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Morphological Studies of Some Cultivated Soils

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PROEFSCHRIFT

ter verkrijging van de graad van doctor in de landbouwkunde
op gezag van de Rector Magnificus, Ir. F. Hellinga,
hoogleraar in de cultuurtechniek,
te verdedigen tegen de bedenkingen van een commissie uit de Senaat
van de Landbouwhogeschool te Wageningen
op vrijdag 21 januari 1966 te 16 uur

1966 Centrum voor landbouwpublikaties en landbouwdocumentatie Wageningen

STELLINGEN

I Bij verbetering van natte zandgronden ten behoeve van de teelt van diepwortelende tuinbouwgewassen, moet naast verlaging van de grondwaterstand aandacht besteed worden aan het losmaken van de ondergrond.

II Ten behoeve van de internationale uitwisseling van bodemkundige gegevens is het belangrijk om het nieuwe systeem van bodemclassificatie van de U.S. SOIL SURVEY STAFF toe te passen. Toetsing, aanvulling en wijziging van dit systeem zijn belangrijker dan het ontwikkelen van nieuwe systemen.

Soil Classification. A comprehensive system. 7th Approximation U.S.D.A. (1960)

III Bij het publiceren van veel analytische gegevens van een bepaalde grond is het gewenst om een zo volledig mogelijke beschrijving van het betreffende pedon volgens de Soil Survey Manual (SOIL SURVEY STAFF, 1951,1962) toe te voegen.

IV Ten behoeve van het bodemgeschiktheidsonderzoek voor de landbouw verdient het gebruik van bodemmorfologische grootheden, zoals het verloop van de bioporiën in de bodem, voorkeur boven het gebruik van bodemfysische grootheden.

V De waarde van de korrelgrootteverdeling van de grond voor de praktijk van de landbouw is vaak overschat.

VI De bodemmineralogie dient in de toekomst een grotere bijdrage te gaan leveren aan het bodemvormingsonderzoek.

VII Bij het opstellen van het bemestingsadvies voor een grond dient meer aandacht besteed te worden aan de structuurtoestand van die grond.

VIII Optimale informatie over de eigenschappen van een grond kan slechts worden verkregen, indien men gebruik maakt van de combinatie van twee groepen monsters. De ene groep dient genomen te worden volgens een bemonsteringspatroon, dat bepaald wordt door in het oog springende eigenschappen van het bodemprofiel. De andere groep monsters dient genomen te worden volgens een systematisch, van het bodemprofiel onafhankelijk, bemonsteringsnet.

IX De praktijkwaarneming, dat bepaalde gronden in de loop van de jaren zwaarder worden, is verklaarbaar uit een toenemende compactie van de bouwvoor in die gronden.

Dit proefschrift

X Het is in het belang van de landbouwwetenschap en van de auteurs, dat publikaties over de Nederlandse landbouw, die van meer dan landelijke betekenis zijn, in het Engels gepubliceerd worden.

Proefschrift S. Slager
Wageningen, 21 januari 1966

Voorwoord

Bij de voltooiing van deze studie wil ik graag allen danken, die mij daarbij geholpen hebben.

Deze studie is aangevangen onder leiding van wijlen Prof. Dr. C. H. Edelman. De leiding, die ik van hem mocht ontvangen, gedenk ik met grote dankbaarheid. Zijn enthousiasme en belangstelling zijn een grote stimulans voor mij geweest.

Graag wil ik mevrouw Dr. A. W. Edelman-Vlam danken voor de gastvrijheid, die ik heb genoten gedurende de vele besprekingen met Professor Edelman.

Veel dank ben ik voorts verschuldigd aan Prof. Dr. P. Buringh, die na het overlijden van Prof. Edelman de leiding van dit onderzoek op zich heeft willen nemen. Dat dit proefschrift geworden is tot wat het nu is, is voor een niet onbelangrijk deel aan hem te danken.

De steun en belangstelling van de medewerkers op Duivendaal 10 hebben veel voor mij betekend.

Volgens Prof. Dr. S. T. Bok zijn enthousiasme en fantasie de opbouwende krachten in de wetenschap en zuivert de latere kritiek de wetenschappelijke fantasieën van hetgeen met de werkelijkheid in strijd is. Dr. J. Ch. L. Favejee en Dr. L. van der Plas hebben gedurende enkele jaren deze kritiek op mijn werk willen geven. Ik ben daar erg dankbaar voor. Dr. Favejee heeft voorts talloze analyses op zijn laboratorium voor mij laten uitvoeren. Hem en de heer A. T. J. Jonker wil ik daar graag voor danken.

De heren G. Buurman en Z. van Druuten droegen zorg voor de vervaardiging van de tekeningen en foto's. Hun toewijding en zorg heb ik erg gewaardeerd.

Mijn assistenten, de heren Th. Pape en G. H. Broekhuizen, dank ik enerzijds voor hun toewijding en enthousiasme bij ons werk, anderzijds voor hun begrip en belangstelling gedurende de periode, waarin ik dit proefschrift schreef.

Voorts wil ik de prettige samenwerking memoreren, die ik mocht hebben met Dr. L. J. J. van der Kloes, Rijkstuinbouwconsulent voor Bodemaangelegenheden. Door hem en zijn medewerkers ben ik geattendeerd op vele praktijkproblemen en werd ik in verschillende Rijkstuinbouwconsulentschappen geïntroduceerd. Hetgeen ik geleerd heb van de assistenten van de Rijkstuinbouwvoorlichtingsdienst reken ik tot een niet onbelangrijk deel van mijn opleiding.

Veel dank ben ik voorts verschuldigd aan de heer A. Jager, Stichting voor Bodemkartering, die mij de beginselen van de profielbeschrijving bijbracht. Ik beschouw het als een voorrecht met hem gewerkt te hebben.

Het PUDOC ben ik zeer erkentelijk voor het opmaken en uitgeven van deze

studie. In het bijzonder dank ik de heer M. J. M. Osse, die deze publikatie voor druk gereed maakte en de heer J. E. Wilson, die zorg droeg voor de correctie van de Engelse tekst.

Velen die zeker mijn dank verdienen, moeten hier ongenoemd blijven. Een uitzondering wil ik maken voor een aantal ingenieursstudenten van de richting Bodemkunde aan de Landbouwhogeschool, die gedurende enkele jaren meegewerkt hebben aan onderwerpen, die in dit proefschrift behandeld zijn. Door hun kritiek en door hun denkbeelden hebben zij een belangrijke bijdrage gegeven aan deze studie. Hun enthousiasme heeft mij vaak gestimuleerd. Ik hoop, dat zij in de toekomst zullen blijven meewerken aan de uitbouw van dit deel van de bodemkunde, waarin nog zoveel onderzoek gedaan moet worden en waarvoor onze leermeester Prof. Edelman gedurende zijn laatste levensjaren zo'n intense belangstelling heeft gehad.

