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RESULTS OF A GROUND WATER LEVEL EXPERIMENTAL FIELD WITH ARABLE CROPS ON CLAY SOIL [1]

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SUMMARY

A description is given of the results of a ground water level experimental field on a heavy clay soil. On this soil profile with a sufficiently large moisture retaining capacity we need expect no shortage of moisture during the growing season. The aeration of the soil and the root development are reduced by a shallow water table, and owing to these factors plant nutrients, in particular nitrogen, are in shorter supply. As there is little need for nutrients during winter a high water level of about 40 cm during this period has no detrimental effect on crop yields.

The different influence of the depth of watertable on the yield of various kinds of crops is mainly determined by the different influence of nitrogen on crops and by the level of nitrogen dressing used. The depression in yield caused by a shallow watertable can be almost completely compensated by increasing the nitrogen dressing.

It may be possible to compensate this entirely by applying more liberal dressings of other nutrients.

When the watertable is shallow there is a decrease in the percentage of large pores and permeability. If the ground water level is kept at a depth of 40 cm throughout the year, the soil structure of the surface layer deteriorates and tillage becomes difficult.

INTRODUCTION

Under the climatic conditions prevailing in the Netherlands the growth of crops under ground water conditions is very important. In order to investigate the influence of depth of watertable on crop yields and soil structure an experimental field was laid down in 1942 by the late Dr. S. B. HOOGHOUDT of the former Agricultural Experiment Station and Institute for Soil Research (now the Institute for Soil Fertility) at Groningen. The experimental field is a part of the "Jacob Sypkensheerd" experimental farm at Nieuw-Beerta in the province of Groningen. It is situated in a polder of the Dollard area which was reclaimed in the middle of the seventeenth century and where the depth of the watertable is usually about 1.20 m below the surface.

The experimental field has a area of about 1 ha and is divided into 5 plots having various depths of water table. By means of a pumping-station, main and lateral tile lines and weirs, the various depths of water table are maintained within limits of some centimetres both in periods of rainfall and drought. From 1942 to 1949 the water tables were at a constant level of 40, 60, 90, 120 and 150 cm below the surface throughout the year. Since 1949, however, the winter water table has been kept at a higher level than the summer one in 4 of the 5 plots. The water table in the first 4 plots is kept at a level of 40 cm (since 1953 30 cm) below the surface from November 1 to March 1,

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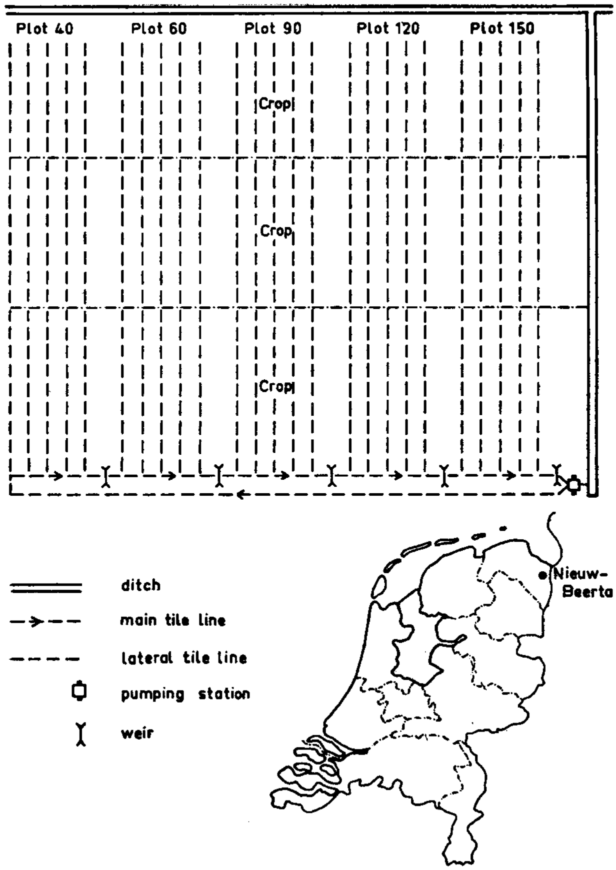

FIG. 1 LAY-OUT OF THE EXPERIMENTAL FIELD.

and at a level of 40, 60, 90 and 120 cm respectively from March 1 to November 1. On one plot the water table is kept at 150 cm below the surface throughout the year as before 1949. According to the depth of the summer water table the plots are referred to in this article as plot 40, plot 60 etc. (Fig. 1).

