Neth. J. Agric. Sci., 15 (1957) : 259—266

Root growth in acid soils

G. P. Wind

Institute for Land and Water Management Research (I.C.W.), P.O. Box 35, Wageningen, The Netherlands

Received 15 March, 1967

Summary

In three experiments with wheat and oats, on peat and sandy soils, a rather sharp limit to the rooting of plants existed at about pH 3.5 (determined in 0.1 N KCl). In the pot experiment on sandy soil this limit was very sharp. Above pH 3.6 the rooting density was hardly influenced by acidity; below pH 3.4 there were hardly any roots.
High acidity not only causes less weight of roots but also a larger diameter of the roots, so its effect on rooting density is even greater than it would appear from the root weights alone. The function of roots in acid soils will also be badly impeded by their shape and anatomical structure.

Introduction

In many peat soils the rooting of nearly all crops is shallow. In peat soils with an artificial sand cover (reclaimed cut-over peat soils in the northern Netherlands) the roots of wheat, rye, oats, barley, potatoes, sugar beets and of almost all weeds are practically confined to the top layer. They penetrate only a few centimeters into the pure peat despite its very favourable physical conditions. Both air and moisture are normally more than sufficient; in many cases, in young sphagnum peat, there is not even any mechanical impedance.
This shallow rooting causes considerable drought damage to most crops, even in normal years, on soils with adequate available moisture. Many attempts have therefore been made to improve such soils (Buringh, 1962; Wind and Pattje, 1964).
Originally the improvements, a mixing of the peat and underlying sand by deep ploughing, were performed without clear understanding of the nature of the problem.
This paper deals with some experiments on the influence of pH on root development and will show that the high acidity of the peat is the main impediment for roots.

Available knowledge

Despite a thorough and expert search [1] only a few papers were found on rooting and soil acidity.
Troughton (1957) reviews six papers, the described experiments giving as result an

[1] The author is much indebted to drs. L. F. Abell, librarian of the Institute, for his thorough search.

Fig. 1 Root growth of oats in pots with young sphagnum peat covered by 5 cm sandy soil. Left: pH 2.7, no roots in the peat. Right: pH 4.1, many roots.

increase in root weight with a decrease in pH. Farr (1928) found a sharp decrease in root hair elongation, to zero if pH decreased to 3.5. Gammon (1957) studied the effect of pH adjustments on root growth and found that lack of calcium was more detrimental than a low pH itself. Rothwell (1957) concluded the same. Calcium appeared to be necessary to form calcium pectate in the cell walls of hair roots which makes them more resistant to distortion.

When H_2SO_4 in different concentrations was added to the soil in a pot experiment, McNeur (1953) found the amount of grass roots increased as soil pH decreased, but the amount of clover roots behaved in a contrary manner. The lowest pH of 3.6 increased to 4.4 at the end of the experiment. Goedewaagen (1942) also found decreasing root development with increasing acidity, though root growth did not completely cease. Of course for growth there must be an upper limit of acidity; in soils with pH 1.0 there will be no growth of higher plants at all. But literature gives little information on the acidity limit for root growth. It is not known whether there is a sharp limit or growth decreases gradually with increasing acidity. Roots of some plant species seem more tolerant of low pH than roots of others. A high content of Ca in soil seems to depress the pH limit for root growth.

Pot experiment with peat soil

Young sphagnum peat, not weathered, pH(KCl) 2.7, was treated with KCl solutions of different strenghts. This resulted in pH values varying from 2.7 to 4.5, after washing until Cl^- was no longer present.

In the soils thus treated, root growth of oats was studied in 5-litre pots, covered with 5 cm of sandy top soil of pH 4.8. Because the roots could not be removed from the peat, no quantitative data can be given. But hardly any roots penetrated

