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Soil-physical aspects of zero-tillage experiments

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Summary

Zero-tillage experiments are of greatest importance for the knowledge of tillage. The soil on untilled plots is usually denser than after ploughing. This can be readily demonstrated by visual rating of soil structure and penetrometer measurements. From core sample determinations it is clear that mean pore space and standard deviation of pore space are generally lower on untilled plots. That means that homogeneity of soil structure increases. However, when is started from pasture, the changes are insufficiently described by stating that the soil is loosened or compacted, because two different soil types are created. The statistical nature of soil structure can be demonstrated by the relation between water content at pF2 (%~0~ of dry weight) and pore space. On the untilled plots water content at pF2 is often lower and there are particularly much more spots with low air content than on ploughed plots. However also other phenomena can be observed, because water content at pF2 depends also on treatment of the soil and especially on weather conditions during a longer time before sampling. The processes observed are parallel for both the tilled and untilled soil, but only in another form.
At least at medium-textured soils potato ridges of reasonable quality can still be obtained after several years of zero-tillage.

Introduction

In future herbicides will offer an alternative for tillage as far as weed control is concerned. This will change the criteria for judging whether the soil has to be tilled or not. Firstly mechanization can make definite demands. Soil tillage is then regarded as a technique which enables efficient crop production in mechanized agriculture. Therefore, it has to be adapted to a distinct crop in a distinct crop sequence. Soil tillage can also act as a growth regulator, in that it can decisevely change the physical condition of the soil. Soil-physical criteria must then indicate if for a certain crop the soil must be tilled and if so, how intensively and how deeply.
Up till now it was impossible to separate these two functions of conventional tillage as weeds could only be controlled efficiently by ploughing followed by frequent cultivations, which of course also affected soil structure. However herbicide application now enables plant growth in a weed-free environment, at least in principal, without mechanical weed control. This offers wide perspectives as the question what crop growth without soil tillage means for soil structure is the reverse of the question what

soil tillage means for soil structure. As a consequence zero-tillage trials are of greatest importance for the knowledge of soil tillage.
With the introduction of larger differences in soil structure, as may be expected between tilled and untilled soil, it will also more rapidly become clear under which climatic conditions and for which soil types soil tillage can change the soil-physical environment of the plant in a relevant way. On the other hand it must be borne in mind that by omitting soil tillage not only soil-physical properties change. We may speak of two total different systems with a high number of variables, for instance changes in the organic-matter cycle, the biological balance and chemical properties of the soil.
At the first orientation with respect to changes in soil-physical condition methods were used which were originally designed for the characterization of the effects of tillage implements on the soil. These methods are especially suited to get an idea about changes in macrostructure. The important parameters in plant growth are linked up with these characteristics, but quite often in an indirect way, so additional determinations are necessary.

Methods

The methods used are only very briefly outlined here. For detailed information the reader is referred to 'West European methods for soil structure determinations' (de Boodt et al., 1967).
As a rule measurements are carried out twice a year, viz in spring, after sowing or planting, and in late summer, normally after harvest, but with potato and sugar-beet before harvest.
As soil structure is often quite variable over short distances, the soil-physical measurements are carried out in at least 10 replications within the sampling site. Usually tillage takes place in the upper 20 cm of the soil profile. For sugar-beet, however, ploughing depth is 25–30 cm. Sampling depths are always the same for all treatments and such that on tilled soil two tilled layers are sampled and one just below the cultivated layer.

Visual rating of soil structure

The visual estimation in the field of total porosity and 'workability' (ease of crumbling by hand) of a dug-up block of soil may already give a good indication of gross soil structure. These factors are both rated on a scale from 1 (very poor) to 10 (very good). The overall impression of soil structure quality is also rated.

Determination of soil : water : air ratio and pF-curve

Undisturbed core samples of 100 cm^3 are taken mostly from the 2–7, 12–17 and 22–27 cm layers. Routine laboratory determinations on these samples are usually restricted to total pore space, moisture and air content, both in field-moist condition and at pF2, as moisture content at this suction represents approximately the equilibrium moisture content of drained Dutch soils without hampering layers in early spring. With 10 replications the standard deviation of the average pore space is usually smaller than 1 % (v/v). Sometimes also the pF curve is determined, for which the same undisturbed core samples are used for suctions up to pF2. At higher suctions moisture equilibrium of additional disturbed samples is established in a pressure membrane apparatus.

Penetrometer resistance

A recording spring penetrometer with a 60° cone of 3.84 or 1.86 cm² base records the resistance versus depth curves to 35 cm depth of all spots within the sampling site on the same strip of waxed paper. Through the curves a mean curve is eye-fitted after which, for convenience, the resistance is numerically averaged in kgf/cm² for different layers, respectively. In some instances a micropenetrometer (cone diameter 1 mm) is used in undisturbed core samples in equilibrium with the 0.1 bar suction (pF2).