Contents

1 General introduction and summary

In the Netherlands, especially after the second World War, a growing need is felt for information about soil conditions in relation to the suitability for agriculture. The purpose of most soil surveys performed, was to collect such data. Although these investigations provided much information, they left certain questions unanswered and gave rise to new ones. These questions, however, can only be answered by using more detailed methods than has hitherto been the case.

New problems result from the increasing rationalization in different branches of agriculture in the Netherlands. The latter problems often result from an intensivation of the land use. They are related to soil suitability and soil improvement in particular.

The aim of this study was to investigate some of the above-mentioned problems in more detail by means of description of soil profile pits and determinations on undisturbed samples. The investigations were restricted to a study of some consequences of the mode of formation and the applied cultural practices for the agricultural suitability of some soils in the Netherlands. In general only those morphological and physical properties will be described in each soil which are considered to govern root development.

With regard to the method of investigation it should be noted that soils will be compared in groups of two or three. These soils originally had the same properties, but they changed by being used for different cultural practices.

In chapter 2 it will be explained that plants can only develop a deep and wide-branched root system, if the soil contains a permanent heterogeneous pore system. A pore system will be called permanent heterogeneous if it includes both small and large pores throughout the year.

The greater part of chapter 2 is filled with a description of the conditions under which the permanent heterogeneous pore system is formed and with a description of methods to characterize such a pore system.

The permanent heterogeneous pore-size distribution results from biological activity (formation of biopores), especially from the combined activity of soil animals and plant roots. This is why the main soil properties governing animal activity and some of the soil properties governing root development will be discussed. It was found that under Dutch climatic conditions soil animals and plant roots require similar living conditions. It will be stressed, however, that under certain conditions soil animals are able to make subsoils accessible to plant roots by removing mechanical plant root barriers. Soil animals, in turn, depend with regard to their nutrition on plants.

When determining the root potentialities of a soil it is important to know to which extent and to which depth a pore system is permanent heterogeneous.

Sometimes it is possible to measure directly the heterogenity of a pore-size distribution (e.g. sandy soils; cf. VAN DER PLAS and SLAGER, 1964; SLAGER, 1964; BOUMA and HOLE, 1965). The measurement is performed by means of a stereo-microscope on soil peels. Often the direct measurement on soil peels, however, is impossible (e.g. heavier textured soils) and a cumbersome technique, using polished and thin sections, should be used.

If a direct measurement of the heterogenity of the pore system is impossible the consequences can be used of the observation that biological activity not only governs the heterogenity of the pore-size distribution, but also the type of soil structure. This is why much attention will be paid to the morphological description of soil structure. In this study the morphological soil structure classification, designed by JONGERIUS (1957) will be used. Special attention is paid to the differentiation between biogenic structures on the one hand and physicogenic and geogenic structures on the other. The former group has a relatively heterogeneous pore-size distribution, the latter a more homogeneous one.

In a number of cases, the relationship between the heterogenity of the pore-size distribution and the presence of biogenic structures, can not be used. Then other consequences of biological activity for the soil properties were studied, e.g. homogenization, perforation and disturbance. Considerable attention will be paid to redefining and measuring biological homogenization (HOEKSEMA, 1953). The clay-trend will be used to define the degree and depth of homogenization. It will be shown, however, that measurement of biological homogenization is of less importance with regard to short term changes in biological activity in the soil. In the latter case perforation, and disturbance of stratified sedimentation structures are important factors. The term degree of perforation will be replaced by "biopore trend". The measurement of perforation and disturbance will be discussed. Both processes open up the subsoil for plant roots.

At the end of chapter 2 the soil structural trend will be discussed. This term, introduced to replace the term soil structural profile (VAN DER KLOES, 1961) is used to designate the vertical succession of structural types in the soil. The soil structural trend is of great value when an over-all picture is required with relation to the heterogenities of pore-size distributions of an entire soil. In analyzing the root potentialities of a soil, the soil structural trend is particularly important. Two types of soil structural trends will be described, which often occur in alluvial soils in the Netherlands. The vertical succession of biogenic and geogenic structural types in river levee soils will be contrasted with the vertical succession of physicogenic structures in river basin soils. The geogenesis of the soils in which the above-mentioned structures occur, will be discussed, together with the drainability and the root potentialities. Finally the possibilities of soil structure survey by means of soil structural trends are stressed.

It forms the synthesis between the study of soil structure and the physiographic soil survey.

In chapters 3, 4 and 5 the consequences will be discussed of some agricultural practices for certain properties of alluvial soils in the Netherlands.

In chapter 3 the influence is described of three cultural practices on two, fairly contrasting, tidal deposit soils. The cultural practices can be summarized as follows: (i) horticulture under glass with heavy dressings of organic manure, sprinkling, artificial drainage and soil desinfection, (ii) arable land with light dressings of organic manure and a crop rotation including many times cereals and beets, (iii) pasture. The investigated soils are: (i) a well-drained, calcareous silt loam, becoming lighter textured with increasing depth, (ii) an imperfectly drained, noncalcareous clay.

The investigations showed that the above-mentioned differences in soil management only result in differences in properties of the surface soils.

The use of the soil as arable land gives rise to the formation of compacted surface soils, consisting of physicogenic structural elements. The formation of this compaction can be attributed to the presence of (mechanical) soil structure degenerating forces, which are not compensated by (biological) soil structure regenerating forces. As examples of (mechanical) soil structure degenerating forces are mentioned: tillage of too moist soils and driving on too moist soils. The absence of (biological) soil structure regenerating forces is caused by the light dressings with organic manure and by injury of soil animals during soil tillage.

The use of the soil for cultivating cucumbers results in the formation of very porous surface soils, consisting of highly biogenic structures. In this case mechanical soil structure degenerating forces are almost absent and many soil animals are active.

The properties of the pasture soil will be shown to be intermediate between those under the two other cultural practices. This can be explained by a combination of a slighter soil structure degeneration than occurs in the arable land and a slighter biological activity than is present in the glass house soil.

Since in all probability all soils which will be discussed in this chapter were originally under pasture, it can be concluded from the observations that the arable soil deteriorated, while the glasshouse soil improved.

Finally it will be shown that both the origin and size of the above-mentioned differences are the same in the well-drained and imperfectly drained soils.

In chapter 4 some observations will be presented about the consequences of the application of grass mulching on the properties of some river loam and river clay soils. A well-drained, light textured soil under grass mulch is compared with the same soil under clean cultivation. It will be shown that the application of grass mulching results in a higher pore space and in a larger number of biopores in the surface soil. The cause of this difference seems to be the supply of albuminous food which stimulates the activity of the smaller earthworms living in the surface soil. Only a small number of biopores is observed in an imperfectly drained, heavily textured soil under grass mulching, where the grass is not often mown. This can be explained by the shallow groundwater level and by the bad nutrition of the earthworms. In a somewhat better drained, lighter textured soil under grass mulching a somewhat larger number of biopores is observed.