The soil profile of the experimental field is homogeneous and consists of a heavy clay to a depth of about 1 m below the surface. Below this the clay content gradually decreases, and at a depth of about 2 m the profile consists of a sandy soil. Some soil properties of the 0–100 cm layer are given in table 1.

Table 1

Layer	Fraction			Humus	$CaCO_3$	pH-KCL	P-citr.	K-HCL
	< 2 μ	2–16 μ	> 16 μ					
0–20 cm	46 %	20 %	30 %	3.1 %	1.0 %	7.1	50	0.026
20–40	48	20	27	2.8	2.5	7.1	55	25
40–60	48	18	27	2.5	4.5	7.2	25	24
60–80	50	20	22	2.5	5.0	7.2	30	26
80–100	45	18	28	2.9	5.5	7.3	30	26

Three crops are grown each year. Tillage and dressing are the same for all plots. No potassium dressing is given. A phosphate dressing of about 80 kg P_2O_5/ha is given once every 3 to 5 years. The annual nitrogen dressing is usually 0 kg N/ha for leguminous crops, 25 kg N/ha for cereals and 90 kg N/ha for the other crops.

Influence of the depth of water table on growth and yield of crops

No difference in germination and growing of the crops can be seen until late spring, depending on the sowing date and prevailing weather conditions. From then on there is a difference in colour and growth of the crops. If the water table is kept at a greater depth the colour becomes dark green, the crop grows heavier and ripens later, and the yield increases unless there is lodging, which in some years occurs on plot 120 and plot 150.

A depression in yield as a result of drought caused by a low water table has hitherto not been observed. The soil profile contains 20–25 % by vol. of water available to the plant between field capacity (pF 2.0) and wilting point (pF 4.2), which is sufficient for climatic conditions in Holland (about 300 mm rainfall and 450–500 mm evapotranspiration during the growing season from April until September).

The influence of the depth of water table on crop yields is about the same each year. A distinct difference between dry and wet years has not been observed. Table 2 shows the average influence for the years 1946–1955. The number of years during which the crop was grown is given in column 2.

Table 2 Relative yields at ground water levels from 40–150 cm below the surface on clay soil for the years 1946–1955. The maximum yield is taken as 100 %.

Crop	Number of years	Grain, roots, tubers					Yield of level 100 % in kg/ha	Straw					Yield of level 100 % in kg/ha
		40	60	90	120	150		40	60	90	120	150	
Cereals													
Wheat	6	58%	77%	89%	95%	100%	4600	59%	75%	84%	92%	100%	8600
Barley	5	58	80	89	95	100	4100	57	76	84	93	100	5150
Oats	3	49	74	85	99	100	5000	60	82	89	98	100	5850
Pulses													
Peas	4	50	90	100	100	100	2750	67	94	100	100	100	3550
Beans	3	79	84	90	94	100	3100	86	95	100	100	100	4500
Other crops													
Caraway	3	80	96	98	100	100	1700	93	98	97	100	100	5100
Rape seed	2	79	95	95	98	100	2500	70	84	92	97	100	6400
Sugar beet seed	1	75	82	90	96	100	4250	78	94	95	100	100	6500
Sugar beet ...	2	71	84	92	97	100	40500						
Potatoes	1	90	100	95	92	96	26000						

The yield of all crops increases at a greater depth of water table, but not to the same degree. The depth of water table has a marked effect on cereals (wheat, barley, oats) and the difference in colour during growth is also very distinct (from yellowish green on plot 40 to dark green on plot 150).

As regards the pulses, the influence on peas is only marked on plot 40, and there is no difference between plots 90, 120 and 150. The influence on beans is moderate from plot 40 to plot 150. There are two reasons for the difference between peas and beans. In the first place, soil structure, which is very poor on plot 40, has a great influence on peas as contrasted with beans. Secondly peas have a strong tendency to lodge, and this may occur on plots 120 and 150. In years when no lodging occurs the influence of the depth of water table is the same from plot 60 to plot 150 for peas and beans.

The influence of the depth of water table on the other crops is moderate. The irregular influence on potatoes was probably due to the selection, as the crop consisted of seed potatoes.