Profile and aggregate distribution of potato ridges

At about one month after the last ridging the profile of both the surface of the ridges and the surface of the firm soil underneath is determined with a reliefmeter. At the same time the total amount of loose soil, the aggregate size distribution and the percentage by weight of clods > 40 and 40–20 mm is determined by collecting the loose soil of 20 cm length of ridge and sieving and weighing it in the field. At the same time samples are taken for determination of moisture content in the ridges.

Results

Visual rating of soil structure

When a dug-up block of soil is broken by hand, visual inspection of the fracture plane reveals already considerable differences in soil structure between zero-tillage plots and ploughed plots. On zero-tillage plots the soil appears to be dense. The finer pores predominate and pore space distribution seems to be fairly homogeneous. The soil is very firm, so the ease of crumbling is poor. On silt soils soil structure is often layered, perhaps due to shear stresses transmitted to the soil by tractor tires.

Table 1 Visual rating (points) of soil structure at Westmaas, 19 May 1969

Crop	*Tillage [1] in autumn 1968*	*'Structure'*		*'Porosity'*		*'Ease of crumbling'*	
		0–10 cm	*10–20 cm*	*0–10 cm*	*10–20 cm*	*0–10 cm*	*10–20 cm*
Winter wheat	—	5+	5	6—	5+	5—	5½
	pl 20 cm	7—	6—	7	6	6½	5½
Lucerne	—	5	5	5+	5	4½	5
	pl 20 cm	7+	6+	7½	6½	8—	6+
Sugar-beet	—	6+	5½	6+	5½	7—	6½
	pl 25 cm	7½	6	7½	6+	8+	7+
Spring barley	cult 5 or 10 cm	6½	5	6½	5	7—	6—
	pl 20 cm	7—	6—	7	6	8—	6+

[1] pl = ploughing; cult = rigid-tined cultivator.

By way of example results of a visual rating of soil structure in the second year of experimentation on a heavy marine silt soil (Westmaas) are given in Table 1. It is obvious that both porosity and ease of crumbling of untilled soil and of deeper layers on only superficially tilled soil are clearly lower rated than those of full-depth ploughed soil. The overall soil structure quality rating is therefore also lower. The relatively good soil structure on the sugar-beet plot may be regarded as a positive effect of the preceding 1½ year of lucerne.

There is a fairly good relationship between the figures obtained in this way and total pore space and penetrometer resistance. Still this method is applicable only as a first approximation.

Penetrometer resistance

As with visual rating of soil structure, also the determination of penetrometer resistance gives a quick impression of soil structure quality. Characteristic results are shown in Table 2. Both in May and September largest resistance is found on the zero-tillage plots. On these plots resistance in the 0–10 cm layer is relatively low for spring barley, as here a superficial cultivation was carried out after the previous potato harvest. In the 10–20 cm layer resistance is usually higher, due to a smaller pore space and/or a lower moisture content. In September pore space was about the same, but the soil was very dry sand so penetrometer resistance is much higher than in May. The increase in penetrometer resistance at about the same decrease in moisture content is clearly larger for the zero-tillage plots. This is in agreement with the fact that the smaller the pore space the larger the effect of decreasing moisture content on penetrometer resistance.

The determination of penetrometer resistance gives more information about the difficulties than about the possibilities for root penetration. Nevertheless, the development of root crops may be negatively influenced by zero-tillage practice. For example, in 1969 at Westmaas the percentages of fanged roots and broken-off root tips were higher than for conventional tillage (12.0 and 11.0, and 7.5 and 3.0, respectively).

The question arises if these observed differences in soil structure are the same for each soil type, if they change in the course of time and how they can be specified. More detailed information is obtained from the determination of the soil : water : air ratio in undisturbed core samples.

Table 2 Penetrometer resistance (kgf/cm^2) at Westmaas

Crop	*Tillage*[1] *in autumn 1968*	*19 May 1969*		*15 September 1969*	
		0–10 cm	*10–20 cm*	*0–10 cm*	*10–20 cm*
Winter wheat	—	7.5	10.0	34.0	32.6
	pl 20 cm	4.3	5.9	13.0	16.0
Lucerne	—	6.9	9.0	33.6	22.2
	pl 20 cm	4.0	5.3	12.7	17.4
Sugar-beet	—	6.4	9.4	35.5	34.4
	pl 25 cm	4.4	5.4	16.9	21.0
Spring barley	cult 5 or 10 cm	5.7	10.2	22.1	31.9
	pl 20 cm	4.0	5.7	13.6	15.8

[1] pl = ploughing; cult = rigid-tined cultivator.

Core sampling

Changes in pore space. Fig. 1 gives a general picture of the differences in mean pore space between tilled and untilled soil on various trial fields. Each dot is the mean value of 60–120 cores of one sampling, nearly 7000 samples are included in the picture. In nearly all cases mean pore space is higher — normally 2–4 % (v/v) — on the tilled plots. Except for field V, the peaty soil, with a very high pore space, this holds for the 12–17 cm layer of all fields.

