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Microstructure, soil strength and root development of asparagus on loamy sands in the Netherlands

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Summary

In the province of Limburg, in the south of the Netherlands, asparagus is cultivated in soils which exhibit a wide variety of yield.

To obtain a better insight into the suitability of these soils for the cultivation of asparagus, the relation between root development and micromorphology of the soil was investigated.

From a detailed field description of the soil structure of five soil subgroups it appeared that within each subgroup the vertical succession of the various structure forms – the structure profile – was practically the same.

The effect of this structure on root growth and the consequent life expectation of the asparagus plant could be shown.

At the end of this article the question is raised as to whether improvement of podzol and other soils by deep reworking will result in a better root development and consequently in improved yields for a period of at least ten years.

Introduction

Interest in the cultivation of asparagus has increased considerably in the last decade, mainly because of the high prices of asparagus for export.

The acreage of asparagus has greatly increased. Despite good plant material, a good tilth and correct care, yields vary considerably. It is probable that soils are now used which are less suited or even very poorly suited to growing asparagus.

After the third full harvest year the yield on the better soil types can exceed 5000 kg/ha, but on the poorer types it often remains below 4000 kg/ha. On many of the worst fields the yield drops after five to six harvest years to less than 3000 kg/ha, and the plants have to be pulled up. On better fields the plants may well have a life of ten to twelve harvest years, although even then yield is reduced after the fifth harvest year.

By studying the soil profile and structure and root growth an attempt was made to ascertain which factors cause these great differences in yield and therefore determine the suitability of the soil for the cultivation of asparagus. Thirty trial fields, which were all planted in 1960 with the new hybrid 'Limburgia' (Mary Washington × Beeren selection), were investigated twice: the first time was in 1962, which was the third year of growth and the first harvest year; the second time was in 1966, the seventh year of growth and the fifth harvest year.

The investigation

Soil classification

All soils are described and classified according to the soil classification system used in the Netherlands (de Bakker and Schelling, 1966). The texture descriptions are according to the Soil Survey Manual (Soil Survey Staff, 1951). The following subgroups can be distinguished.

'Veld' podzol soils (Aquods). Sand to loamy sand, recently reclaimed from heath land. Mean highest water-table within 80 cm. The Ap horizon is very dark gray (10YR 3/1)[1] and has on the average 4% organic matter. The B horizon, which could originally have been 10 to 40 cm thick, is usually partly ploughed through the topsoil during reclamation and is subsequently sometimes completely ploughed through before growing asparagus. The light yellowish brown (2,5Y 6/4) to light gray (2,5Y 7/2) C horizon is usually partly homogenised and is often stratified at a quite shallow depth.

'Vorst' vague soils (Psamments) in cover sand. Loamy very fine sand to very fine sandy loam, slightly podzolized. Mean highest water-table is well below the solum. The Ap horizon has on the average less than 2% organic matter. The subsoil has a light yellowish brown (10YR 6/4) weakly developed B horizon, of which the moder humus is strongly degraded and often occurs as debris cutans around the sand grains. The C horizon is often well homogenized some decimetres deep.

These soils, which were formerly covered mainly with forest, are given as soils of inland dune sand on the Provisional Soil Map of the Netherlands (1950). They have traditionally been used for asparagus growing.

'Vorst' vague soils (Psamments) and moder podzol soils (Orthods) in river sand. These older river deposits are generally somewhat coarser than the coversands and contain 5-8% of clay. Mean highest water-table is well below the solum. The organic material content in the Ap horizon averages 2.5%.

A weakly developed B horizon is also found under the plough layer and mostly a fairly perfect or partly degraded moder humus can be recognized. If the percentage of organic material in this horizon amounts to 1.0 to 1.5% and the colour is brown (10YR 5/3), the horizon is called a moder-B. If the percentage of organic matter in this horizon is too low (< 1%) and the colour is light yellowish brown (10YR 6/4), then these soils are also included as Psamments. Although some of these soils were probably planted with forest formerly, they have long been in use as arable land and many fruit orchards have been planted.

Brown 'enk' earth soils (Brown Plaggepts). These are man-made arable soils with an Aan horizon more than 50 cm thick that was produced by heightening with earth-containing manure for centuries. Mean highest water-table is always deeper than 80 cm below the surface.

The Aanp horizon is dark grayish brown (10YR 4/2) and organic matter content is low (less than 3%). Texture of these soils is loamy sand to sandy loam. In the subsoil a buried Orthod is nearly always present.

[1] According to the Munsell Soil Color Charts.

Black 'enk' earth soils (Black Plaggepts). These are also man-made soils with an Aan horizon more than 50 cm thick. Mean highest water-table, however, is sometimes shallower than 80 cm below surface.

The Aanp horizon is very dark grayish brown (10YR 3/2) or black (10YR 2/1); the content of organic material is nearly always more than 3%. Texture of these soils is also loamy sand to sandy loam. The clay content is somewhat higher than in the Brown 'enk' earth soils. In the subsoil a buried Aquod is usually present.

Investigation of structure

Amongst other features, the microstructure of each soil horizon in profile pits was described according to the microstructure classification of Jongerius (1957). A field binocular with magnification of about × 35 lin. was used. Three main groups have been differentiated: microaggregate structures, matrix structures and single-grain structures.

Micro-aggregate structures consist of a combination of small micro-aggregates (mainly humus) and sand grains. This group is subdivided according to the quantity of humus and the degree of porosity of the micro-aggregates. Attention is also paid to whether the sand skeleton is open or densely packed.

Matrix structures consist of matrix (lute and filling of amorphous humus, iron and aluminium hydroxides, clay, etc.) and a skeleton of sand grains. According to the degree to which the matrix covers the sand grains, binds them or fills the intergranular spaces, these structures are subdivided into mantle structures, bridge structures, massive structures and spongy structures, respectively.

Single-grain structures are packings of loose sand. The sand is sometimes stratified.

Additional data about morphology have been observed in mammoth-sized thin sections (Jongerius and Heintzberger, 1963) of the same soils.

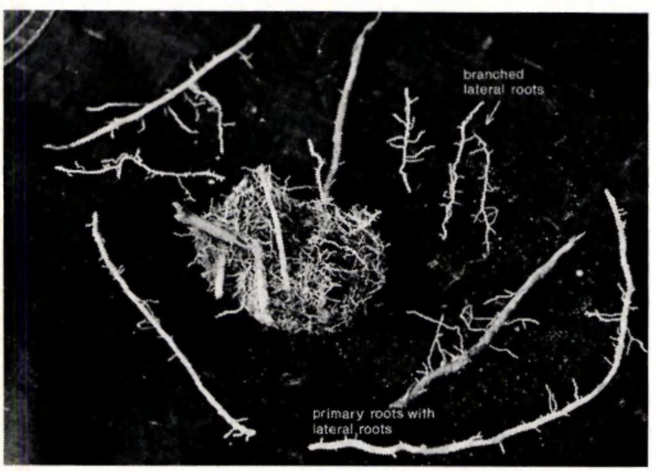

Fig. 1. Primary roots and branched lateral roots of the Asparagus plant. Photograph: Stiboka (No R 24-114).