The results for the first years 1943 and 1944 have been omitted from table 2, the influence of the depth of water table being much less than in later years. The cause of this phenomenon will be dealt with later. The year 1945 was not representative owing to wartime conditions.

In the years succeeding 1949 no greater differences in growing and yield of crops have been observed to date between plots 40, 60, 90 and 120, where the winter water table is kept at 30 to 40 cm below the surface, and plot 150, than were recorded during the years 1946–1949. Apparently a winter water table of 30 to 40 cm, followed by a water table of a greater depth during the growing season had no harmful effect on the crops.

Influence of the depth of water table at various levels of nitrogen dressing

The influence of the depth of water table on crops shows symptoms of the same kind as the influence of nitrogen on crops. In order to investigate how far the influence of the ground water level can be lessened by increasing the nitrogen dressing, different quantities of nitrogen were applied to plots 40 and 150 since 1947, and to plot 90 since 1952.

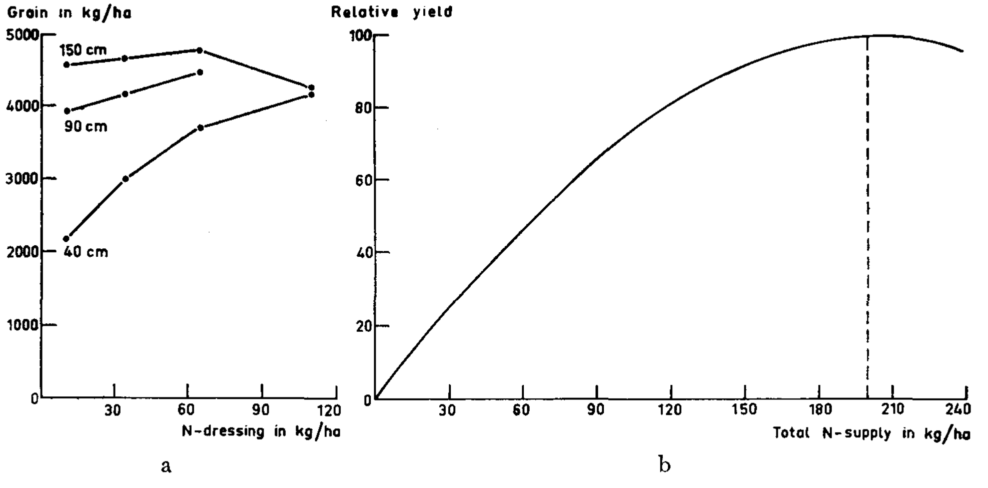

Fig. 2a Influence of nitrogen dressing on yield of cereals at various depths of water table.

Fig. 2b Influence on yield of cereals of total amount of nitrogen supplied by soil and fertilizer.

As an average for the years 1947–1955, the influence of nitrogen dressing on cereals at ground water levels of 40, 90 and 150 cm below the surface are given in Fig. 2a. The influence of nitrogen dressing decreases at a greater depth of water table.

Fig. 2b shows the influence of total nitrogen supply (the nitrogen supplied by the soil and the fertilizer) on the yield of cereals. This figure is based on experiments with nitrogen dressing conducted by MULDER (1).

In Fig. 2c the results of Fig. 2a are combined with the curve of Fig. 2b. The curve of Fig. 2b is assumed to be the same at various ground water levels, so that the yields can be extrapolated in the three cases according to the same curve. Apparently the decreasing influence of nitrogen dressing at a greater depth of water table is to be attributed to the greater amount of nitrogen supplied by the soil. The average amount of nitrogen supplied by the soil during 1947–1955 is 100 kg/ha more at a ground water level of 150 cm than at one of 40 cm. The average increase of the nitrogen supplied by the soil was about the same for caraway, rape seed, sugar beet seed, sugar beet and potatoes.

Otherwise the depression in yield caused by a high ground water level can be almost compensated by increasing the nitrogen dressing.