For the 2–7 cm layer especially field O seems to be an exception. Here the top soil is very loose by the action of moles. Variation of pore space in time is considerable, but generally less on tilled than on untilled plots. On the untilled plots the 2–7 cm layer is looser than the 12–17 cm layer, except field V, the very loose peat soil. On the tilled plots this holds only for fields R and W, the two experiments that started from arable land.

Still more detailed information about the changes in pore space is obtained by study-

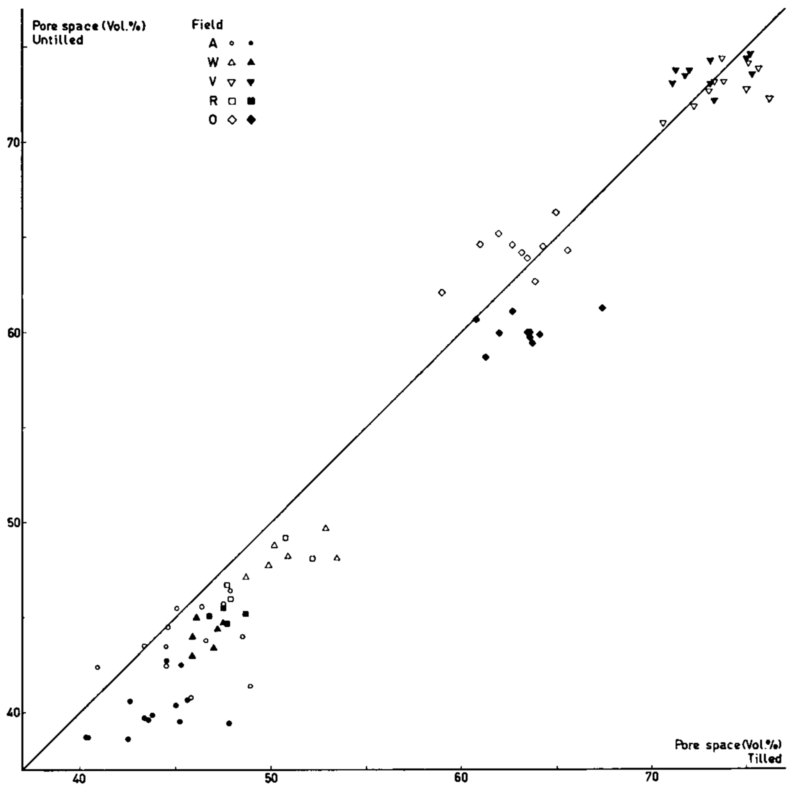

Fig. 1 Comparison of mean pore space of tilled and untilled plots of several trial fields at different samplings.
Open marks = 2–7 cm; closed marks = 12–17 cm.
A = Achterberg (sandy soil); W = Westmaas (heavy marine silt); R = Randwijk (heavy river clay); O = Ossenkampen (heavy river clay rich in organic matter); V = Veenkampen (peaty heavy river clay).

Table 3 Pore space in % (v/v) at Westmaas, 15 September 1969

Crop	Treatment [1]	Tillage [2] in autumn 1968	Pore space at layer		
			2–7 cm	12–17 cm	22–27 cm
Winter wheat	rat	cult 10 cm	**45.0**	43.6	42.5
	conv	pl 20 cm	47.0	48.1	48.8
	zero	—	42.5	43.8	43.9
Lucerne	rat	cult 10 cm	**49.6**	43.6	44.4
	conv	pl 20 cm	52.0	48.9	47.1
	zero	—	43.7	44.5	44.0
Sugar-beet	rat	pl 28 cm	**52.7**	**49.8**	**49.5**
	conv	pl 28 cm	46.8	43.8	45.3
	zero	—	45.2	45.8	46.5
Spring barley	rat	cult 12 or 15 cm	**50.9**	**46.0**	44.7
	conv	pl 20 cm	52.5	49.5	47.8
	zero	cult 5 or 10 cm [3]	51.3	43.9	43.4

[1] rat = rational; conv = conventional.
[2] cult = rigid-tined cultivator; pl = ploughing.
[3] Levelling with rigid-tined cultivator after potato harvest.

ing the results of the various experimental fields seperately. An example is given in Table 3 for a heavy marine silt soil (Westmaas), in which the overall mean pore space, as given in Fig. 1 for the whole trial field, is specified for different crops (Bakermans et al., 1970).

The largest pore space in all three layers is found after conventional tillage, which is in agreement with the intensive way in which the soil is tilled and with the greater working depth. The sugar-beet plots form an exception as here pore space is clearly smaller than after rational tillage, which in this case also means ploughing in autumn to 28 cm depth. The smaller pore space on the conventional tillage plot is probably due to the fact that here the seedbed was prepared with a powered harrow, while on the rational tillage plot a wooden float was used for this purpose. Also in 1968 and in 1970 it was found that after seedbed preparation with a powered harrow pore space on the conventional tillage plot practically equalled pore space on the zero-tillage plot.