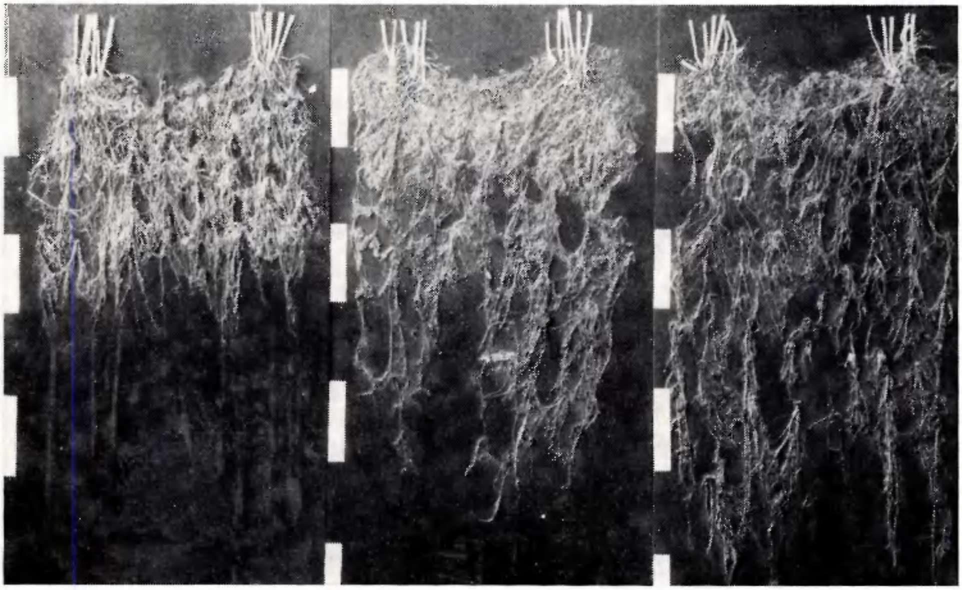

Fig. 2 Root growth of spring wheat in a field experiment on an untreated and two treated soils. From left to right: subsoils (> 15 cm) with pH 3.1, 3.5 and 4.5. Each block on the scale is 10 cm.

into the peat at pH < 3.1. Up to pH 3.4 there were only very few roots in the peat; above that value, in most cases many roots were present. In most acid soils there were some roots growing between the peat and the plastic wall of the pot but sometimes even these were absent. Fig. 1 indicates how roots developed in an acid and a neutral soil during the experiment.
The few roots in the acid soils were thick and had hardly any branch roots.

Field experiment with peat soil

An area of 2500 m² cut-over peat soil, with 15 cm sandy soil (20% organic matter, pH 4.7) covering 100 cm of young moss peat (95% organic matter, pH 3.1) were thoroughly mixed to a depth of 60 cm with a rotary mixer. Before mixing, half of this area was dressed with 25 ton $CaCO_3$/ha.
After mixing the whole area was covered with 12 cm pure sand. This top layer was mixed with about 5 cm of the underlying peat-sand mixture. The surface layer thus obtained was limed to a pH of 4.7.
So, with 1250 m² of undisturbed soil, three soils were in the experiment, the top layer of each almost the same and a subsoil of peat different in pH. One year after mixing, this pH of the subsoil was 3.1 (control), 3.5 (mixed) and 4.5 (mixed + lime). In the mixed subsoils the organic matter content was 40% and in the control soil 90%.
Fig. 2 shows the root development of spring wheat one month before harvesting. In the control soil the rooting was confined to a depth of about 25 cm. Many of the

originally horizontal roots at the bottom did turn vertical with the washing. In the soil of pH 4.5 rooting was even to a depth of 60 cm, while in the soil of pH 3.5 rooting was to 50 cm in some parts but elsewhere not deeper than 30 cm.

Pot experiment with sandy soil

Plastic 5-litre pots were filled with a sandy soil containing 4.5% organic matter. The top 7 cm had a pH (KCl) of 4.8; the lower part, 7–21 cm deep, was treated with different concentrations of H_2SO_4. The concentration ranged from zero for treatment 1 to 1 N for treatment 7. The pots of treatment 8 did receive 1 N Na_2SO_4 to see whether the $SO_4^=$ ion was responsible for bad rooting. The same amount of water was given to each pot. The pots were then placed in the open and were leached by 50 mm of rain in 10 days. This resulted in the acidities given in Table 1. None of the pH values was lower than 3.4 in this experiment.
Oats was sown on 23 March 1966. The pots remained in the open until 20 May when the experiment ended. Evaporation was usually low and rainfall was high enough to prevent drought. Only once, on 10 May, 15 mm water was added. In the last 10 days with bright weather the plants were allowed to dry out the soil.
Root weights were estimated by washing each layer separately. The roots were dried to estimate dry matter and burned to estimate sand. The results are given in Table 1.

Table 1 Yield of tops and roots of oats in the experiment with sandy soil (g sand-free dry matter per pot)

Treatment		pH 7–21 cm	Tops	Roots	
				0–7 cm	7–21 cm
1	H_2O	4.52	7.7	5.0	3.7
2	H_2SO_4	4.33	9.3	7.9	5.5
3	,,	3.95	8.0	6.9	4.4
4	,,	3.85	9.1	7.5	4.6
5	,,	3.65	8.4	7.2	3.4
6	,,	3.53	6.8	7.6	0.91
7	,,	3.42	6.4	7.8	0.11
8	Na_2SO_4	4.50	7.3	6.2	3.9

Each treatment was in triplicate. There were practically no roots in the three pots of treatment 7; and about 1 g of roots in the pots of treatment 6. In all other pots there were more than 3 g in the treated layer. In Fig. 3 all 24 roots weights from the 7 to 21 cm layer are plotted against pH. A very sharp limit to rooting appears to exist between pH (KCl) 3.4 and 3.6. Below this pH root growth is almost impossible; above this limit root growth is hardly affected. There is a slight hint of optimum root growth about pH 4.2, which would support McNeur's (1953) results.