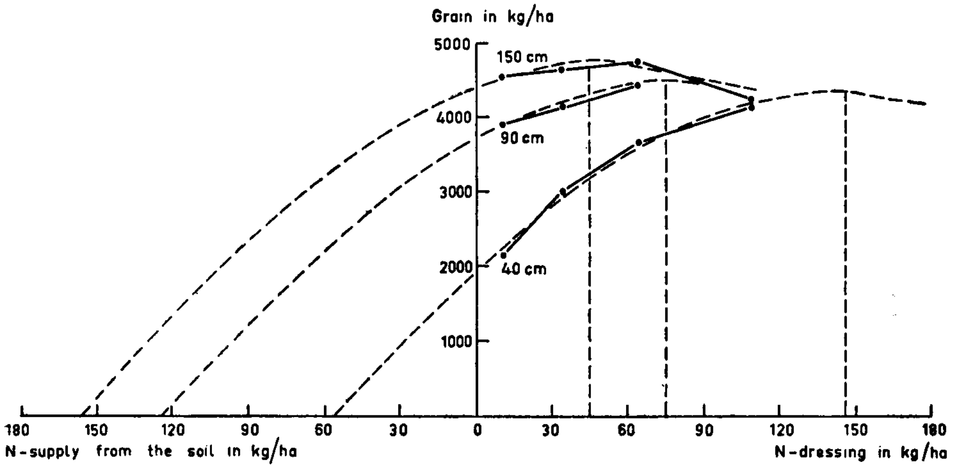

FIG. 2c INFLUENCE OF DEPTH OF WATER TABLE ON NITROGEN SUPPLIED BY THE SOIL, RESULTING FROM FIG. 2a AND 2b.

The crop analysis shows that the nitrogen percentage in the crop generally decreases at a shallower depth of water table. To a lesser degree the same is true of the phosphatic and potassic contents of the crops. According to Fig. 2c, which shows a maximum yield of 4350 kg/ha at a ground water level of 40 cm and a maximum yield of 4750 kg/ha at a ground water level of 150 cm, it is not possible to compensate entirely the influence of a high ground water level by increasing the nitrogen dressing. At a smaller depth of water table there is not only a shortage of nitrogen, but also of potassium, phosphate and possibly other plant nutrients.

If the influence of the depth of water table is mainly attributed to the nitrogen supplied by the soil, it is possible to explain the difference between

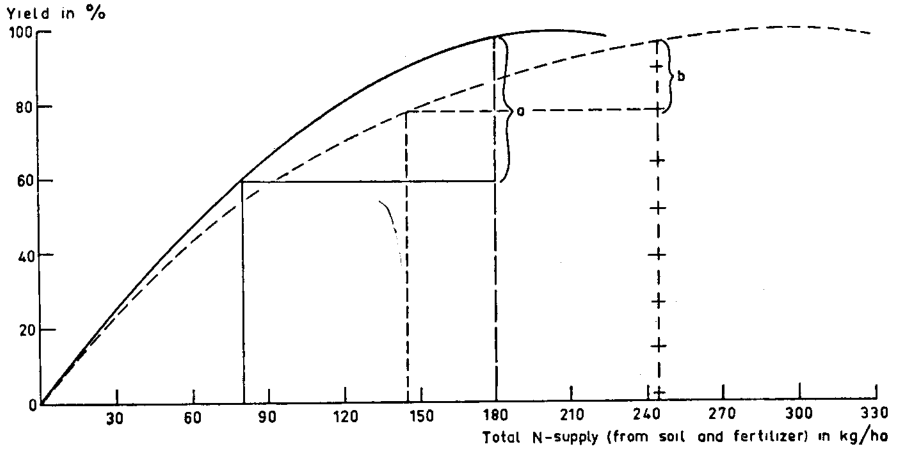

FIG. 3 THE INFLUENCE OF DEPTH OF WATER TABLE ON CROP YIELDS IS DETERMINED BY THE INFLUENCE OF NITROGEN ON CROP YIELDS AND THE LEVEL OF NITROGEN DRESSING.
a = difference in yields of cereals grown at a ground water level of 40 (———) and 150 cm (——·——) with a dressing of 25 kg N/ha.
b = difference in yields of potatoes and sugar beet grown at a ground water level of 40 (-----) and 150 cm (+—+) with a dressing of 90 kg N/ha.

the various crops (see table 2). Fig. 3 shows the influence of total nitrogen supply on cereals, potatoes and sugar beet. Whereas according to the investigation carried out by MULDER (1) the influence of nitrogen supply on potatoes is nearly the same as the influence on sugar beet, according to the investigation carried out by KUIPERS (2), the same curve is taken for both crops. We will now consider the difference in yield for the crops on plot 40 and plot 150.