The clearly higher pore space in the 22–27 cm layer of the spring barley plots after 20 cm ploughing might be regarded as a residual effect of 25 cm ploughing for the preceding crop (potato). On the winter wheat and lucerne plots ploughing depth likely must have been greater than 20 cm.

On the rational tillage plots pore space is larger than on the zero-tillage plots over the full depth of the tilled layer (bold type in Table 3), with the exception of spring barley, where the zero-tillage plot was treated with a rigid-tined cultivator after the previous potato harvest.

On the zero-tillage plots pore space is small and, except for spring barley, very uniform for the various layers. It is interesting to note that pore space for sugar-beet is relatively high, which is in agreement with the visual rating of soil structure (cf. Table 1).

At the start of the experiment before ploughing in autumn 1967 pore space was small below 7 cm depth. Air contents at pF2 were only 9.1 and 7.9 for the 12–17 cm and 22–27 cm layer, respectively. Pore space below 7 cm has not changed essentially in

Table 4 Pore space in % (v/v) at the start of the experiment (X), pore space averaged for all crops and experimental years ($\overline{X}$) and fluctuation in pore space in the course of the years 1968–1970 ($S_{\overline{X}}$), at Westmaas

Layer (cm)	September 1967	Zero-tillage		Conventional tillage	
	X	$\overline{X}$	$S_{\overline{X}}$	$\overline{X}$	$S_{\overline{X}}$
2–7	47.3	48.1	0.93	51.7	0.79
12–17	44.8	44.4	0.24	46.9	0.37
22–27	45.4	45.0	0.23	46.1	0.38

the course of time on the zero-tillage plots (Table 4). Conventional tillage results in a clearly larger mean pore space but the fluctuations in time are also larger, due to successive loosening by ploughing and compaction by traffic over the field. Fluctuations are largest in the 2–7 cm layer, for both the tilled and untilled plots, which is quite understandable as especially this layer is exposed to weathering, to traffic over the field and in the case of conventional tillage to different superficial tillage treatments. Moreover, also on zero-tillage plots potatoes have to be grown on ridges, which requires a loosening of a considerable part of the top soil. Last but not least the potato and sugar-beet harvests entail an intensive loosening of the topsoil, necessarily followed by a superficial levelling treatment with a rigid-tined cultivator.

Obviously this stable medium-textured soil does not become denser in the course of time. However on several other soils pore space kept decreasing gradually for two or three years, but only the first year in a considerable way.

As is discussed elsewhere in this issue (Boone and Kuipers, 1970, p. 262 sqq.), the average of a quantity like pore space is not likely to be an adeqate characterization, because the average eliminates the influence of extreme values, that in this case are

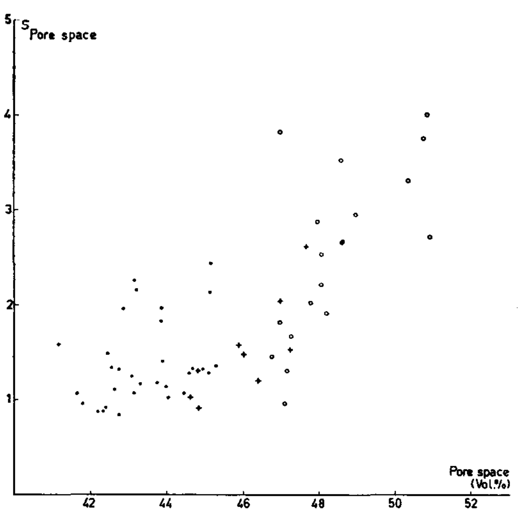

Fig. 2 Changes in mean pore space and standard deviation of pore space in 100-cm³ samples on a heavy river clay (Randwijk) after introduction of zero-tillage.
• several years of zero-tillage; + untilled for one or two years; o tilled.

Table 5 Penetrometer resistance in kgf/cm² on 5 spots in 5 samples of a tilled and an untilled sugar-beet plot on sandy soil at Achterberg, May, 1970. Depth 11–16 cm

Sample	Tilled spot					Untilled spot				
	1	*2*	*3*	*4*	*5*	*1*	*2*	*3*	*4*	*5*
1	25.2	26.2	27.3	25.2	20.1	45.3	50.4	49.3	51.4	50.4
2	9.0	20.1	20.1	20.1	15.2	50.2	47.4	48.4	49.3	48.2
3	20.1	14.1	20.1	30.3	22.2	48.4	50.4	51.4	51.4	40.3
4	33.3	19.2	26.2	42.4	19.2	51.4	50.2	51.4	51.3	47.4
5	22.6	27.2	29.4	33.3	25.2	40.5	48.4	48.4	48.4	50.3

likely to be decisive, because only a minor part of the soil will be needed for a well-developed root system.