The above-mentioned observations lead to the conclusion that grass mulching will result in soil improvement only in cases where previous to the application of grass mulching the bad nutrition of the earthworms formed the main barrier to the development of a high biological activity. This implies that grass mulching on insufficiently drained soils does not result in soil improvement and that well-drained, but compacted, arable soils might be improved by grass mulching.

In chapter 5 the influence will be discussed which some cultural practices exert on the improvement of some river clay soils which were recently better drained. The cultural practices are pasture, arable land and grass orchard. It will be shown that improvement of soil drainage alone does not lead to soil improvement. For instance the number of biopores in arable land is found to be very small after improvement of soil drainage. The numbers of biopores under pasture and under grass orchard are considerably higher. Although the soil improvement is only possible after improvement of soil drainage, it is due to the activity of soil animals. The observations lead to the conclusion that in order to improve insufficiently drained soils, after improvement of soil drainage, special attention should be paid to a good supply of food to the soil animals.

From the observations mentioned in chapters 3, 4 and 5 some important conclusions can be drawn in relation to soil suitability and soil improvement. The morphological and physical methods used in the above-mentioned chapters are rather detailed and time-consuming. Therefore it was thought worthwhile to try to simplify these methods in order to be able to use them for practical purposes such as soil survey. The results of this simplification and the application on soil survey work are presented in chapter 6.

First a survey is given of the used morphological and physical methods and a separation is made between those which are directly applicable in the field and those which are not. To the former group belong macro-soil-structure and its trend in the soil, the abundance of the biopores and the depth of disturbance of the stratified sedimentation structures. Tentative schemes are presented for the classification of biopores according to size and abundance. Finally recommendations are presented for the observation and quantification of biopores in the field.

The results are presented of two detailed soil surveys in which the concept of biopores is applied. One of the surveys concerns 50 hectares of river loam and river clay soils situated in the centre of the Netherlands (Betuwe area). The other deals with 100 hectares sand and loam soils in the Northeast of the Netherlands (Province of Drente). In both surveys observations have been collected by means of soil auger and spade. Some deep profile pits were selected in each of the investigated areas for detailed morphological descriptions and for sampling for physical investigations.

Many shallow pits were dug up to a depth of 50 centimetres for additional morphological investigations. In the latter pits the deeper parts of the soil were studied by means of a soil auger.

Thanks to the introduction of the concept of biopores in these soil surveys suggestions can be given for the suitability of the investigated soils for deep rooting crops. In each of the two investigated areas one type of soil is well-suited for the cultivation of deep rooting crops. Among the river loam and river clay soils it is the river bank on river levee soil. This soil permits roots to penetrate to a depth of at least 1.50 m. after lowering the groundwater level, thanks to biopores occurring to that depth. Among the sandy soils the slightly loamy sandy old arable land soil with an Ap-horizon of more than 60 cm. thick is well suited for cultivating deep rooting crops. This soil enables roots to penetrate deeply, provided the soil is sprinkled.

The suitability studies mentioned in chapter 6 are mainly based on the abundance of biopores. Thanks to the application of the concept of biopores more information can be collected concerning soil suitability. It is therefore suggested that the measurement of abundance of biopores should be used in soil survey work in future.

A proposal for the definition of soil phases based on the abundance of biopores (perforation), the occurrence of biogenic structures (biostructuration) and the disturbance of stratified sedimentation structures is presented.

Finally an attempt is made to estimate the storage factor μ in sandy soils from the abundance of very fine biopores.

Some remarks on the soil classification of the investigated soils are presented in chapter 7. It will be shown that most of the cultivated alluvial soils which were investigated fit into the 7th Approximation of the scheme for soil classification developed in the United States (U.S.D.A., 1960, 1964). Most of the observed differences in soil properties result in differences in nomenclature. Differences in important properties which do not yet result in differences in nomenclature will do so at a lower level of classification.

It is stressed that a great advantage of the 7th Approximation is the fact that an unambiguous classification is possible if all required data are available. It will be stressed also, however, that many of the required data can only be obtained by laboratory analyses. A suggestion is made therefore to try to use the depth of disturbance of the stratified sedimentation structures and the abundance of biopores as factors for differentiation at lower levels of classification. The advantage of the use of these morphological characteristics is that they can readily be observed and quantified in the field and that they consequently allow an unambiguous classification in the field.

2 Soil structure, biological activity and some soil physical factors; their interrelation and influence on root development

2.1 Introduction

In the following chapters the influence will be discussed which some cultural practices exert on a number of soil properties, in particular on soil structure. The motive for the investigations was a number of opinions about the consequences of some cultural practices; these opinions have been generally accepted, but have not been investigated in detail.

One of these opinions for instance stated that grass mulching often results in soil improvement. It may now be asked: "What is included in such a soil improvement?" and "Why does grass mulching result in soil improvement in some cases and not in others?"

The method used in the investigations includes the comparison of the properties of two or more soils, which originally had the same properties, but have been subject to different cultural practices. In the case of the grass mulching, for instance, a soil under grass mulch (research treatment) was compared with the same soil under clean cultivation (blank treatment).

Since the criteria for selection, used for most soils, were similar, they will be discussed first. This discussion will be followed by one about the properties which were described in each soil.

2.1.1 The criteria for the selection of the investigated soils

In selecting soils we had always to answer the following question: "Were the properties of the research treatment originally similar to those of the blank?" The answer to this question is of great importance, since it is possible that the properties of a soil under a specific cultural practice are said to be due to that practice, but that these properties were already present before application of that practice. The following rule was adopted during the selection of the soils, viz., in determining the influence of a certain cultural practice on the soil properties by comparing two or more soils, these soils should be so selected that they differ in one property only, viz., the application of the specific cultural practice.

In practice, however, it was usually impossible to entirely fulfil this condition. Soils are natural objects which are never entirely the same. Usually, however, it was possible to find soils of which it could be presumed that originally they closely resembled each other.

During the investigations it became clear that in many cases the changes in soil properties, due to the application of a specific cultural practice, were correlated with changes in the activity of soil animals. Soils were therefore assumed to be identical if the living conditions in these soils for soil animals were identical. These living conditions (as far as soil physical properties are involved) were assumed to be identical when the soil drainage and the soil textural trend were similar in both soils.