According to Fig. 2c the average amount of nitrogen supplied by the soil is 55 and 155 kg N/ha respectively at depths of water table of 40 and 150 cm. The average nitrogen dressing being 25 kg N/ha for cereals and 90 kg N/ha for potatoes and sugar beet, the total nitrogen supply is 80 and 180 kg N/ha for cereals and 145 and 245 kg N/ha for potatoes and sugar beet. The difference in yield between the two plots for cereals (a) is larger than the difference for potatoes and sugar beet (b). The different influence of the depth of water table on various crops is mainly determined by the different influence of nitrogen on crops, as well as by the level of nitrogen dressing.

The moderate influence of the ground water level on pulses given no nitrogen dressing may be explained as follows. The pulses are provided with nitrogen by the activity of Rhizobium radicicola and do not require the nitrogen supplied by the fertilizer and the soil in the same degree as the other crops. Although the bacterial activity will probably decrease at a shallower depth of water table, the nitrogen supply is such that the crops are only moderately affected by the ground water level, except in the case of peas at a high ground water level of 40 cm, this being due to the poor soil structure on this plot.

INFLUENCE OF THE DEPTH OF WATER TABLE ON THE UPTAKE OF NUTRIENTS

As mentioned above, the uptake of plant nutrients, in particular nitrogen, is reduced by a high ground water level during the growing season. It is apparently owing to the low demand for nutrients during the winter that no influence of the ground water level was observed during this period.

The small uptake of nutrients at a high ground water level is caused by the low degree of aeration. Below the water level no air is present. Above the water level the air percentage is generally lower at a shallower depth of water table, except in the case of the surface layer 0–10 cm (Fig. 4).

Before the experimental field had been laid down the ground water level was about 120 cm below the surface. In the first years 1943 and 1944 5–10 % by vol. of air was still present below the water level on plots 40, 60 and 90 where the water level had been raised (Fig. 4). In 1944 15 % of the total root quantity on plot 40 was below the water table in the layer 40–80 cm below the surface. The smaller influence of the ground water level in the first years, as compared with the 1946–1955 period, can be explained by the higher degree of aëration. The experimental field needed a certain period in which to adjust itself to new conditions.

As a result of the low degree of aeration the uptake of nutrients may decrease because the uptake by the root system decreases and the soil provides a smaller quantity of nutrients.

As regards the first possibility, according to GOEDEWAAGEN and SCHUURMAN (3) there is generally no root development below the ground water level, and the total root quantity accordingly decreases where there is a shallow water table. No clear difference in the root development above the ground water level was observed between the different plots. It is possible, however, that the uptake by the roots also decreases when the water table is shallower, as the aeration above the water level is generally lower (Fig. 4).

As regards the second possibility, when there is a low degree of aeration conditions are less suitable for such bacteriological processes as nitrification and nitrogen fixation and more suitable for denitrification, the result being that less nitrogen becomes available. Owing to a different degree of decomposition of organic matter at various ground water levels there might be a change in the humus content as compared with the situation before 1943. In connection with his investigation into the Dollard area MASCHHAUPT (4) observes that the humus content of the Dollard soils, which have a deep ground water level, is generally lower than the humus content of other sea and river clay soils in the Netherlands which have the same clay content and are used as arable land over a long period. However, no difference in humus content between the various plots could be detected in 1955 either in the 0–20 cm surface layer or the deeper layer at 20–100 cm. A 0.1 % change in the humus content in the 0–100 cm layer represents a difference of 750 kg N/ha. While it is very difficult to measure a difference of 0.1 %, the period from 1942 to 1955 was possibly too short for the observation of a change in the humus content.

INFLUENCE OF THE DEPTH OF WATER TABLE ON SOIL STRUCTURE

In the first years after the experimental field had been laid down no difference was observed in tillage and in soil structure of the surface layer. Since 1947, however, a distinct difference has emerged between plot 40 and the other plots. The 0–20 cm surface layer on this plot is wetter and tough in spring, autumn and winter, so tillage is more difficult. The mean size of soil aggregates during summer is much greater on plot 40 (about 2.9 cm) than on the other plots (about 1.9 cm). The surface layer on plot 40 has a greater number of large clods.