Fig. 2. Rooting investigation by the method of Reijmerink. Photograph: Stiboka (No R 26-115).

Investigation of root development

The asparagus plant is perennial, dioecious and herblike. It has a somewhat woody rhizome upon which many unbranched primary roots, about 5 mm thick, are found. For the most part these grow vertically, but in soils with compacted layers at shallow depths they can also grow horizontally. Thin, partially branched lateral roots grow on the 'fleshy' primary roots (Fig. 1). Thus an extensive network of roots is formed.

The extension of the root system of two plants, one male and one female, was studied in profile pits, according to the method of Reijmerink (1964). With this method a plexiglass plate is set against the wall of the profile pit in which the roots have been exposed by washing away the soil with water. On the plate a sheet of plastic foil is attached upon which the root system can be traced and the limits of the soil and structure horizons can be indicated (Fig. 2).

The number of primary and lateral roots per soil horizon can be counted on the tracing, and the surface of each horizon can be planimetrically determined. In this way both the percentage of roots and the root density, that is the number of roots per unit of surface (n/dm^2), were calculated for each soil horizon.

Results

The microstructure of loamy sand

Practically no macrostructure elements appeared in sand soils. It was only in the Ap horizon that small crumblike or granular clods were sometimes to be found, but these were a result of tillage. They had no natural planes and thus could not be considered as structure elements (peds), but as clods. However, this fact does not mean that sand soils are structureless. In these soils many *microstructures* could be distinguished. Each of these structure types was more or less bound to a fixed position in the profile. The natural vertical succession of these structure types in the soil profile is analogously known as *structure profile* (Hulshof et al., 1960).

Table 1. Structure profiles in sand soils in Central Limburg (the Netherlands).

Aquods	Orthods	Psamments	Black Plaggepts	Brown Plaggepts
Ap: +20 – 20 cm micro-aggregate structure S: half-open packed H: coalesced pellets, filled inter-granular voids	Ap: +20 – 20 cm micro-aggregate structure S: half-open packed H: degraded pellets, filled inter-granular voids	Ap: +20 – 20 cm micro-aggregate structure S: half-open packed H: degraded pellets, scattered	Aanp: +20 – 20 cm micro-aggregate structure S: half-open packed H: coalesced pellets, filled inter-granular voids	Aanp: +20 – 20 cm micro-aggregate structure S: half-open packed H: intact pellets, filled inter-granular voids
....	....			
B: 20 – 35 cm mantle structure S: half-open packed H: amorphous humus	B: 20 – 50 cm mantle structure S: half-open packed M: silt + humus	B: 20 – 50 cm micro-aggregate structure S: half-open packed H: intact pellets, scattered	Aan2: 20 – 60 cm micro-aggregate structure S: half-open packed H: coalesced pellets, filled inter-granular voids	Aan2: 20 – 80 cm micro-aggregate structure S: half-open packed H: intact pellets, filled inter-granular voids
		....	....	
C11: 35 – 50 cm single-grain structure S: half-open or densely packed (partially homogenized)	C11: 50 – 80 cm bridge structure S: half-open packed M: silt	C11: 50 – 80 cm single-grain structure S: half-open packed	B2b: 60 – 80 cm spongy structure S: densely packed M: silt + humus P: macro-, meso- and micro-pores	B2b: C11: 80 – 120 cm micro-aggregate and very weakly developed mantle structure S: half-open packed H: intact pellets, scattered and debris cutans
				....
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Cg: > 50 cm single-grain structure S: densely packed (sometimes stratified)	Banded B: > 80 cm bridge structure S: densely packed M: clay + iron hydroxides	C12: > 80 cm single-grain structure S: densely packed	Cg: > 80 cm single-grain or massive structure S: densely packed M: clay + iron hydroxides	C12: > 120 cm single-grain structure S: densely packed
Average[1] yield in kg/ha in 1968				
3850	3500	4400	4300	5400

[1] Yield data assembled and made available by the Horticulture Department of the Netherlands Soil Survey Institute
S = sand, H = humus, M = matrix, P = porosity.
- - - - - - - - - - - - - - = maximum depth of rooting.
.... = depth of micro-aggregate structures.

In the five soil units studied, the structure profiles are roughly as listed in Table 1.

The micro-aggregate structures were found principally in the topsoil (A horizon), in the B horizon of the Orthods, in the weakly developed B horizon of the Psamments and in the humose cover (Aan horizon) of the Plaggepts.

The matrix structure appeared principally in humus podzol-B's, textural-B's, banded-B's, and in strongly loamy or iron-rich B and C horizons.

The single-grain structures were mainly restricted to the subsoil (C-horizon).

The relation between the soil structure and root development

Much research has already been carried out on the relation between soil structure and root development. Hidding (1961) found that the minimum pore volume for roots to penetrate into the soil is 40%.

Still more important than the total pore volume is the pore size and the bulk density. Wiersum (1957a, b) found that the average minimum diameter in a rigid system was 200 μm. Schuurman (1965) pointed out that the bulk density plays an important role in sudden changes which may occur in root development; roots from a loose layer have greater difficulty in penetrating a firm and compact layer than roots from a firm and compact layer have in penetrating a very firm and compact layer – this is because in the first case the contrast is too great.

A good measure of the strength of the soil is the penetration resistance. Taylor and Burnett (1964) found that soil strengths greater than 25 to 30 bars at field capacity prevent root penetration in the soil mass. Van Dam and Hulshof (1967) noted a reduced root development with increasing penetration resistance (measured with a cone of 1 cm^2 surface).

It could be seen from the structure of those layers into which the roots no longer penetrated, that the pore volume was often less than 40%. But because pore size is dependent on the granular composition and degree of packing of the sand, a sand layer with a total pore volume of 40-45% and made up of moderately fine and extremely fine sand can be so densely packed that either there are scarcely any pores greater than 200 μm, or it is impossible for the roots to widen smaller ones (Fig. 3a). Further in certain microstructures the sand grains can be so bound together by binding agents such as iron hydroxides, clays, silty material or amorphous humus that a firm skeleton is formed in which the roots can only penetrate if pores with sufficient diameter are present (Fig. 3b and 3c).