The soil textural trend is assumed to be the vertical succession of layers with varying particle-size distribution. The textural trend can be determined by means of systematic sampling of the soil profile, followed by a number of particle-size analyses. Soil drainage is assumed to be the totality of groundwater levels during the year. Detailed data about the movement of the groundwater level during the year were not generally available, but estimates were available. Estimates were also available about the long-term changes (generally lowering of the groundwater level) of the soil drainage. Since it was possible to conclude from the above-mentioned information whether changes in soil drainage were similar for two soils, a detailed comparison of the soil drainage could be drawn by means of such morphological characteristics as mottling, concretions and possible reduction colors. By means of the method presented in the SOIL SURVEY MANUAL (1962), the descriptions of these items may be made in a fairly reproduceable manner.

If two soils had similar soil drainage, but a slightly different soil textural trend, they were still supposed to be equal if they had a similar soil structural trend, i.e. if the vertical succession of structural types was the same (cf. 2.6).

2.1.2 The properties described in each soil

Originally soils were only described in the field. These descriptions comprised the scheme of soil profile description of the SOIL SURVEY MANUAL (1962) and the scheme of description of macrostructure according to JONGERIUS (1957). Later the determination of the degree of perforation (by earthworms) was included (cf. HOEKSEMA and OP 'T HOF, 1960). Later still, laboratory determinations were introduced, viz., particle-size analyses, calcium carbonate and organic matter content determinations, pH, pore space, pF and water permeability determinations. Finally micromorphological methods were used in combination with the above-mentioned methods, viz., investigations on soil peels by means of a stereoscopic microscope (cf. VAN DER PLAS and SLAGER, 1964; SLAGER, 1964) and investigations of polished and thin sections.

Not all data were collected for each soil. In the case of soils which were investigated at an early stage, only a few determinations were used. The conclusions derived from these data were less detailed than from those collected later.

In interpreting the collected data, the following basic principle was used, viz., the applied specific cultural practice changed the physical properties of the soil, whether or not via changes in biological activity. These changes are reflected by changes in soil structure. The whole process may have changed the root potentialities of the soil under discussion. Since this train of thought will appear in one way or another in each of the following chapters, some important aspects of the interrelation of some soil physical factors, the activity of soil animals and soil structure will be discussed in the following sections.

2.2 The influence of some soil physical factors on root development

2.2.1 The permanent heterogeneous pore-size distribution

Many factors may inhibit plant development. Among the pedological factors are the soil physical ones. The development of a plant may be inhibited by soil physical factors via inhibition of root development in the following ways, viz., (i) lack of plant available moisture, (ii) lack of oxygen or excess of carbon dioxide, (iii) presence of mechanical root barriers. These three conditions will be discussed below in more detail.

(i) The amount of plant available moisture at a certain depth in the soil depends on supply, transport and storage of moisture. The supply is a function of climatic conditions, although it may be influenced by artificial supply. Moisture is usually supplied naturally by means of precipitation or capillary rise from the groundwater level. The latter possibility will not be discussed.

Channels are needed in the soil to transport the moisture which passed the air-soil boundary. These channels are fissures and holes. The holes are an important factor under Dutch climatic conditions, since swelling of the soil often closes the fissures during the period when they are most needed.

According to JONGERIUS (1957) only the precipitation which arrives in large quantities will be transported through channels wider than 100 micron (macro-pores). Under other conditions it will be transported through meso-pores, i.e. pores with a diameter between 30 and 100 micron. In the latter case moisture is transported relatively slowly and in such a way that the smaller pores, intended for the storage of the soil moisture, will gradually be filled. According to JONGERIUS (1957) the moisture is stored in pores with diameters smaller than 30 micron (micro-pores).

(ii) Lack of oxygen or excess of carbon dioxide may be caused by lack of transport facilities. JONGERIUS (1957) stated that the macropores in particular are important for the quick transport of the gases in the soil.

(iii) Recently some data became available on the relation between pore size and the mechanical resistance for roots. According to WIERSUM (1957) plant roots which penetrate into the deeper parts of the soil (primary and secondary roots) need pores with diameters exceeding 200 micron if the pores have rigid walls. Apart from these macro-pores the root system also needs smaller pores to reach the water and nutrient supplies stored in the soil.

It may be concluded from the above-mentioned data that the root development may be inhibited if not both small and large pores are present in the soil to a great depth. Moreover this condition of heterogenity of the pore-size distribution should be fulfilled during a great part of the year. HOEKSEMA (1953) summarized the above-mentioned conditions as a permanent heterogeneous pore system.

Soils which have a permanent heterogeneous pore system to great depth under Dutch conditions are known as good soils, i.e. as soils which produce for long periods high yields of good quality. The condition, however, of a deep permanent heterogeneous pore-size distribution is only fulfilled in a small number of soils. Excluded, for instance, are soils containing little more than fissures. The pore system may be heterogeneous in such a case, but it is not permanent. Soils or parts of soils which only contain pores resulting from the spatial arrangement of the primary particles (primary pores) are also excluded, since the resulting pore-size distribution usually is not heterogeneous enough. The only pore systems that fulfil the condition of being both permanent and heterogeneous are those that contain apart from primary pores and fissures also biopores. The latter pores are those which judging, for example, from their shape, are assumed to originate from the activity of roots and soil animals (SLAGER, 1964).

Preliminary investigations, which have not yet been completed showed that the diameter of these biopores may vary from some tens of microns to about one centimetre. In good soils biopores were observed in large numbers to a relatively great depth. In bad soils few if any biopores were noticed. To judge from their diameter, it is more probable that they are used as transport channels for moisture and gases and as growing channels for roots rather than for moisture storage.

2.2.2 Physical determinations

The changes in the soil which result from specific cultural practices concern the air and water household of the soil. The changes, however, in soil physical properties are accompanied by changes in soil morphological properties.

In soil physics, methods are used to characterize the air and water household of the soil. These methods, however, require a well-equiped laboratory, so that routine soil survey prefers an extension of the morphological methods that can be used in the field, or only require a small amount of laboratory equipment. The morphological determinations under discussion refer to the direct measurement of the heterogenity of the pore-size distribution or to the determination of morphological data which are correlated with that heterogenity (cf. sections 2.4 and 2.5).

Soil physical techniques are also mentioned in this publication. They were necessary for two reasons, viz., (i) the morphological characteristics are relatively new and they should be introduced together with physical characteristics for comparison, (ii) in a number of cases (e.g. pF determination) no morphological characteristic is present to replace the physical one.

In the case of most samples the soil-water-air-ratio was determined at one or more pF-values. In the case of some samples of sandy soils, water permeability determinations were performed. These determinations were performed to obtain information about the amount of plant available moisture, possible shortages of oxygen and the rate at which excess of water is removed through the soil. Some technical data about the methods which were used, were collected in Appendix I. Only a few remarks will be made hereafter about the interpretation of the data resulting from the soil physical methods employed.