Therefore, more information may be obtained from the variability in pore space. Variability generally decreases at decreasing pore space as is shown in Fig. 2, referring to a trial on a heavy river clay soil (Randwijk). This means that in compacting the soil the dense parts of the soil are rather little compacted, whereas the originally loose parts disappear gradually.

Consequently homogeneity increases. From the results of these pore space determinations with cores of 100 cm³ it did not appear that, on this heavy clay, soil homogeneity still increased after one (or two) years. This could be caused by the fact that specific density is not determined for each sample separately. However more information about the redistribution of the solid parts may be obtained from micropenetrometer measurements in samples when a standard water tension is used.

On a sandy soil (Achterberg) mechanical resistance determined in this way (Table 5) was clearly much higher and variability was much smaller on the untilled plot. As a result a relatively large percentage of sugar-beet rooted only superficially, while the beets were small and deformed.

Changes in water and air content. A change in pore space has consequences for the water content. Air content depends on both. Hereby it is of great importance whether is started from pasture or from old arable land. When pasture is ploughed the topsoil is homogenized: the organic matter, which was concentrated in the upper few centimetres, is distributed over 20 cm depth. It is known that organic matter content and water-holding capacity are closely related, especially on sandy soils. As a consequence the water-holding capacity in the upper part of the tilled layer decreases, but it increases clearly in the lower part. For the sandy soil of the trial field at Achterberg (Fig. 3) redistribution of organic matter results in an equal pore space in the 1–6 cm layer for tilled and untilled plots. In accordance with the lower organic matter content and the involved lower water content at pF2, air content on the tilled plot is clearly higher in this layer.

In the 11–16 cm layer water-holding capacity and pore space have both clearly increased. As a consequence of these opposite influences the increase in air content is only small. In the 21–26 cm layer the differences in pore space between untilled and ploughed soil are small. Just below the ploughed layer root development is much less intensive than in the ploughed layer, but often still more intensive than on the untilled plot. The observed increase in water content at pF2 indicates that ploughing depth was sometimes more than 20 cm.

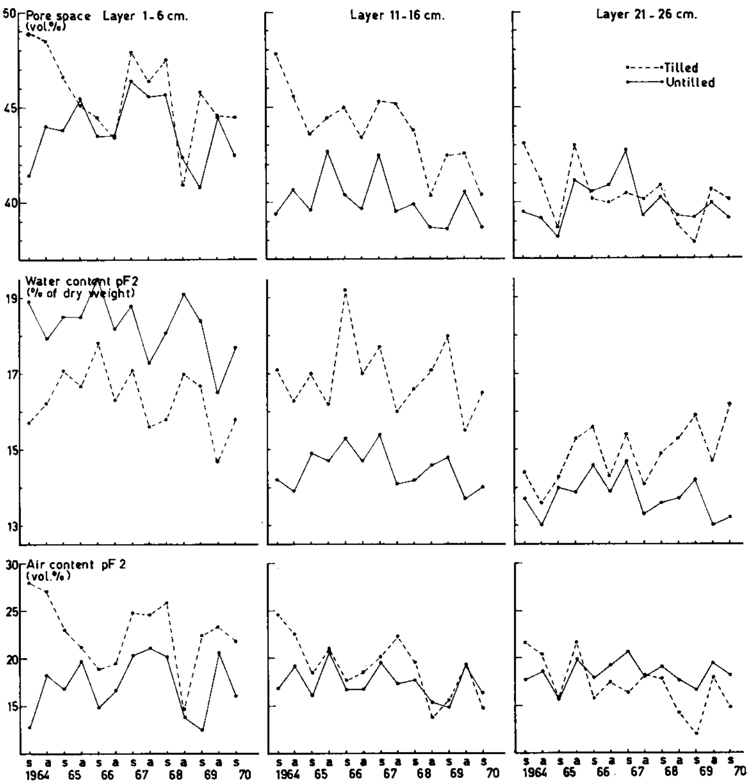

Fig. 3 Mean pore space, water and air content at pF2 in different layers in the course of time on tilled and untilled plots on a sandy soil (Achterberg).
•- - - - -• *tilled;* •———• *untilled.*

It may be concluded that, when starting from pasture, the changes in soil structure are insufficiently described by stating that the soil is loosened or compacted. It is more realistic to say that here two different soil types are created each with their own advantages and drawbacks.

When is started from old arable land the situation is less complicated. The pF curves for heavy marine silt (Westmaas and Marknesse) show a strong decrease in moisture content in % (v/v) at suctions over 0.1 bar (pF2), but on untilled plots this moisture content stays on a clearly higher level than on the ploughed plots. As pore space is usually lower, this means that air contents are considerably lower than on ploughed plots. At suctions below 0.1 bar the pF curve of untilled plots touches the saturation line already at relative low moisture contents, which means that under wet conditions nearly the whole pore space is filled with water and practically no air is left in the soil. It may be concluded that zero-tillage not only reduces total pore space but also radically changes pore space distribution: the larger pores disappear and therefore finer pores predominate.