Massive structures, in which the space between the sand grains is entirely filled with matrix, often also contain a high percentage of micropores and mesopores. These layers also, even though they may not be cemented, are practically impermeable to roots (Fig. 3d).

The relationship between soil profile, porosity and root development for the five soil units under study is given in Table 2. This table compared with the structure profiles in Table 1, shows that:

- micro-aggregate structures are in general favourable or very favourable to root development;
- matrix structures vary widely, but in general allow a very meagre root development;
- single-grain structures with open packings are moderately favourable to root development but when densely packed do not permit rooting.

The relationship between depth of rooting and age of plant

To ascertain whether the depth of rooting is dependent on the structure of the soil or on the age of the plant, in 1963 fields with asparagus plants of varying age were studied.

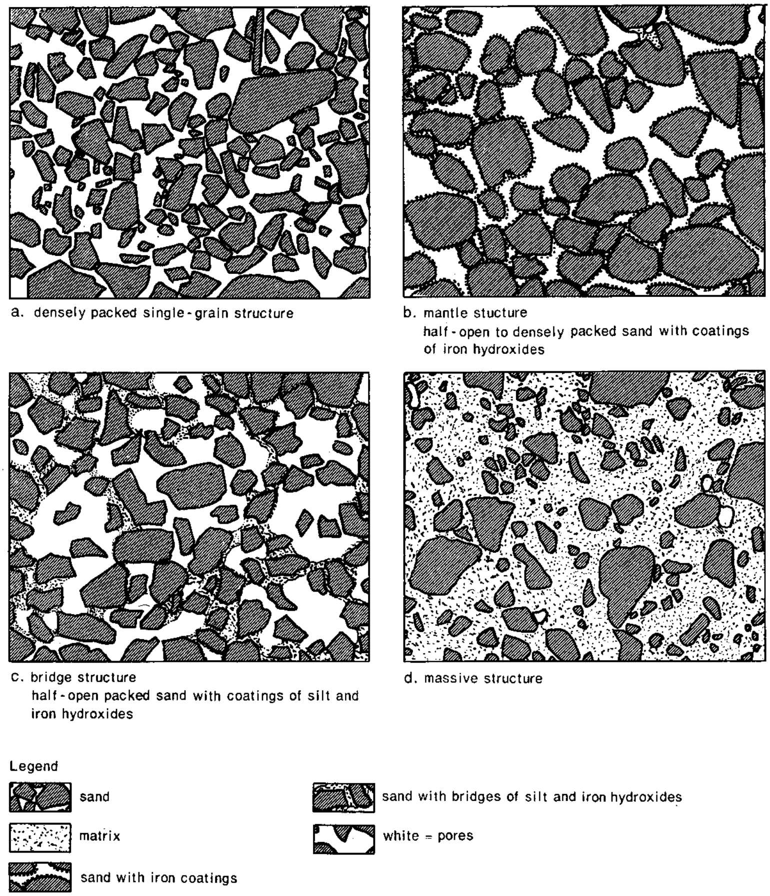

Fig. 3. Disturbing microstructures in the subsoil of sandy soils in Limburg, the Netherlands.

After 1, 4, 6 and 12 years of harvesting there was hardly any difference in the depths of rootage, a fact which had already been ascribed to the influence of the microstructure of the subsoil. This concept was confirmed in 1966 when rooting was again investigated in all 30 trial fields. Only in the Black Plaggepts was rooting somewhat deeper because in 1962 the root development had remained shallow as a result of a high water-table.

The average and maximum depth of root development below the rhizomes of the plants in both years and on all trial fields was 40 and 65 cm for the Aquods, 75 and 100 cm for the Orthods, 80 and 120 cm for the Psamments, 65 and 90 cm for the Black Plaggepts and 90 and 150 cm for the Brown Plaggepts, respectively.

During the investigation in 1963, however, a quite different phenomenon was also observed which hereafter will be referred to as 'ageing'.

Fig. 4 gives the distribution as a percentage of the lateral roots of plants of various ages in three different soils. Initially and in all soil subgroups, 60 to 90% of the lateral roots appeared in the ploughed and humose topsoil as well as in the humose cover of the

Table 2. Relationship between soil profile, prosity and root development.

Horizon	Porosity (%)	Root development (lateral roots)			
		1962 (%)	1966 (%)	description	remarks
Aquods					
Ap	48 – 52	82.6	79.4	Very intensive	
B + C11	42 – 45	17.4	20.6	Meagre	In C11 only along old root channels
Cg	< 40	0.0	0.0	None	
Psamments and Orthods in river-sand					
Ap	44 – 48	86.2	66.8	Very intensive or intensive	
B + C11	44 – 48	13.8	33.2	Meagre or moderate	
Banded-B	39 – 43	0.0	0.0	None	
Psamments in coversand					
Ap	47 – 49	74.6	58.3	Intensive	
B + C11	44 – 46	25.4	41.7	Moderate	Regularly decreasing
C12	43 – 45	0.0	0.0	None	
Black Plaggepts					
Aanp	44 – 50	84.9	74.7	Very intensive	Irregular
Aan2 + B2b	47 – 52	15.1	25.3	Meagre	Rapidly decreasing with respect to groundwater
Cg	39 – 42	0.0	0.0	None	
Brown Plaggepts					
Aanp	48 – 50	78.7	64.5	Intensive	
Aan2 + B2b + C11	46 – 48	21.3	35.5	Moderate	Regularly decreasing
C12	44 – 46	0.0	0.0	None	

Plaggepts. After several years the percentage of lateral roots in the Ap and Aanp horizon above the rhizomes decreased strongly, whereas in the layer underneath it was somewhat variable and in the subsoil it strongly increased.

A distinct shift in the rooting pattern was observed which increased as the plants became older. On the old primary roots there were no longer any lateral roots in the topsoil. It was only on the younger parts of these roots in the usually humus-poor subsoil that a reasonable number was still found, but these lateral roots were less branched. It was only on the new primary roots, and then in the topsoil, that new lateral roots still developed (Fig. 5).

This great reduction in the number of lateral roots in the topsoil can be caused by various factors. The upper parts of the older primary roots may become somewhat woody, so that no more lateral roots can grow. A certain 'poisoning' may occur. It is well known that in fields where asparagus has once grown, asparagus will never grow again. It is thought that the roots give off a particular type of toxin.