As stated above, plant growth is not only inhibited by lack of plant available moisture, but also by lack of oxygen or excess of carbon dioxide. According to BUTIJN (1961) an air percentage of less than 10 (by volume) inhibits the growth of fruit-trees. Preliminary investigations revealed that roots of apple trees do not penetrate into layers which have less than 10% of gaseous phase at pF 2.0. This observation is in agreement with the above-mentioned statement by BUTIJN (1961). Such layers, however, are characterized by structural types which show few if any traces of biological activity. The phenomenon is a good example of the possibilities of correlating soil physical and soil morphological properties.

Pore space determinations were made for most of the samples of the soils studied. They were reported as PS%. In general these data refer to the percentage of the total soil mass which is filled with water or air at fieldcapacity. Only in some cases are they related to a somewhat lower or higher pF-value. At first we tried to correlate pore space (which is easily determined) with morphological data. If the pore space was relatively high (higher than 50 to 55%) or relatively low (lower than 35 to 40%), such a correlation was found. In the former case a maximum of biopores was present, in the latter case a minimum. If the pore space percentage was intermediate, as it generally is, no correlation was found. The reason became evident later. In the determination of pore space three groups of pores are included, viz., primary pores, fissures and biopores. The differences in morphological properties, however, mainly refer to the differences in the number of biopores or in general to the number of traces of biological activity.

Recently we started to determine in undisturbed samples the part of the pore space that is occupied by the biopores (bioporosity). An obvious correlation was found between the bioporosity and certain morphological properties of soil structure.

It is clear from the foregoing that a permanent heterogeneous pore-size distribution which occurs to a great depth in the soil, favours a good root development. So far as known to us such a pore system can only be created by an intense biological activity operating till a relatively great depth in the soil.

2.3 Some factors governing the biological activity in the soil

Biological activity is the term used to designate the activity of the soil flora and the soil fauna, i.e. the activity of roots, micro organisms and soil animals. Some factors determining root development have already been discussed (cf. section 2.2). The activity of micro organisms will not be discussed. In this section only those factors will be discussed which may restrict the activity of soil animals, in particular the activity of earthworms.

According to STÖCKLI (1958) it is incorrect to speak of "the" earthworm, in discussing the importance of earthworms in relation to soil properties. The statement reads as follows: "Die Regenwurmfauna eines Bodens ist nach Menge und Artenzusammensetzung eine Funktion der ökologischen Verhältnisse. Der Einfluss der einzelnen Regenwurmarten auf die Beschaffenheit des Bodens ist sowohl qualitativ als quantitativ von sehr verschiedener Art und Intensität. Es ist also nicht zuverlässig wie es bis vor kurzem gebräuchlich war kurzerhand von Einfluss des 'Regenwurms' auf dem Boden zu sprechen".

Several classifications of earthworms are known. A differentiation is made, for instance, between small species which mainly live in the surface soil, and the larger species which retire into the subsoil. A differentiation is also made between edaphon consumers (geophages) and the litter consumers (phytophages).

The great importance of the litter consumers (phytophages) is due to the phenomenon that they move through the surface soil, mixing organic material with the mineral particles and loosening the surface soil. The edaphon consumers (geophages) spread the nutrient elements through the soil and mix them thoroughly with the mineral particles. The geophages also perforate the soil to a great depth and disturb stratified sedimentation structures. These data were derived from the following publications: DARWIN (1881), FINCK (1952) and STÖCKLI (1958). According to these authors the activity of earthworms also results in an increase of the water holding capacity of the soil and in an increase of the aggregate stability.

The above data show that earthworms are of great importance for maintaining or improving the properties of a soil. Several factors, however, may restrict the earthworm activity.

STÖCKLI (1958), for instance, stated that poor nutrition results in a low activity of the earthworm fauna. The phytophagous earthworms require fresh, albuminous plant litter and the geophages need albuminous edaphon. FINCK (1952) and STÖCKLI (1958) showed that a good nutrition of the phytophages indirectly favours the nutrition of the geophages.

The activity of earthworms may also decrease if they consume certain compounds used for soil desinfection (cf. BLANCKWAARDT and VAN DER DRIFT, 1961) or compounds sprayed as plant protectants, e.g. copper oxychloride and Bordeaux mixture (cf. HIRST, LERICHE and BASCOMB, 1961).

Injury of earthworms, for instance, by means of implements used for soil tillage, also seems to inhibit their activity. According to STÖCKLI (1958) it is a myth that an earthworm can be cut into two parts both of which remain active. In arable land soils in particular this mechanical injury to earthworms seems to be one of the main causes of the low activity of these soil animals.

The activity of earthworms may also be restricted by cold and by drought. Under these conditions the small earthworms which live in the surface soil may be found coiled up in holes which they did not make themselves. The deeper burrowing species flee to deeper parts of the soil. The reaction of the latter species is interesting from a pedological point of view, since it is only possible in a small number of soils. On the one hand earthworms cannot live without oxygen, and on the other they seem to be unable to dig in media which contain much coarse sand. These restrictions imply that in case of cold or drought earthworms cannot retire more deeply into the soil than the groundwater level or the top of layers which contain much coarse sand.

It can be concluded from the above that earthworms may develop well in soils, (i) where they receive a good nutrition, (ii) where they do not receive poisonous compounds, (iii) where they are not injured by soil tillage implements, (iv) where they can retire to deeper parts of the soil in case of cold or drought.

Other soil animals may be active. The mole, for instance, which according to HOEKSEMA (1953) also plays a part in the process of biological homogenization (cf. section 2.5) mainly lives on earthworms according to this author. Thus the activity of the mole is indirectly restricted by the same factors which restrict the earthworm activity.

In many sandy soils where earthworms are not active, other soil animals are of importance, e.g. Collemboles, Julides and Glomerides. These animals seem to be more drought resistent than earthworms. They are less exacting as regards food. Lack of oxygen, however, restricts their activity, as it does with earthworms. Hence their activity is restricted by similar factors which restrict the activity of earthworms, but the living requirements of the animals in sandy soils are on a lower level.

In general the soil animals require no other conditions in a soil than plant roots do. In soils, under Dutch climatic conditions, where plants show a deep and wide spread root system, many traces of animal activity may be observed.

It should also be stressed that in many soils plant roots can only enter certain deeper layers if soil animals have made these layers accessible. For their nutrition the soil animals depend in turn on the plants. Hence there is an obvious relationship between the soil flora and the fauna.

2.4 The morphological description of soil structure

It may be concluded from the summary of section 2.2 that it is important to know the pore-size distribution on various depth levels in a soil to determine the agricultural suitability of that soil.