On first sight moisture conditions on the zero-tillage plot might be advantageous in dry periods, because a larger part of the pore space is water-filled. However the amount of available water (i.e. the difference in moisture content in % (w/w) at pF4.2 and pF2) is the same. This is in accordance with the fact that above pF2 the water-holding capacity in % of dry weight is not influenced by tillage treatments, and so structural differences have no effect. This is not always true, because at pF2 there may be a difference as is discussed later. It is quite probable, however, that capillary transport of water is better on the untilled plots.

Changes in the relation between pore space and moisture content at pF2. A still more informative characteristic for soil structure quality than pore space can be found in the relationship between moisture content at pF2 (in % of dry weight) and total pore space of the various samples. This will be demonstrated on a few graphs referring to experimental fields on a stable medium textured soil and a very heavy clay. When pore space is large this relationship is a horizontal line, the level of which depends on soil type but also on other factors that are not yet sufficiently recognized.

Below a certain pore space the horizontal line turns off downward and runs parallel with the saturation line S (indicating water content at saturation). In this range of pore spaces air content at pF2 is lowered and the distance between the curve and the saturation line is a measure for the volume of entrapped air. The pore space where the curve is beginning to turn off may be regarded as a criterium for the distinction between compacted and non-compacted soil (Kuipers, 1961).

It is clear that in the example of Fig. 4, referring to a stable medium-textured soil (Westmaas), the dots related to the untilled plot are situated on the left-hand side of the graph, while dots related to the ploughed plot are distributed along the curve from small to large pore spaces. This means that on the zero-tillage plot there are much more spots with low air content at pF2 than on the ploughed plot.

The statistical nature of this matter is clearly shown in this type of graphs. This stresses once again the importance of the heterogeneity aspect of soil structure. The question arises what part of the soil should have a good aeration.

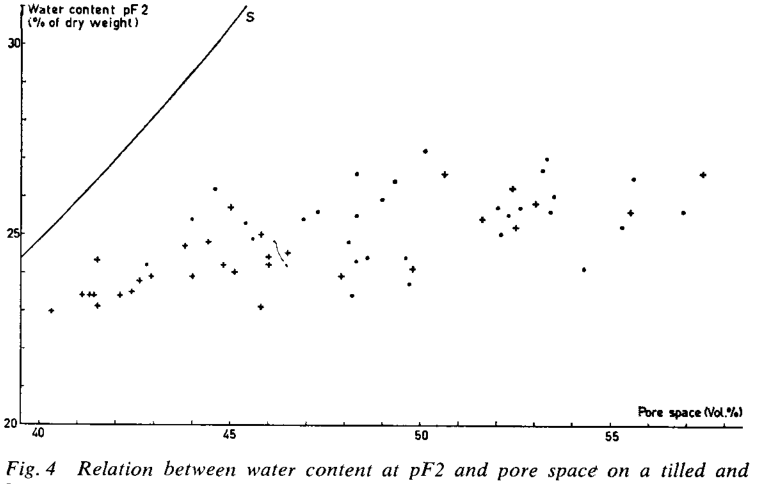

Fig. 4 Relation between water content at pF2 and pore space on a tilled and an untilled plot on a heavy marine silt (Westmaas). Spring barley after potato.
Statistical character of difference between treatments; 15 September 1969. • ploughing; + zero-tillage.

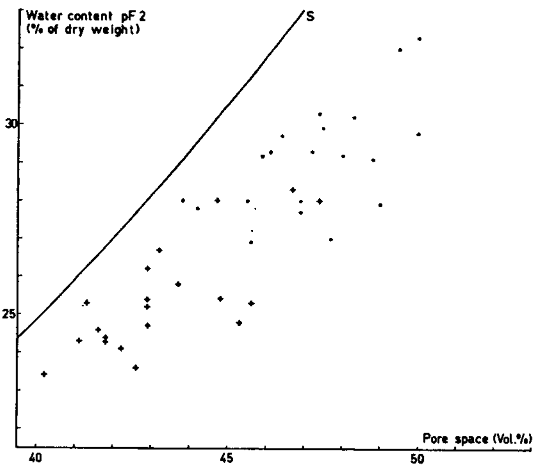

Fig. 5 Relation between water content at pF2 and pore space on a tilled and an untilled plot on a heavy marine silt (Westmaas). Spring barley after potato.
Higher moisture content on tilled plot after potato harvest and ploughing.
• ploughing; + zero-tillage.