The percentage and quality of the organic matter may also influence the number of lateral roots. Another possible cause is the chemical exhaustion of the tillage layer. The physical deterioration of the tillage layer as a result of the destruction of the original micro-

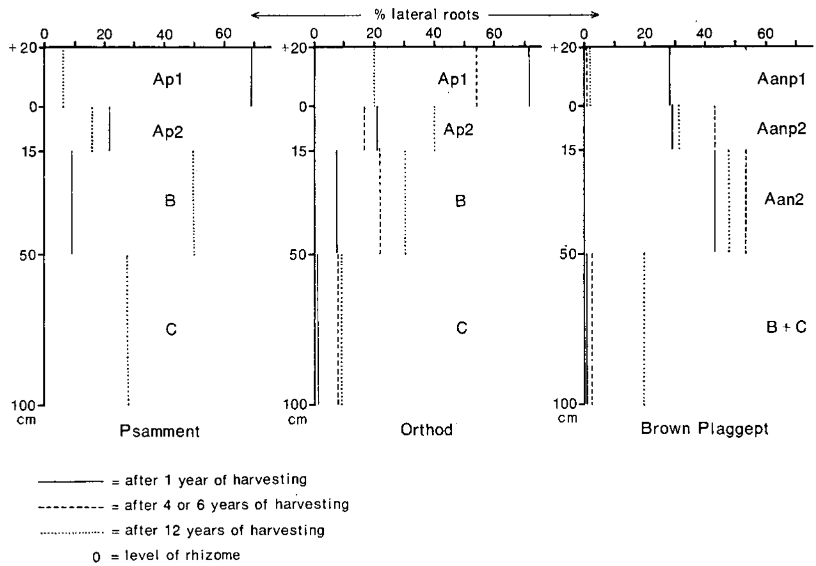

Fig. 4. Root distribution of *Asparagus* sp. of various ages in three soils.

aggregate structure and the increasing compaction of the second layer, could also reduce the number of lateral roots.

The first possibility (ageing) is probably the most important, because this phenomenon was observed both in wild and cultivated asparagus.

In comparing the root development of plants of equal age in the 30 trial fields both in 1962 and in 1966, this ageing was found. The reduction from 1962 to 1966 in the number of lateral roots relative to primary roots in the Ap horizon was always much greater than in the subsoil, where the ratio even increased. Thus when a great reduction in the number of lateral roots in the topsoil is not compensated by the possibility for the roots to penetrate into the subsoil, the deterioration of the plant and consequently of the yield will be very great.

This deterioration can be seen in Table 1, where the average yield of 1968 is given for each soil unit. Above the dotted line (. . . . .) the micro-aggregate structures are to be seen which are favourable for root development. Under the disjoined line (- - - -) are to be found the unfavourable matrix and single-grain structures. In between there are layers with various structure types with moderate or very irregular rooting.

In these profiles with undisturbed subsoils the yield increases as the number or the total thickness of the layers favourable for rooting also increases.

The Aquods and Orthods in river sand each have a toplayer with a micro-aggregate structure which is very favourable for rooting, and two layers in the subsoil with a micro-structure which is moderately favourable; the average yield after five years of harvesting is in both cases less than 4000 kg/ha.

The Psamments in cover sand and the Black Plaggepts each have two layers in the topsoil with a microstructure favourable for root formation and one layer in the subsoil moderately so; in this case the average yield amounts or 4000 to 4500 kg/ha.

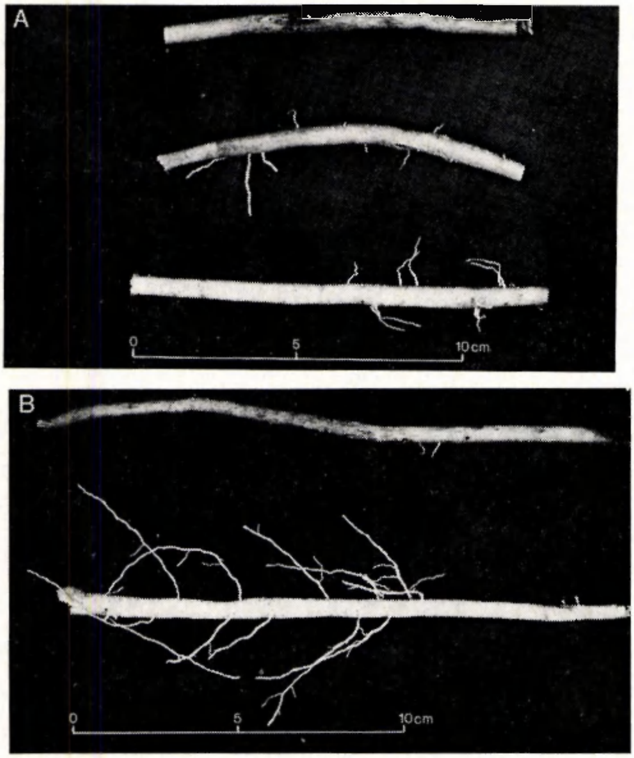

Fig. 5A. Ageing of primary roots: various parts of the same primary root. Above: at 20 cm distance from the rhizome; very woody (dark colour); no lateral roots. Middle: at 40 cm distance from the rhizome; becoming woody; lateral roots both live and dying off. Below: at 80 cm distance from the rhizome; not woody (light colour); lateral roots living. Photograph: Stiboka (No R 33-111).
Fig. 5B. Ageing of primary roots: primary roots of various ages in the same soil horizon, at 20 cm distance from the rhizome. Above: old primary root; woody (dark colour); no lateral roots. Below: young primary root; not woody (light colour); many living lateral roots. Photograph: Stiboka (No R 33-110).

In the Brown Plaggepts, in which the layers favourable for rooting continue to the subsoil, the yield is the highest and averages after five years even more than 5000 kg/ha.

As a rule of thumb the following can be put forward: with 50 cm of soil suitable for rooting below the rhizome, the plant can remain productive for at least five years; with a depth of 100 cm at least ten years is possible and with still deeper rooting, even more than ten years.

One must take into account, however, that the total production is not only determined by depth of rooting, but also by root density and root activity (intake of water and nutrients).

A full description of the profile, the microstructures and the rooting pattern of two soils – an Aquod with conditions for shallow rooting and a poor yield, and a Brown Plaggept permitting deep rooting and high yields – is given in the next section.

Profile descriptions

Profile: No 47

Area: Limburg, the Netherlands
Vegetation: asparagus
Parent material: Pleistocene eolian sand (coversand)
Topography: flat
Human influence: reclaimed from heath land in 1920
Classification: Aquod
General description: Sand to loamy sand. Moderately humose podzol soil with hydromorphic characteristics at less than 80 cm below surface (Table 3). In the course of reclamation the B horizon was almost completely mixed with the Ap. The BC horizon is disturbed here and there as a result of loosening and is indicated as BC(p).

Table 3. Grain-size analysis of an Aquod.