Rooting density

Under a binocular microscope the diameter of about 300 random roots was measured for each treatment. The quadratic mean of diameter was calculated. Table 2 gives some results. The roots from acid soils in treatment 6 and 7 were much thicker than in other treatments. That was caused by the lack of fine roots (< 0.1 mm ⌀) in the acid soils.

From the fresh root weights (assuming a specific weight of 1.0) and the root diameter, the total length of roots was calculated. By dividing this length by the volume of soil and assuming that all roots were vertical, the number of roots per cm^2 could be calculated. This appeared to be more than 10 for the soils with pH > 3.6 and 1.5 for pH 3.53 and as few as 0.07 for pH 3.42. Sodium sulphate affected neither root weight nor root diameter.

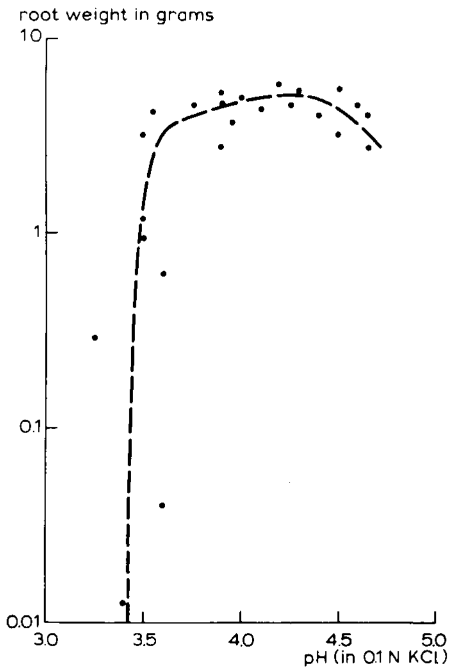

Fig. 3 Dry weight of oat roots, in g per pot in the experiment with sandy soil, plotted against pH.

Table 2 Diameters of roots, calculation of rooting density and relation to moisture extraction in various pot experiments in sandy soil

	Treatment							
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*
pH	4.52	4.33	3.95	3.85	3.65	3.53	3.42	4.50
Quadratic mean of root diameters (mm)	0.26	0.30	0.29	0.32	0.31	0.41	0.64	0.30
Cross-sectional area of roots (mm^2)	0.052	0.069	0.065	0.082	0.074	0.133	0.328	0.071
Fresh root weight (g/pot)	25.5	42.8	31.5	33.1	31.5	7.7	0.9	31.2
Total length of roots (m/pot)	490	620	485	405	425	58	2.7	440
Number of roots per cm^2	12.9	16.3	12.8	10.6	11.2	1.5	0.07	11.6
Soil moisture in % by weight	3.2	3.1	4.3	3.9	3.8	6.8	8.1	3.7

Table 3 Root diameter distribution of 300 arbitrary chosen roots in the various treatments of sandy soil pot experiments

Treat-ment	*pH*	*Root diameter (mm)*													
		0.1	*0.2*	*0.3*	*0.4*	*0.5*	*0.6*	*0.7*	*0.8*	*0.9*	*1.0*	*1.1*	*1.2*	*1.3*	*1.4*
1	4.52	99	93	50	20	12	6	3	1						
2	4.33	78	81	71	33	28	5	1	1	1					
3	3.95	88	91	56	32	20	10	1	0	1					
4	3.85	130	57	43	26	18	11	7	0	8					
5	3.65	113	68	62	23	20	6	6	2						
6	3.53	39	80	53	44	43	19	7	8	2	3	1			
7	3.42	5	29	46	34	39	24	27	17	14	24	8	7	5	7
8	4.50	120	67	44	34	20	5	3	3	4					

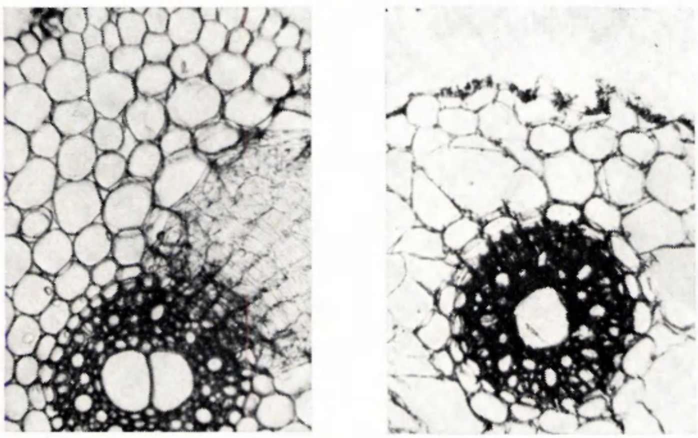

Fig. 4 Sections of roots grown in sandy soils with pH 3.5 (left) and 4.5 (right).