Theoretically the determination of these pore-size distributions could be performed by means of thin or polished sections. For practical purposes this method is too cumbersome. The permanent heterogeneous pore-size distribution which is of great importance for root development, only occurs in a small number of structural types, which can be described in a detailed and reproducible way. This is why we preferred the indirect way of soil structure characterization in the field to a time-consuming determination of the heterogenity of the pore-size distribution.

A disadvantage of the indirect method is that it is not always practicable. This restriction results from the phenomenon that not all soils have a distinct macro-structure (cf. JONGERIUS, 1957).

According to JONGERIUS (1957) soil structure is one of the most frequently used terms in soil science; this proves the importance of soil structure studies and also the difficulty of determining exactly what is meant by soil structure and how soil structure should be characterized objectively. JONGERIUS (1957) succeeded in preparing a scheme for the description of macro-structure which is an extension of some existing schemes (cf. CLARK, 1961). The new scheme is more detailed and enables the user to describe the macro-structures in the field objectively.

JONGERIUS (1957) defined soil structure as: "The spatial arrangement of the elementary constituents and any aggregates thereof, and of the cavities occurring in the soil." Where the term soil structure is used in this publication it is to be understood in this sense. In this section part of the classification of soil structure according to JONGERIUS (1957) will be discussed. Some practical data are presented in Appendix I.

JONGERIUS described type and porosity among other soil structure characteristics.

A differentiation was made by this author between structures with structural elements and structures without. The structural elements which result from soil forming processes were subdivided at two levels. The first subdivision resulted in a differentiation between holoedrical (spherical), prismlike and platelike structural elements as in the scheme of the SOIL SURVEY MANUAL (1962). The further subdivision was based on several criteria which all are morphological. Two types which belong to the group of the structures without structural elements are the hole structure (including the sponge) and the stratified sedimentation structure.

The description of porosity includes the estimate of the amount of pores per surface unit and the heterogenity of the pore-size distribution. Although the description is relatively subjective, a fairly good differentiation can be made between a heterogeneous pore system and a more homogeneous one.

In this study the scheme of JONGERIUS was used in combination with that of the SOIL SURVEY MANUAL (1962). Some details of the JONGERIUS-scheme were omitted. Apart from the phenomena to be discussed in section 2.5, only minor changes or additions were included.

In discussing the mode of formation of soil structural types, JONGERIUS (1957) distinguished two processes, viz., granulation and fragmentation. Granulation is the "formation of more or less rounded, porous elements as result of biological activity". Fragmentation is "the formation of certain types of structural elements as result of shrinkage of layers which are compact under wet conditions". The term granulation cannot be used in relation to the formation of porous structural types without structural elements. In 1961 JONGERIUS introduced the terms active, passive and geogenic structures. In this concept active structures result from biological activity, passive ones from such physical processes as swelling and shrinking. Types labelled as geogenic were those which still had the original properties resulting from such geological processes as sedimentation.

Although we are of the same opinion as JONGERIUS about the mode of formation of the discussed soil structural types, we propose a modification in the terminology. Since the active structures result from biological activity they may be labelled as biogenic structures (cf. DE HAAN, 1965). Since the passive structures result from physical processes they are better labelled as physicogenic structures (cf. DE HAAN, 1965). The term geogenic structures is retained.

According to JONGERIUS (1961) and EDELMAN *et al.* (1963) among others the following structural types belong to the group of the biogenic structures: granular subangular blocky, and sponge. These authors regarded angular blocky elements, prisms and plates as physicogenic structures. The stratified sedimentation structures are assumed to be geogenic structures. Not all structural types found, fit into this group classification. Intergrades may be found. They are important when soil structure changes as a result of a change in soil management. In general the biogenic structures are characterized by a heterogeneous pore-size distribution, whereas the pore systems of the physicogenic and geogenic structures are more homogeneous. If the soil structure is altered as consequence of changes in soil management, changes in heterogenity of the pore-size distribution are revealed earlier than changes in soil structural type. For this reason intergrades in soil structural type were grouped on basis of the heterogenity of the pore-size distribution.

To summarize it can be stated that a correlation was observed between the structural types and the heterogenity of the pore system. Biogenic structures were generally found to be characterized by a heterogeneous pore-size distribution. These structures can be recognized. They can be described reproducibly according to the JONGERIUS-scheme (1957, 1961).

HULSHOF *et al.* (1960) studied soil structure from the viewpoint of the root development. Their publication lead to the interesting but not unexpected conclusion that in general root development is the best in soils which have been most influenced by biological activity. The study of HULSHOF *et al.* (1960) had a preliminary character, i.e. they only studied the root development of apple trees on alluvial clay and loam soils. In the case of apple trees the biogenic structures again proved to be the best from the viewpoint of root development. Simultaneously the physicogenic and geogenic structures were shown to be inferior in quality. We consider the study of HULSHOF *et al.* (1960) to be very important because its results demonstrate the existence of a positive correlation between the heterogeneous pore-size distribution, intense biological activity, the presence of biogenic structures and favourable soil physical conditions, together resulting in a soil which is attractive from the point of view of root development.

2.5 Biological activity and biological homogenization

2.5.1 Introduction

HOEKSEMA (1953) defined homogenization as follows: "Natural homogenization is understood as the mixing of soil constituents under the influence of flora and fauna". EDELMAN *et al.* (1963) replaced the term 'natural homogenization' by 'biological homogenization'. The above-mentioned publication of HOEKSEMA (1953) was the first of a series of publications on the consequences of biological activity for the soil properties. As a result of these investigations it was possible to provide an objective description of a number of soil characteristics. These characteristics form a supplement to the scheme of JONGERIUS (1957) for description of soil macro-structure. This supplement was necessary for two reasons, viz.:

(i) It proved difficult to apply the JONGERIUS-scheme to sandy soils. Sandy soils usually have no macro-structure. A description according to the SOIL SURVEY MANUAL (1962) leads to such terms as very weak subangular blocky or structureless. The scheme for the description of the micro-structures of sandy soils (JONGERIUS, 1957) is only applicable in a small number of soils. A direct measurement of the biopore trend was therefore introduced (VAN DER PLAS and SLAGER, 1964; SLAGER, 1964). It is intended as the first step in measurement of the heterogenity of the pore-size distribution. This was undertaken fairly recently by BOUMA and HOLE (1965) for a small number of soils.

(ii) In clay and loam soils showing an increasing biological activity, for instance after improvement of soil drainage, the increase of the heterogenity of the pore-size distribution cannot be satisfactorily characterized by means of the scheme of description of the macro-structure.

Most publications dealing with the influence of earthworms on soil improvement and soil genesis which publications followed the publication of HOEKSEMA (1953) have the disadvantage of using the terms 'biological activity' and 'biological homogenization' to denote the same process. The concept of biological activity, however, is much wider than that of biological homogenization. Besides mixing of soil constituents, perforation of dense layers and disturbance of stratified structures are also assumed to result from biological activity.