Changes in pore space and a decrease in water content at pF2 are not the only phenomena that can be observed in the graphs under discussion. Also an increase in moisture content at pF2 may be observed. Sometimes the reason is more or less clear as in the case where loose and very fine and therefore very wet soil of potato ridges after harvest is transported to deeper layers by ploughing (Fig. 5). Also puddling, occurring at ploughing under wet conditions or at sugar-beet harvest may have given rise to an increase in moisture content (Koenigs, 1962; Kuipers, 1966). However also on untilled plots an increase in moisture content at pF2 was observed as is demonstrated in Fig. 6, referring to a heavy river clay soil (Randwijk).
In this case on many spots air content would not have been very low when water

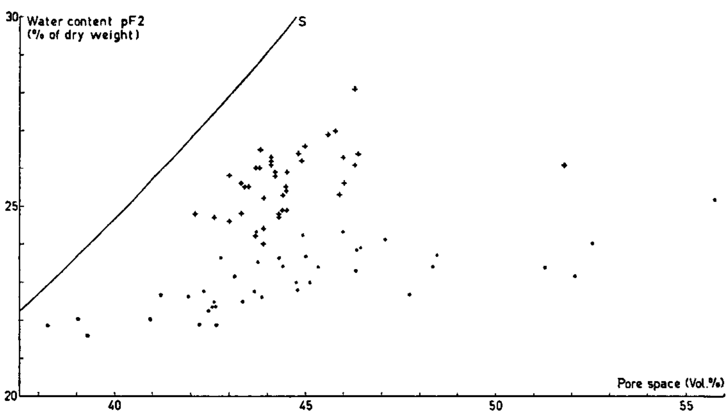

Fig. 6 Relation between water content at pF2 and pore space on a tilled and an untilled plot on a heavy river clay (Randwijk), showing decrease in pore space and increase in water content at pF2 after one year zero-tillage.
• spring 1964; + spring 1965.

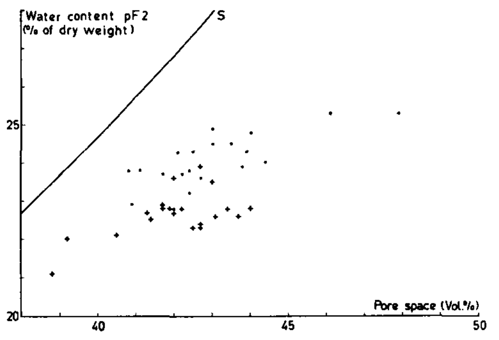

Fig. 7 Relation between water content at pF2 and pore space on an untilled plot on a heavy river clay (Randwijk), showing decrease in water content at pF2 during winter.
• autumn 1967; + spring 1968.

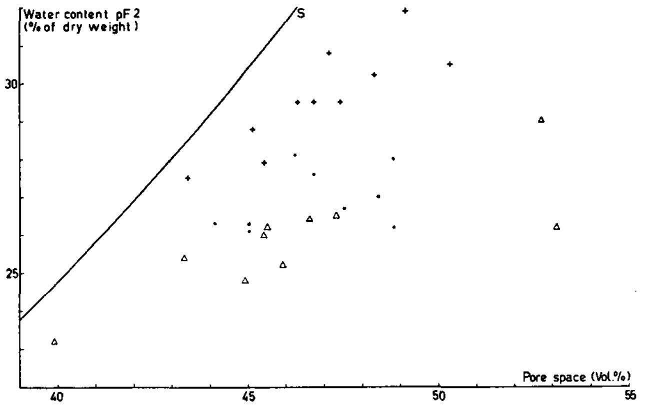

Fig. 8 Relation between water content at pF2 and pore space on a tilled plot on a heavy river clay (Randwijk). For explanation of marks, see Fig. 9.

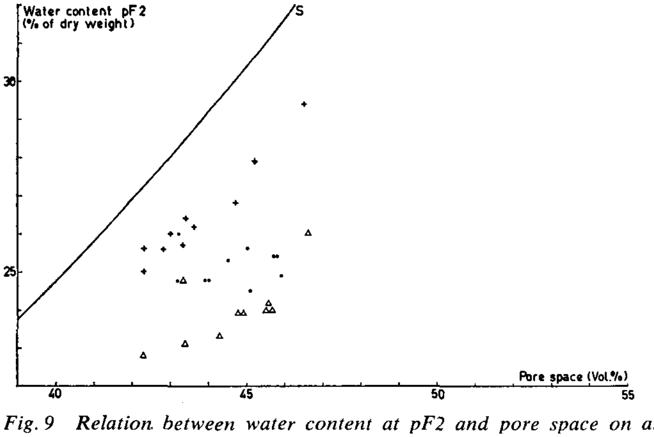

Fig. 9 Relation between water content at pF2 and pore space on an untilled plot on a heavy river clay (Randwijk). Changes in water content at pF2 are parallel to Fig. 8.
• autumn 1968; + spring 1969; △ autumn 1969.

content had not increased to such an extent. A reasonable explanation might be that also compacted untilled soil can swell considerably during long wet periods, but perhaps also flow of soil particles beneath (tractor) wheels under wet conditions may contribute to this process, because in these flow processes a smearing effect is involved (Kuipers, 1966). Regeneration of soil structure by frost as a result of dehydratation involved was clearly only of minor importance in this case. In other instances it could have been the main factor as is demonstrated in Fig. 7 for the same soil.

