thick top layer of humus-rich sand. The pure sand had in half the number of pots a pore-volume of 35, in the other of 45 %. As a crop, rye was used. Rooting depth was determined.

   In other pots the same profile was made, the layer with low pore volume was built there at different depths, the crop was fodder corn. Rooting depth and dry yield were determined.

   The top layer in these pot experiments had an ample supply of N, K and phosphate. The soil in the top layer never came below pF 3.4. The pots were drained, so a water table was non-existent.

c. On part of an experimental field, the soil was loosened by hand to a depth of 70 cm., taking care all existing layers were kept in place. The undisturbed profile consisted of a 30 cm. thick top layer of humus-rich sand; a 20 cm. thick (from 30 to 50 cm. below surface) B-horizon, rich in iron and with a pore volume of 39 to 40 %; a subsoil of yellow sand, pore volume 35 %. The ground-water table was present at depths of more than 1.50 m. below surface. The crop was oats. Determined were rooting depth and yield. See for an example of the effect of deep plowing, the figures 1 and 2.

In all the above cases it was ascertained first, that impediment of root growth could not have been caused by any other factor than the mechanical resitsance of the soil.

Results and conclusions

a. Of the non-rooted samples only one had a pore volume of 42 %, all others a pore volume of less than 38 %. One of the rooted samples had a pore volume of 35 %, all others a pore volume of more than 40 %.

b. In all pots with a sand subsoil with a pore volume of 45 %, the root systems had reached the bottom. In the other pots only some of the roots had reached more than 10 cm. into the pure sand.

The yield determined for the fodder corn, did show a positive correlation with rooting depth although no water deficiency occurred:

rooting depth in cm. below surface	25	45	65	85
yield in tons dry matter per ha.	2.4	3.0	3.3	3.7

An explanation of this may be, that the nutrients leached to the subsoil and out of reach in the pots with shallow rooting depths.

c. In the undisturbed profile of the trial field, roots did not occur below 50 cm. below surface. In the treated profile rooting was intensive up to 70 cm. below surface, the depth to which the soil was loosened.
The yield in kg. oats per ha. was respectively: 2730 (untreated) and 3115 (treated). Both yields can be considered to be very low, as a result of the exceptionally dry growing season in 1959.

From the above, the following conclusions can be made.

1. In many instances impediment of root growth in sandy layers with a low silt- and humus content will be the result of mechanical resistance.
2. Rooting is prevented by means of mechanical resistance, when the pore volume is less than 40 % of the total soil volume.

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Summary

The cause for the absence of root systems in sandy layers with a low silt- and humus content, will often be the mechanical obstruction to the penetration and secondary growth of roots. From the examined natural profiles and from artificially built profiles, it appeared that rooting is prevented by means of mechanical resistance when the pore volume is less than 40 % of the total soil volume.

Résumé

L'absence de systèmes radiculaires dans des couches sableuses pauvres en limon et en humus trouve souvent sa cause dans l'obstruction mécanique opposée par ces couches à la pénétration et la croissance secondaire des racines. Il fut constaté, lors de l'étude de profils naturels et de profils reconstitués artificiellement, que l'enracinement est empêché par résistance mécanique dès que le volume des pores tombe à moins de 40 % du volume total du sol.

ZUSAMMENFASSUNG

Der Grund der Abwesenheit von Wurzelsystemen in sandigen Schichten mit einem geringen Schluff- und Humusgehalt, dürfte öfters der mechanische Widerstand gegen Eindringen und sekundärem Wachstum der Wurzeln sein. Aus der Untersuchung natürlicher, sowie künstlich aufgebauter Profile ging hervor, daß Bewurzelung durch mechanischen Widerstand verhindert zu werden scheint, wenn das Porenvolum weniger als 40 % des totalen Bodenvolums beträgt.

DISCUSSION

ROBERT M. HAGAN: 1. The possibility that minimum pore size or mechanical impedance limits root growth might be explored by growth of plants directly on the sands without the overlying clay and humus layers. Has this been investigated?

2. Is it possible that because of the interference between clay and sand, which may interfere with downward flow of water and thus cause some accumulation of water at the interface, limited aeration may be restricting root growth into the sandy layers?

A. P. HIDDING: 1. If a sandy soil (poor in humus) is on top, the total pore volume is usually higher than in underlaying sand. Moreover, there is more possibility of 'removal' of some particles during initial growth, so that pore volume increases.

2. In our cases 15 % water (on volume basis) was present and the total pore volume about 40 %. So, 25 % pore volume of the soil contained air. Limitations of root growth with this air content is highly improbable.

H. FRESE: One can often find that roots do not pass the borders between two differently structured layers even if the underlaying zone is coarser or looser than the surface layer. This may be due to more favorable conditions, what kind so ever, in the upper layer which roots do not want to leave.

C. VAN DEN BERG: Roots have to leave to deeper layers as long as no absolute barrier exists. Moisture in sandy layers was in our case not lacking (at the moment that roots arrive at the sandy layer, soil moisture is still about at full capacity). There is no reason why roots would not like to grow (in principle) in an environment where water is available at low potential, air is not lacking and sufficient minerals may be low but not lacking. Mechanical impedance seems to be the only logical explanation.

NIJENSOHN: Which is the size distribution of the sandy layer of these soils?

C. VAN DEN BERG: The mean grain size of the sandy subsoils is about 150 μ.