Depth in cm with respect to the rhizome	Horizon	Mineral particles (mm) as % of the soil					Organic matter	pH (KCl)
		moderately fine and coarse sand > 0.150	very fine sand 0.150–0.105	extremely fine sand 0.105–0.05	silt 0.05–0.002	clay < 0.002		
+8 - 8	Ap	46.9	24.9	14.4	9.4	0.2	4.2	5.3
26 - 23	BC(p)	42.4	32.5	18.7	4.7	0.2	1.5	4.5
34 - 70	Clg11	48.7	27.9	15.9	7.0	0.0	0.5	4.6
76 - 100	Clg12	42.8	26.8	18.9	10.9	0.0	0.6	4.6

Micromorphological description [1]

Apl	+24 — +8 cm	Black (10YR 2/1) coalesced moder humus, which entirely surrounds the sand grains; micro-aggregate structure.
Ap2	+10 — —8 cm	Black (10YR 2/1) strongly coalesced to amorphous moder humus; which entirely surrounds the open-packed sand grains: micro-aggregate structure. Porosity 47.5%; penetration resistance 10-15 kg/cm².
Ap3	8 — 16 cm	Mixture of A and B material. The A material has a micro-aggregate structure, but the moder humus is much less coalesced than in the layers above (Fig. 6). The B material, originating from the upwards-ploughed B2 horizon, is a dark reddish-brown (5YR 3/3) strongly coalesced to amorphous humus which appears irregularly as thick cutans on the sand grains. The penetration resistance of the whole layer amounts to ± 15 kg/cm².
BC(p)	16 — 34 cm	Alternatively half-open and closely packed very fine sand, covered with thin yellowish-brown (10YR 5/4) cutans of dominantly amorphous humus: matrix structure (Fig. 7). Porosity 50%; penetration resistance varying between 13 and 20 kg/cm².
Clg11	34 — 70 cm	Closely packed very fine sand, partially filled in with extremely fine sand and loam; sometimes stratified: single-grain structure. Porosity 42%; penetration resistance between 34 and 40 cm increasing from 20 to 30 kg/cm² and between 40 and 70 cm from 30 to > 50 kg/cm².
Clg12	> 70 cm	Closely packed very fine sand, the pores of which are largely filled with extremely fine sand and loam; strongly stratified with small bands of moderately fine sand, the pores of which are entirely filled with clay and silt: single-grain structure (Fig. 8). Porosity 40%; penetration resistance > 50 kg/cm².

[1] Zero is level of rhizome.

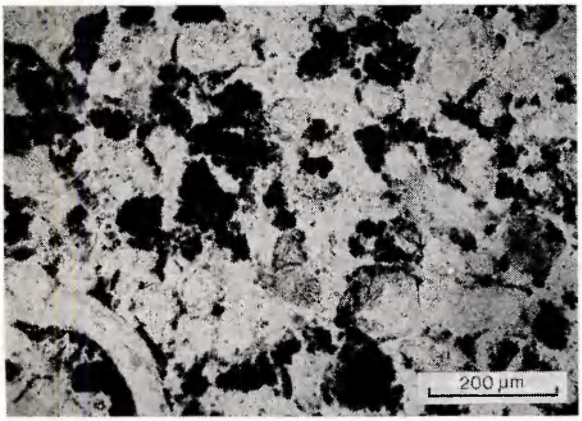

Fig. 6. Micro-aggregate structure in Ap horizon of an Aquod; Profile No 47, about 10 cm below level of rhizome.

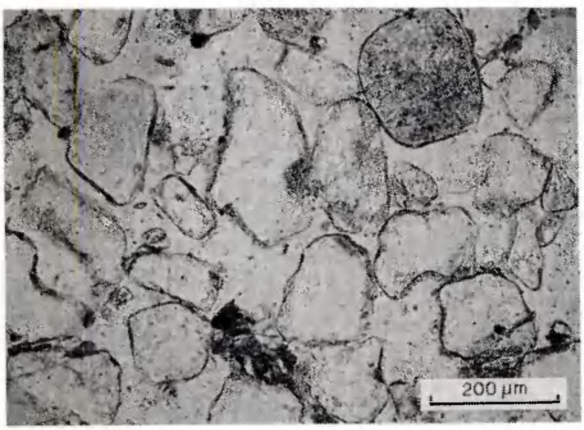

Fig. 7. Mantle structure in BC horizon of an Aquod; Profile No 47, about 25 cm below level of rhizome.

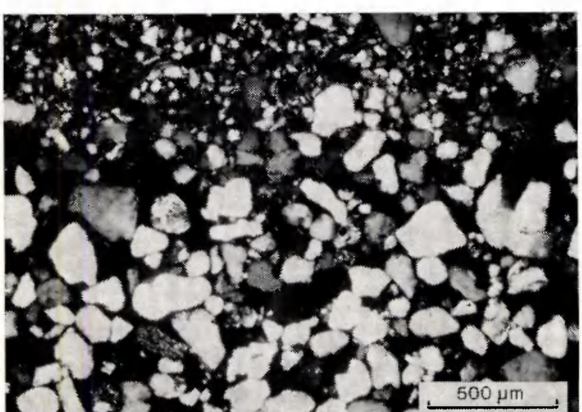

Fig. 8. Single-grain structure (stratified) in Cg12 horizon of an Aquod; Profile No 47, about 85 cm below level of rhizome (crossed nicols).

Table 4. Root distribution in a shallowly and deeply reworked Aquod.

Depth in cm with respect to the rhizome		Surface area in dm²	Primary roots			Lateral roots			Year of obser-vation
			number	%	density of the rooting	number	%	density of the rooting	
+10 – 0	Subtotals	7.83	0	0.0	0.00	292	15.0	37.29	1962 [2]
+ 8 – 0	down to the	6.48	5	5.7	0.77	152	10.4	23.46	1966 [2]
+16 – 0	rhizome[1]	13.60	24	20.3	1.76	196	14.7	14.41	1966 [3]
0 – 14	Subtotals between	10.90	30	39.5	2.75	736	37.7	67.52	1962 [2]
0 – 16	rhizome and	13.15	47	53.4	3.75	639	43.9	48.59	1966 [2]
0 – 15	plough depth	12.75	51	43.2	4.00	290	21.8	22.75	1966 [3]
14 – 28	Subtotals	27.42	46	60.5	1.68	921	47.3	33.59	1962 [2]
16 – 32	in the	26.71	36	40.9	1.35	664	45.6	24.86	1966 [2]
15 – 80	subsoil	72.25	43	36.4	0.60	843	63.4	11.67	1966 [3]
+10 – 28	Totals for the	46.15	76	100.0	1.65	1949	100.0	42.30	
+ 8 – 32	whole profile	46.34	88	100.0	1.90	1455	100.0	24.86	
+16 – 80		98.60	118	100.0	1.20	1329	100.0	13.48	

[1] Ap1 is not included in the calculation, it is regularly tilled.
[2] Shallowly reworked in 1960, observations in 1962 and 1966.
[3] Deeply reworked in 1962, observations in 1966.