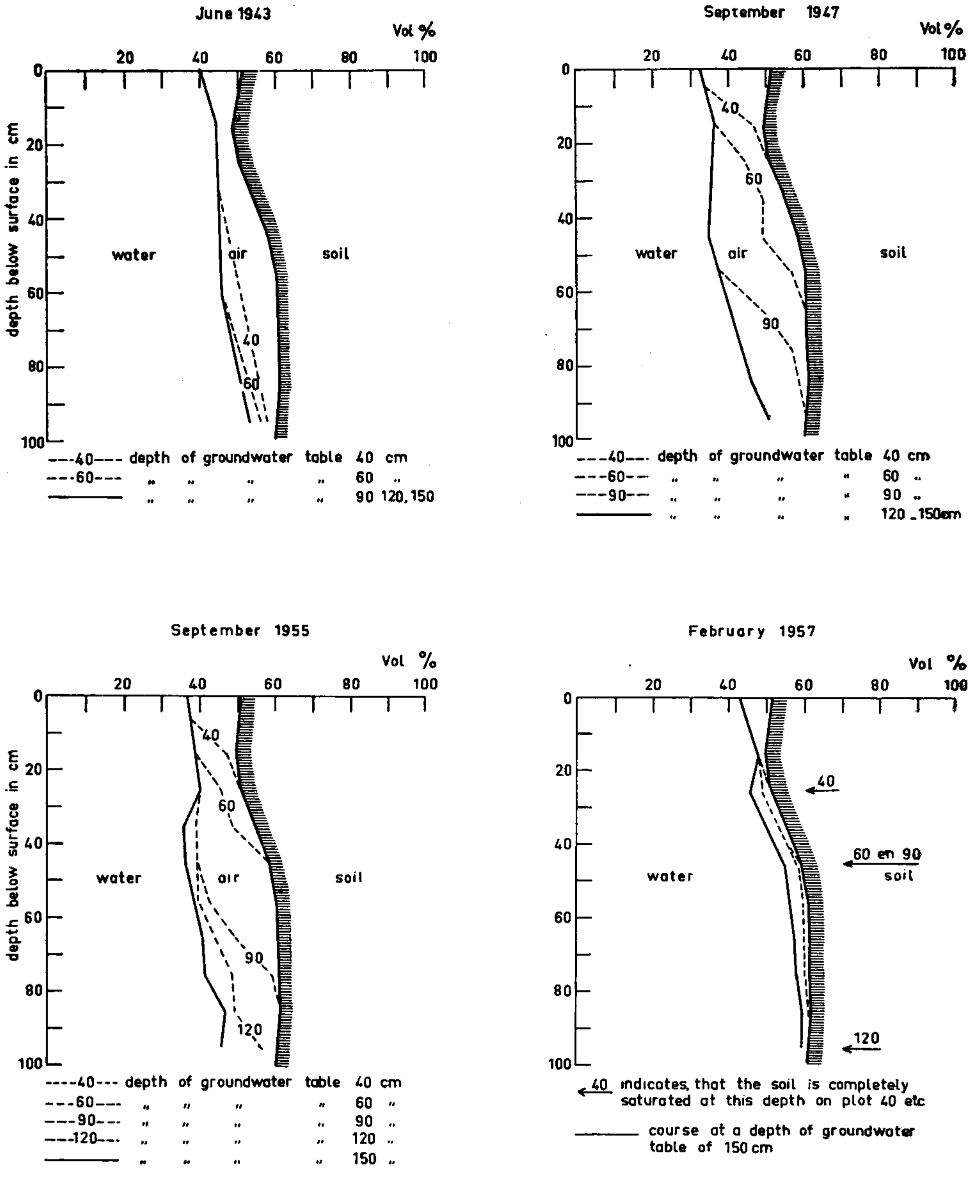

FIG. 4 COURSE OF THE WATER AND AIR CONTENT IN THE SOIL AT VARIOUS DEPTHS BELOW THE SURFACE. FIGURES NEAR CURVES REFER TO THE DEPTH OF WATER TABLE.

The deterioration of soil structure may be explained by the change of the soil-water-air ratio in the soil profile (Fig. 4). In June 1943 there was a fairly high percentage of air below the ground water level on plots 40, 60 and 90. The differences between the plots were small. In September 1947 there was no air below the water table and the percentage of air decreased directly above the ground water level. Between plots 120 and 150 there was no difference in the 0–100 cm layer. In September 1955 there was hardly any air in the layer 10 to 20 cm above the water table on plots 40, 60 and 90. There was some difference in air content between plots 120 and 150. In February 1957, when the depth of water table was kept at 30 cm below the surface on plots 40, 60, 90 and 120, air was present below the water table on plots 60 and 90 in the 30—40 cm layer and on plot 120 in the 30—100 cm layer (about 1 %).