The processes of perforation and disturbance have in fact been recognized. HOEKSEMA and OP 'T HOF (1960) introduced the so-called degree of perforation. It was defined as the number of earthworm holes (whether or not subdivided into a number of size classes) per surface unit on a horizontal cross-section through the soil at a certain depth. JONGERIUS and REYMERINK (1963) published a study on the changes of the degree of perforation with increasing depth.

JONGERIUS (1957) included in his classification system of the macro-structure a type to characterize the partly disturbed stratified sediments.

The use of the terms 'biological activity' and 'biological homogenization' for the same process has caused particular difficulties in sandy soils, where usually no true homogenization is, as has been reported by several authors (e.g. EDELMAN and OP 'T HOF, 1960). When the term 'homogenization' is used in publications on sandy soils (EDELMAN, 1960, 1963; DE CONINK and LARUELLE, 1964) the authors mean 'disturbance of the sedimentary structure'. EDELMAN (1960, 1963) first used the depth of the undisturbed subsoil in sandy soils to indicate the lower boundary of the zone where root development is possible and animal activity occurs. This characteristic appeared to be inapplicable where sandy soils showed to great depth no sedimentary stratification. Later in the same publication EDELMAN (1960, 1963) proposed measuring the heterogenity of the pore-size distribution to distinguish the zone influenced and the zone not influenced by biological activity. VAN DER PLAS and SLAGER (1964) and SLAGER (1964) began the direct measurement of the heterogenity of the pore-size distribution. It was found possible to count rapidly the numbers of pores with a diameter exceeding 200 micron per surface unit in soil peels of sandy soils by means of a stereoscopic microscope. BOUMA and HOLE (1965) who used the same method succeeded in measuring the pore-size distribution in other soils as well. The above-mentioned studies revealed that the pores larger than 200 micron which were counted, resulted from biological activity and they were therefore termed biopores. At the same time (cf. VAN DER PLAS and SLAGER, 1964) the concept of biopore trend was introduced. It is the graph representing the number of biopores per surface unit at each depth level in the soil.

The great interest shown in the consequences of the biological activity is partly due to its importance for soil improvement. An objective evaluation of the contribution of the soil flora and soil fauna to the soil improvement can be made, provided, the changes due to biological activity can be defined and measured. The concepts of homogenization, perforation and disturbance will be discussed below for that reason. At the same time some suggestions will be presented for the measurement of these characteristics.

2.5.2 Biological homogenization

In defining natural homogenization, HOEKSEMA (1953) noted that it is caused by soil particles falling into root or animal holes and by active displacement of soil constituents resulting from the activity of earthworms and moles. During the last decade homogenization was characterized by means of a number of vague, more or less correlated properties such as a thick A1-horizon. The degree of homogenization could never be determined objectively. EDELMAN *et al.*, (1963) correlated the homogenization with the clay trend of a soil. They were inlcined to call that part of a soil homogenized which showed no changes in clay content with increasing depth. It is not true, however, that the homogenized part of the soil is homogeneous. EDELMAN *et al.* (1963) presented data which showed that homogenization (with exception of the zone of the upper 30 centimetres) only results in a constancy of a number of particle-size fractions over the depth of the homogenized zone.

Although calcium carbonate is returned to the surface soil by certain soil animals (cf. HOEKSEMA, 1953) leaching is more intense, resulting in an increase of calcium carbonate over the homogenized zone with increasing depth, provided the soil is still not fully decalcified. Organic matter also shows changes with increasing depth (decrease), notwithstanding homogenization.

A study performed with permission of the senior author, on particle-size distribution data used for the publication EDELMAN *et al.* (1963), revealed that the coarser fractions (larger than 50 micron) also remain inconstant over the zone of the soil which the above-mentioned authors regarded as being homogenized. The above-mentioned considerations gave rise to the following concept of biological homogenization: 'biological homogenization is the mixing of soil constituents by means of soil flora and soil fauna, ultimately resulting in at least a constancy of the clay content (within narrow limits) over the part of the soil called homogenized'. Starting from this concept, both the degree and the depth of homogenization can be defined. The degree of homogenization is reflected by the differences in clay content over a certain depth in the soil. The smaller the differences, the more complete is the homogenization. In our opinion layers with differences of less than 3% should in most cases be regarded as completely homogenized. The 3%-limit corresponds to the maximum error, under normal conditions, of the particle-size analysis. With the use of more accurate methods (cf. SLAGER and KOENIGS, 1964) this 3%-limit possibly might be reduced to 1% or less.

The concept of complete homogenization can be used to compare soils which are deeply homogenized (deeper than 80 centimetres below the surface) with soils which are only homogenized to a slight depth (deeper than 30 centimetres and shallower than 50 centimetres). A preliminary study revealed that:

(i) in deeply homogenized soils all particle-size fractions and organic matter and calcium carbonate contents show more gradual changes with increasing depth than soils which are homogenized to slighter depths. A similar phenomenon was reported by EDELMAN *et al.* (1963).

(ii) in deeply homogenized soils the differences in calcium carbonate content at 80 and 25 centimetres below the surface, and at 80 and 50 centimetres are smaller than in soils which are homogenized to slighter depths. HOEKSEMA (1953) attributed this phenomenon whose existence he conjectured from observations of lime-rich earthworm droppings, to the return of calcium carbonate from the subsoil to the surface.

(iii) in deeply homogenized soils the organic matter content at 80 and 50 centimetres below the surface is higher than in shallower homogenized soils. EDELMAN *et al.* (1963) attributed this phenomenon to a deeper penetration of plant roots and animals into the soil.

(iv) the highest groundwater level in clay and loam soils which are deeply homogenized is deeper than soils of the same texture but homogenized to slighter depths.
(v) the depth to where the subangular blocky structures continue and the depth where the stratified sedimentation structure (if present at all) occurs is greater in deeply homogenized soils than in others.

Though it is possible to determine both the depth and degree of homogenization by the method discussed above, no further attention was paid to the study of homogenization, the reason being that characterization of the depth and degree of homogenization requires many time-consuming laboratory analyses. Homogenization, however, does not provide information if one is interested in the consequences of soil improvement or of specific cultural practices. In case of biological soil improvement considerable improvement might be made which is not reflected by the constancy of the clay content over the depth of the soil. Homogenization might be a fine characteristic for the final stages of the process, but it is no index of a process still in progress. The studies on biological homogenization provided, however, many valuable data on the conditions prevailing when the process of biological activity is at its maximum. These studies also provided data on the ultimate consequences of the process of biological activity.