Root development

Fig. 9 shows the root pattern in autumn 1966. In Table 4 data on rooting are given for 1962 and 966.

It can be seen in Fig. 9 that as a result of regular tillage practically no roots are present in the Ap1.

Rooting in the Ap2 and Ap3 is reasonably good. Some 45% of all lateral roots appear in the loosened BC horizon. The situation is, however, decidedly heterogeneous. Large lumps of loosened BC material appear in this layer which are otherwise undisturbed so that the sand grains are still cemented by cutans and bridges of amorphous humus; rooting does not take place in these patches. Between these lumps there are sand grains, the braced structure of which is broken up by the intervention of subsoiling machinery, so that an open-packed flexible skeleton comes into existence, favourable to rooting and having a porosity of 50%. The roots do not penetrate in the C1g11, despite a porosity of 42%. In the first place this is because of the relatively great change in porosity. Further, the aggregation of the sand is such that the penetration resistance increases in a very short distance to above the maximum permissible level of ± 30 kg/cm².

The yield of this trial field in the years from 1963 to 1966 inclusive amounted to 3 000, 3 300, 3 650 and 3 700 kg/ha, respectively, with an average of 3 450 kg/ha. The average yield in these years for all five test areas on an Aquod amounted to 4 100 kg/ha. This field is thus one of the worst. This must be partly a result of bad management.

Profile: No 17

Area: Limburg, the Netherlands
Vegetation: asparagus
Parent material: Pleistocene eolian sand (coversand)
Topography: slightly undulating
Human influence: very old forest clearance; thickened during centuries with earth-containing manure
Classification: Brown Plaggept
General description: Loamy sand, moderately poor in humus, brown-coloured old arable land with sandy loam intermediate layers resulting from wind transport during the period of thickening (Table 5). In the subsoil there is a well-developed moder podzol, below which (> 100 cm) there is a degrading banded-B horizon (Bir).

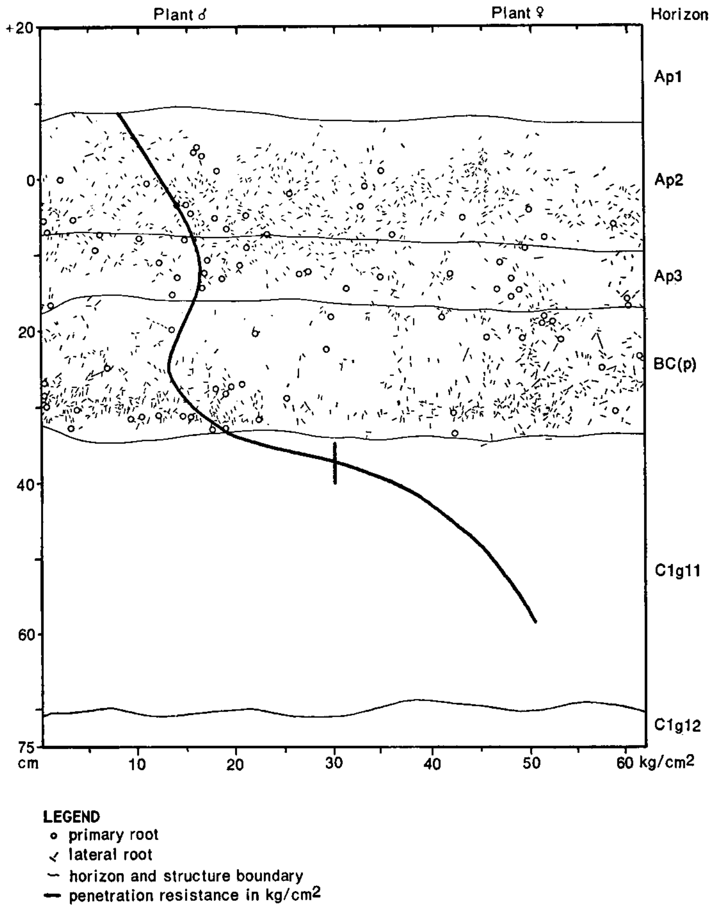

Fig. 9. Diagram of rooting in an Aquod, which was shallowly reworked until circa 35 cm below level of rhizome (Profile No 47). Survey: 1966.

Micromorphological description

Aanp1	+37 — +15 cm	Recently tilled; no description given.
Aanp2	+15 — 0 cm	Very dark grayish-brown (10YR 3/2) porous moder humus which is distributed in the pores between half-open packed, very fine sand grains. The moder clusters are in part strongly mechanically comminuted, so that debris cutans of silt and finely divided humus surround the sand grains: micro-aggregate structure and weakly developed mantle structure. Porosity 44%; maximum penetration resistance 12 kg/cm².
Aanp3	0 — 20 cm	Brown (10YR 5/3), partially strongly degraded moder humus which to a great extent surrounds the half-open to densely packed, very fine sand grains; the cutans are somewhat more strongly developed: micro-aggregate structure and mantle structure (Fig. 10). Porosity 48% (probably too high as a result of primary roots being included in some samples); penetration resistance 10-12 kg/cm².
Aan2	20 — 40 cm	Brown (10YR 5/3) porous moder humus which regularly surrounds the half-open packed, very fine sand grains: micro-aggregate structure. Porosity 48.5%; penetration resistance 12-8 kg/cm².

Table 5. Grain-size analysis of a Brown Plaggept.

Depth in cm with respect to the rhizome	Horizon	Mineral particles (mm) as % of the soil					Organic matter	pH (KCl)
		moderately fine and coarse sand	very fine sand	extremely fine sand	silt	clay		
		> 0.150	0.150–0.105	0.105–0.05	0.05–0.002	< 0.002		
+15 – 0	Aanp2	35.2	24.4	19.6	18.6	0.0	2.2	5.5
0 – 20	Aanp3	33.6	28.7	21.8	13.9	1.0	1.0	4.5
20 – 40	Aan2	30.7	24.7	23.8	18.3	1.5	1.0	4.5
40 – 52	Alb	29.2	27.7	24.7	17.3	0.0	1.1	4.4
52 – 80	B2b	35.6	23.6	22.6	16.3	0.4	1.5	4.6
80 – 105	C11	28.8	22.8	23.8	23.8	0.0	0.8	4.8
105 – 130	C12g	26.7	27.7	24.9	19.9	0.4	0.4	4.6

A1b 40 — 52 cm Dark grayish-brown (10YR 4/2) moder humus and irregular black (10YR 2/1) humus fragments which are regularly found scattered in the pores between open-packed, very fine sand grains: micro-aggregate structure (Fig. 11). Porosity 49,5%; penetration resistance 8 kg/cm^2.