Table 2 relates the number of roots to the final moisture content of the soil. This shows that rooting density of treatments 6 and 7 was too small for efficient moisture extraction. This is in accordance with Wind's (1961) calculation that about 1–2 roots are necessary per cm^2 for almost completely drying of the soil.

Size and anatomical structure of the roots

Table 3 gives the distribution of root diameters. There was little difference between the treatments 1–5, and 8, the not too acid soils. Treatments 6 and 7 had more big roots and fewer fine roots.

Fine branch roots are fewer and main roots are thicker in acid soils than under normal conditions. The difference in diameter is caused only by a much thicker cortex of roots from acid soil (Fig. 4). The same was observed by Jonker (1958) for roots impeded in their growth by dense packing of the soil.

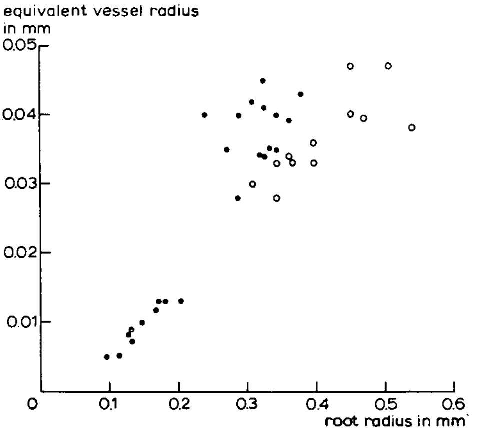

Fig. 5 *Radii of root xylem vessels of roots grown in sandy soils with pH 4.5 (●) and pH 3.5 (○).*

Transport by the roots was investigated by measuring the radius of the xylem vessels [2]. Vessels were about 20% smaller in acid than in normal soil. This is demonstrated in Fig. 5 where the equivalent vessel radius is plotted against root radius. The equivalent vessel radius R_e was obtained from the occuring vessel radii $r_1, r_2, r_3, \ldots r_n$ in one root, by the following calculation:

$$R_e = (r_1^4 + r_2^4 + r_3^4 + \ldots r_n^4)^{1/4}$$

This accords with Poiseuille's law, in which flow is proportional to the fourth power of vessel radius (see also Wind, 1955).
By applying Poiseuille's law for root radii which are 20% smaller than normal a transport function comparable to 40% of normal is found.

References

Buringh, P., 1962. Bodemvernieuwing in de Veenkoloniën. *Tijdschr. Koninkl. Ned. Heidemaatschappij,* 73 : 177–180.
Farr, C. H., 1928. The effect of calcium and hydrogen ions upon root hair growth. *Proc. 1st Intern. Comp. Soil Sci.,* 3 : 393–415.
Gammon, N., 1957. Root growth responses to soil pH adjustments made with carbonates of calcium, sodium or potassium. *Soil Crop Sci. Soc. Florida, Proc.,* 17 : 249–254.
Goedewaagen, M. A. J., 1942. Het wortelstelsel der landbouwgewassen. Algemene Landsdrukkerij, 's Gravenhage.
Jonker, J. J., 1958. Bewortelingsonderzoek en ondergrondbewerking in de Noordoostpolder. Van Zee tot Land, No. 25.
McNeur, A. J., 1953. Effect of soil acidity on growth of pasture plants. *New Zealand J. Sci. Technol.,* 35 A : 311–326.
Rothwell, D. F., 1957. The effect of lime on root distribution. *Soil Crop Sci. Soc. Florida, Proc.,* 17 : 67–71.
Troughton, A., 1957. The underground organs of herbage grasses. *Commonwealth Bur. Past. Field Crops, Bull.,* 44.

[2] The author is much indebted to Mr. D. R. Verkerke of the Agricultural University, Wageningen, for the anatomical investigation.

Wind, G. P., 1955. Flow of water through plant roots. *Neth. J. Agr. Sci.*, 3 : 259–264.
Wind, G. P., 1961. Capillary rise and some other applications of the theory of moisture movement in unsaturated soils. *Inst. Land Water Management Res., Tech. Bull.*, 22 : 12–15.
Wind, G. P. en Pattje, D. J., 1964. Resultaten van diepploegen en woelen te Borgercompagnie in 1963. *Tijdschr. Koninkl. Ned. Heidemaatschappij*, 75 : 175–181.