There was also a change in the distribution of the pore size. According to Fig. 5 the percentage of large pores ($> 30\ \mu$) decreased and the percentage of very small pores ($< 0.2\ \mu$) increased directly above the ground water level. During winter the percentage of large pores decreases on plot 60 in the 20—30 cm layer, on plot 90 in the 20—70 cm layer and on plot 120 in the 20—100 cm layer. To a lesser extent the same is true of plot 150.

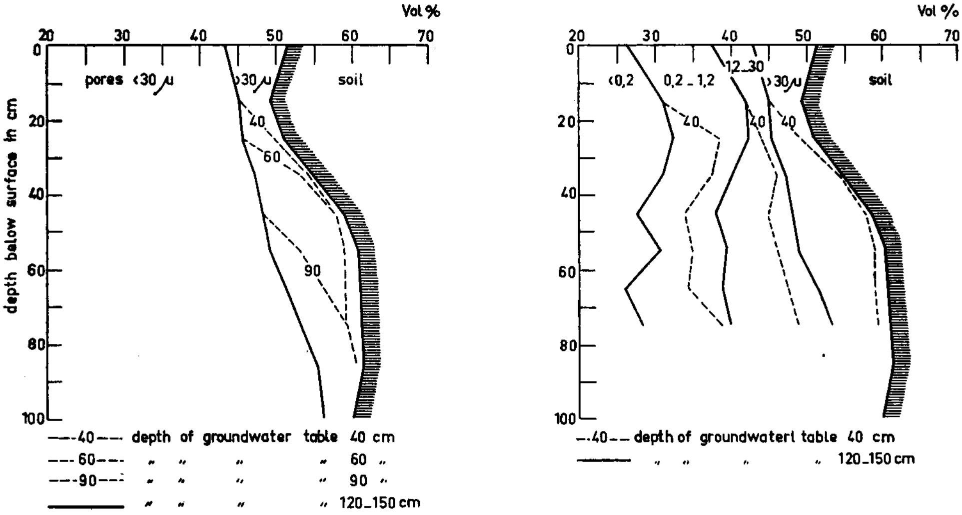

FIG. 5 COURSE OF THE PORE DISTRIBUTION IN THE SOIL AT VARIOUS DEPTHS BELOW THE SURFACE. SEPTEMBER 1955. FIGURES NEAR CURVES REFER TO THE DEPTH OF WATER TABLE.

The large pores retain moisture with a suction smaller than that corresponding to pF 2.0 and generally contain air above the water table. The very small pores retain moisture with a suction greater than that corresponding to the wilting point pF 4.2. Comparing plots 40 and 120 or 150, the percentage of water available to the plant between pF 2.0 and 4.2 remained almost the same, but the percentage of large pores decreased in the case of a shallow water table.

Table 3 Permeability in metres per day in the 50—90 cm layer during winter.

Plot	40	60	90	120	150	Adjacent field
Permeability	0.35	1.0	2.5	2.5	20	3.0

As a result of the change in the percentage of large pores the permeability was also changed, as is shown in table 3. The permeability on plot 90 and plot 120 during winter appears to be the same as on an adjacent field which is comparable with these plots, as there is also a shallow water table during rainy periods in winter. On plot 60, and especially plot 40, the permeability decreased as contrasted with plot 150 where the permeability increased.

Acknowledgements

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References

1 Mulder, E. G.: De invloed van stikstof op granen en aardappelen. *Internal report 1946. Agr. Exp. Station and Institute for Soil Research*, T.N.O., Groningen.

2 Kuipers, H.: Een streekonderzoek gericht op de factoren bodemstructuur en stikstofbemesting. *Verslagen van landbouwkundige onderzoekingen* No. 61.9 (1955).

3 Goedewaagen, M. A. J. and J. J. Schuurman: Root development of grassland with special reference to water conditions of the soil. Transactions 7th International Grassland Congress.

4 Maschhaupt, J. G.: Bodemkundige onderzoekingen in het Dollardgebied. *Verslagen van landbouwkundige onderzoekingen,* 54.4 (1948).