B2b 52 — 80 cm Yellow-brown (10YR 5/4) moder humus regularly surrounding the half-open packed very fine sand grains; the humus micro-aggregates are partially degraded to debris cutans around the sand grains: micro-aggregate structure and a very weakly developed mantle structure (Fig. 12). Porosity 48.5%; penetration resistance 8-10 kg/cm^2.

C11 80 — 105 cm Light yellow-brown (10YR 6/4) debris cutans of silt-sized material entirely surround the half-open packed, very fine sand grains: very weakly developed mantle structure. Porosity 49%; penetration resistance 10 kg/cm^2. Gradually changing into:

C12g (Bir) 105 — 130 cm Densely packed, very fine sand, the pores of which are for the most part filled up with extremely fine sand and silt: single-grain structure. Porosity 46%; penetration resistance increasing from 10 to 30 kg/cm^2. In the strong-brown (7.5YR 5/6) mottles of the Bir the sand grains are cemented by bridges of clay and iron. The pores are sometimes completely filled up with this matrix: bridge structure or massive structure.

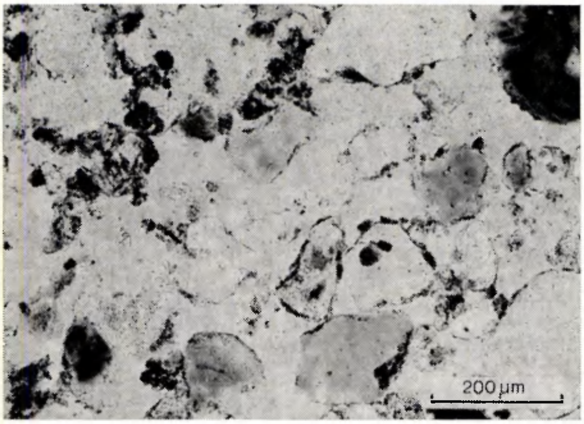

Fig. 10. Micro-aggregate structure and weakly developed mantle or coating structure in the Aanp3 horizon of a Brown Plaggept; Profile No 17, about 15 cm below level of rhizome.

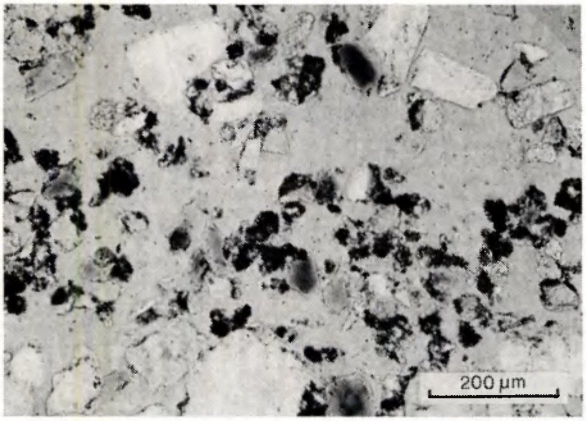

Fig. 11. Micro-aggregate structure in the A1b horizon of an Orthod below a Brown Plaggept; Profile No 17, about 40 cm below level of rhizome.

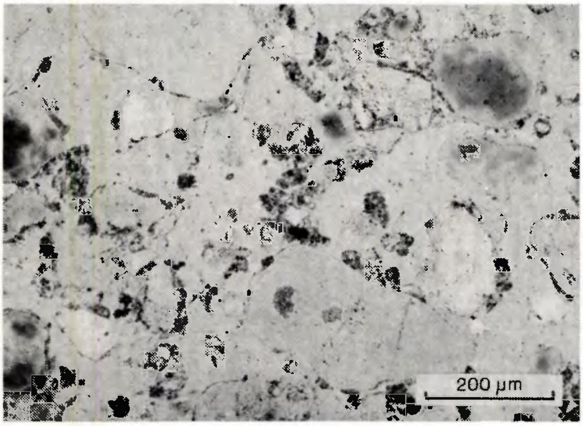

Fig. 12. Micro-aggregate structure and extremely weakly developed mantle or coating structure in the B2b horizon of an Orthod below a Brown Plaggept; Profile No 17, about 48 cm below level of rhizome.

Root development

Fig. 13 shows the root development in autumn 1966. In Table 6 the rooting data for 1962 and 1966 are given.

It can be seen that here also there is little or no rooting in the Aanp1 as the result of regular tillage. Further, there is a fairly intensive but regular decrease in the rooting throughout the profile down to 100 cm below the rhizome. In 1962 the Aanp3 was somewhat firmer and there was therefore less rooting.

The rooting in the Aan2, A1b and B2b notably increased in the period 1962-1966.

At depths greater than 100 cm below the rhizome the packing of the sand grains in the C horizon becomes gradually denser and the amount of rooting decreases. The remnants of a Bir which occur in some places also have an unfavourable effect on root development. Lateral roots were found, however, down to 130 cm below the rhizome.

The yield of this trial field amounted to 5 275, 6 200, 6 400 and 5 900 kg/ha in the years 1963 to 1966 respectively, which averages out at 5 950 kg/ha. This is 2 500 kg/ha more than for the Aquod No 47. The average yield in these years for all six of the trial fields on a Brown Plaggept amounted to 5 600 kg/ha, which is 1 500 kg/ha more than that of all the Aquods.

So, this field is one of the best. This must be partly a result of good management.