Also during the growing season dehydratation takes place, so it is often found that moisture content at pF2 decreases during summer (Fig. 8 and 9) and increases again during winter. A comparison of Fig. 8 and 9 shows that processes run parallel for both the tilled and untilled soil, but only in another form. That regeneration takes place in summer is in accordance with the fact that soil structure on medium and heavy clays profits from prolonged droughts.

As a rule it can be stated, therefore, that water content at pF2 depends on weather conditions during a longer period before sampling. In consequence also air content at pF2 is not a constant value. Much more research has to be done about the processes involved and the consequences of the heterogeneity of soil structure.

Cross-section and aggregate size distribution of potato ridges. In a normal Dutch crop sequence it is impossible to leave the soil always untilled because at the present state of mechanization potatoes still have to be grown on ridges. On two fields on a heavy marine silt soil it was tried to make clod-free ridges of a sufficient size after several years of zero-tillage.

At Marknesse the seedbed was prepared with a two-bar powered harrow. A single pass with this implement on the 20-cm ploughed plot resulted in a sufficient amount of loose soil for planting. On the zero-tillage plot, however, three passes were necessary. Two weeks after planting both plots were treated with an inter-row rotavator and were ridged at the same time.

On the zero-tillage plot at Westmaas a combination of a full-width rotavator and an automatic planting machine was used. In 1969 this plot was rotavated to a depth of 4 cm in the row and 7 cm between rows. On the 25-cm ploughed plot, however, a two-bar powered harrow (working depth 10 cm) was used. Only the ploughed plot was ridged another two times.

In 1970 the untilled plot was rotavated to a depth of 8 cm and after planting there was an additional 4-cm treatment with the interrow rotavator. In this year the ploughed plot was again treated with a powered harrow, but slightly deeper (12 cm) and ridged 2 times after planting.

There was only little difference between the profiles of the ridges at Marknesse. On the ploughed plot the denser inner part of the ridge had a steeper slope, indicating that the rotavator worked deeper in the bottom of the furrow between the ridges than on the zero-tillage plot. The cross-sectional area was 620 and 595 cm^2 for ploughing and zero-tillage, respectively, which could give a layer of 8.3 and 8.0 cm depth if the loose soil were distributed evenly over the surface. The ridges on the zero-tillage plot were coarser and initially wetter (Table 6). It is interesting to note that in the middle of a drought period the coarser ridges were drier: moisture contents in % of dry weight in the 0–10 cm layer were 2.8 and 4.4 for zero-tillage and ploughing, respectively, and in the 10–20 cm layer 11.5 and 14.7%, respectively.

The ridges of the zero-tillage plot at Westmaas in 1969 were also somewhat smaller than those on the ploughed plot (Table 7). They were much coarser, but this was

Table 6 Aggregate distribution and moisture content of potato ridges at Marknesse, 3 June 1970

Aggregate fraction (mm)	*Aggregate distribution (% of dry weight)*			*Moisture content of aggregates (% of dry weight)*	
	zero-tillage	*ploughing*		*zero-tillage*	*ploughing*
> 60	—	—		—	—
60–40	1.8	0.5		5.0	5.3
40–20	6.3	4.2		11.8	6.4
20–10	13.3	6.9		9.6	7.4
10–5	23.6	18.9		13.2	9.4
5–2.5	11.2	12.2		12.8	10.4
< 2.5	43.8	57.3		11.4	10.5
MAD [1]	7.5	5.1	MC [2]	11.8	9.8

[1] Mean aggregate diameter (mm).
[2] Average moisture content (% of dry weight).

Table 7 Amount of clods and depth of the loose layer of potato ridges at Westmaas

	17 June 1969				*29 June 1970*			
	zero-tillage		*ploughing*		*zero-tillage*		*ploughing*	
	kg	*%*	*kg*	*%*	*kg*	*%*	*kg*	*%*
Clods > 40 mm	0.3	3.2	0.1	1.1	0.4	2.2	0.2	1.7
Clods 40–20 mm	2.2	23.2	0.7	7.4	1.3	8.1	0.8	6.9
Total clods	2.5	26.4	0.8	8.5	1.7	10.3	1.0	8.6
Mean aggregate diameter (mm)	—		—		10.0		8.5	
Average moisture content (%)	—		—		12.3		13.0	
Depth of loose layer (cm)	6.9		7.2		11.9		8.1	

probably chiefly due to the fact that rotavating took place late and in a drought period. In 1970 the ridges were much larger, especially on the zero-tillage plot, where the ridges were again somewhat coarser and drier at sampling.

From these results it may be concluded that at least at these medium-textured soils potato ridges of reasonable quality (Kouwenhoven, 1967) can still be obtained after several years of zero-tillage. However the degree of success depends to a large extent on the type of implement, the way in which it is used and on soil conditions.

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