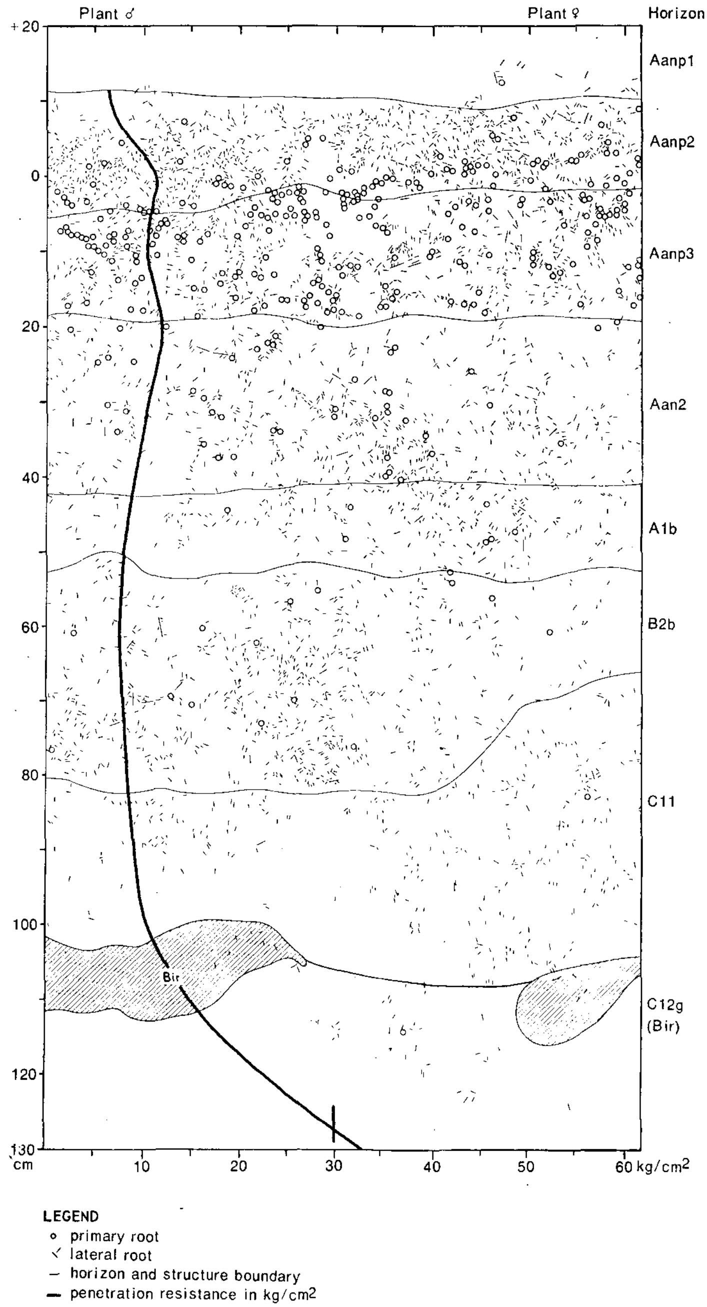

Fig. 13. Diagram of rooting in a Brown Plaggept which was shallowly reworked until circa 20 cm below level of rhizome (Profile No 17). Survey: 1966.

Table 6. Root development in a shallowly reworked Brown Plaggept.

Depth in cm with respect to the rhizome		Surface area in dm²	Primary roots			Lateral roots			Year of obser-vation
			number	%	density of the rooting	number	%	density of the rooting	
+15 – 0	Subtotals down to the	10.54	37	32.2	3.51	912	41.9	86.53	1962
+10 – 0	rhizome [1]	8.39	46	13.2	5.48	769	21.3	91.66	1966
0 – 17	Subtotals between rhizome	11.59	58	50.4	5.00	473	21.8	40.81	1962
1 – 20	and plough depth	16.00	230	66.3	14.38	871	24.1	54.44	1966
17 – 56	Subtotals in humose	27.54	15	13.1	0.54	442	20.3	16.05	1962
20 – 78	subsoil	46.80	69	19.9	1.47	1587	43.9	33.91	1966
56 – 130	Subtotals in the subsoil	51.18	5	4.3	0.10	346	15.9	6.76	1962
78 – 130	poor in humus	41.22	2	0.6	0.05	387	10.7	9.39	1966
+15 – 130	Totals for the whole	100.85	115	100.0	1.14	2173	100.0	21.55	
+10 – 130	profile	112.41	347	100.0	3.09	3614	100.0	32.15	

[1] Aanpl is not included in the calculation, being regularly tilled.

Discussion

In soils in which deep rooting is possible, yield is higher and plants remain productive longer. Certain microstructures offer no possibilities for rooting and these structure types can appear at shallow depth, particularly in the Aquods. Therefore it is important to investigate whether cultivation of these and other soils to a depth of one meter is recommendable.

In woods on Psamments along the coast is was noted that wild asparagus on deeply artificially mixed soils always had fewer lateral roots than that growing on non-mixed soils.

In the south of the Netherlands it was also noted that in three fields in soils that had been deeply loosened, the number of lateral roots of cultivars hardly increased after some years; in one case it was even much less than in soil which was not so loose (Table 7).

For the Brown Plaggept (No 50) the number of lateral roots is slightly increased. However, it is known from the literature (Goedewaagen and Peerlkamp, 1952) that in Plaggen soils a great increase in the number of lateral roots above a certain maximum does not further improve yield. Furthermore, roots deeper than one meter require so much energy for transportation of nutrients that the improvement in yield can be zero or even negative.

For the Psamment (No 14) a strongly decreased number of lateral roots is shown in the deeply reworked profile. This decrease is in the first place the result of the destruction of the natural open sand skeleton in the subsoil; after reworking a more densily packed structure with higher penetration resistance was found. Likewise, the mixing of the strongly loamy sand from the subsoil with the moderately humose topsoil results in a less favourable structure in the Ap horizon.

If the 1966 observations of shallowly and deeply reworked soils (Table 7) are compared, it appears that the number of lateral roots in the Aquod (No 47) is only decreased slightly. However, Table 4 shows that an important shift in the rooting pattern has taken place.

Table 7. Rooting in shallowly and deeply reworked soils [1].

No	Soil	Number of lateral roots		
		in 1962 (shallowly reworked soil)	in 1966 (shallowly reworked soil)	in 1966 (deeply reworked soil)
50	Brown Plaggept	1561	1699	1783
14	Psamment	1782	1819	1170
47	Aquod	1949	1455	1329

[1] See for time of reworking the foot-notes of Table 4.

About 55% of the roots in the shallowly reworked soil are found in the humose Ap horizon, whilst in the deeply reworked soil only about 35% occurs in that layer. It is to be expected that these soils will produce less in the first years after deep cultivation, because a large part of the roots is then growing in a substrate which is poor in nutrients. Thus if deep reworking is to have a favourable effect in production, it must always be accompanied by subsoil manuring.

To investigate the results of deep reworking together with subsoil manuring a trial field was laid out in the autumn of 1968 on an Aquod. The following treatments have been chosen: normal ploughing to a depth of 40 cm; ploughing to 40 cm together with subsoiling to 90 cm; rotary tillage to 70 cm and to 90 cm, respectively.

All the treatments are carried out using various quantities of manure which are applied before deep reworking, so that the manure can be mixed through the whole profile.

After several years the results of this trial field will probably show whether the expenditure on the operations and the supplied manure is justified in terms of production.

Acknowledgments

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