The importance of the process which HOEKSEMA (1953) called homogenization, is reflected by the phenomenon that mineral constituents, organic matter, micro-organisms and other soil constituents are thoroughly mixed (DARWIN, 1881; FINCK, 1952; GUILD, 1955; STÖCKLI, 1958). One result of the mixing process is the formation of small aggregates which are very stable in water, very porous and which have a highly heterogeneous pore-size distribution and a high water holding capacity and in which roots can readily penetrate. It is a striking fact that the above-mentioned authors all stressed other features than the homogenity of the homogenized soil.

2.5.3 Perforation and disturbance

Perforation and disturbance better characterize the properties in soils which have undergone biological soil improvement than does homogenization.

In relatively light textured soils (sandy soils) and in alluvial soils with a sandy subsoil, the disturbance of the stratified sedimentary structures is important. In the stratified structures root penetration is generally impossible (cf. WIERSUM, 1957; EDELMAN, 1960, 1963; SLAGER, 1964). If the stratified structures are disturbed, for instance by biological activity, root development may follow. In practice it was found important to determine the depth of the upper boundary of the undisturbed stratification. In a number of cases it might be interesting to characterize in more detail the zone where the stratification was partly disturbed, for instance by means of the percentage of the surface area of the profile wall where stratification was still undisturbed (cf. EDELMAN, 1960, 1963).

In more heavily textured soils the degree of perforation is an important factor.

The best evidence is furnished by the roots themselves, many of which follow the earthworm holes in soils with physical deficiencies. The degree of perforation (cf. HOEKSEMA and OP 'T HOF, 1960) is determined in the field. Some investigators counted three size classes of earthworm holes (HOEKSEMA and OP 'T HOF, 1960; JONGERIUS and REYMERINK, 1963). A detailed study showed that it is usually not worthwhile counting earthworm holes having diameters of less than 2 mm. When many earthworm holes are present in this size class, the operators error amounts to such high values (up to 50%) that a reproducible measurement is impossible. The operators error for counting the holes in the 2–4 mm. size class is much smaller (10–15%), while that for counting the largest holes is fairly small (some 5%).

In order to bring more uniformity in the terminology we suggest replacing the term 'degree of perforation' by 'number of biopores per surface unit'. The graph representing the number of biopores at various depth levels in the soil may consequently be termed the 'biopore trend' (cf. VAN DER PLAS and SLAGER, 1964). Like JONGERIUS and REYMERINK (1963) we prefer a systematic measurement of the number of biopores per surface unit with many repetitions, as to enable a biopore trend to be drawn.

The importance of both perforation and disturbance by means of biological activity lies in the disclosure of the subsoil. In these processes mechanical barriers for roots are removed and deeper aeration and soil drainage become possible. The final result of these processes often is a deeper penetration of the root system (FINCK, 1952; HOEKSEMA, 1953; GUILD, 1955; STÖCKLI, 1958).

To summarize it can be stated that changes in the heterogenity of the pore-size distribution cannot always be determined by observing the macro-structure. It also became clear that the study of the direct consequences of the biological activity – which is responsible for the formation of the heterogeneous pore-size distribution – may lead to unambiguous and reproducible characteristics. Further investigations revealed that the study of the biological homogenization is of great importance, but that both depth and degree of homogenization are unmanageable characteristics, especially for determining the short-term consequences of biological activity. It was also found that in light-textured soils or soils with light-textured subsoils, the depth of the undisturbed stratification is an important characteristic which might be determined reproducibly. In heavier soils the biopore trend was also found to be important. The reproducibility of the latter determination was discussed together with the necessity of a systematic measurement.

2.6 The soil structural trend

It is striking in comparing a fairly large number of profile descriptions of soils which are situated in an area as the Netherlands that many soil profile descriptions show a great similarity. This is particularly true for the vertical sequences of the soil structural types.

VAN DER KLOES (1961) introduced the term 'soil structural profile'. This term was later adopted by EDELMAN *et al.* (1963) and introduced to designate the vertical sequence of soil structural types in a soil. Since the term profile is already used in soil science in another meaning (cf. JOFFE, 1949; LAATSCH, 1957; CLARK, 1961) we suggest replacing the term 'soil structural profile' by 'soil structural trend'.

EDELMAN *et al.* (1963) regarded the soil structural trend as the synthesis of a great deal of knowledge collected during the previous decades on the macro-structure and influence of biological activity on the soil in general.

The practical value of the soil structural trend becomes clear if it is realized that this characteristic enables us to give brief much information of importance for the agricultural suitability of the soil. The structural trend may also be an important factor in comparing soils which originally had similar properties (cf. section 2.1).

It was found that when the soil structural trend is viewed in the light of the soil physical properties and biological activity, it is not merely the vertical succession of macro-structures, but due to the presence or absence of heterogeneous pore-size distributions at each depth level in the soil.

Consequently it becomes possible to discuss the root development of a single layer in relation to the root potentialities of a whole soil.

Apart from the structural trends containing structures resulting from mechanical soil structure degeneration (cf. chapters 3 and 5), the following three main soil structural trends were found to exist:

(i) This type (1) includes the following macro-structures: granular, subangular blocky, sponge, stratified sedimentation structure and single grain structure. These macro-structures occur in the soil in this order from top to bottom. One or more types may be absent on either side of this sequence. This type of structural trend was observed in the following soils, viz., river levee soils, creek ridge soils and estuary silt soils (cf. EDELMAN, 1950). In general the soil is light-textured and the textures become lighter with increasing depth. These soils have always been relatively well-drained and/or have a high drainability.

(ii) This type (2) includes a succession of structural elements bounded by more or less sharp edges and flat faces.Usually no other macro-structures occur than angular blocky and prismatic elements, with exception of the macro-structures occurring in a thin surface soil. This type of structural trend was observed in river basin clay soils and heavy marine and estuary deposit soils. (cf. EDELMAN, 1950). These soils are usually heavily textured, relatively poorly drained and have a low drainability.

(iii) Type (3) is used for all trends intermediate between type (1) and type (2). In the river loam and clay soils occurring in the central part of the Netherlands, the following combinations may be observed, viz., type (1) on (2), or the reverse. Even more complex types were noticed, such as type (1) on (2) on (1) in the river levee on river basin on river levee soils.

The two extreme types of structural trends will be discussed below. For comparing these types the following soils were used as examples, viz., soil Beuningen (profile description P7) (a river levee soil) as an example of type (1) and soil Opheusden 2 (cf. chapter 6) (a river basin clay soil) as an example of type (2). The following striking differences were noted between these soils:

(i) The origin. Soils like Beuningen 1 were built up by mineral particles which sedimentated from water, in this case from a river. In the beginning relatively coarse sand was deposited resulting in a layer with single grain structure. As soon as the water flows more slowly, finer material will be transported and deposited. The resulting structure is an alternation of bands of alternately somewhat coarser and somewhat finer textures, which is called a stratified sedimentation structure. As soon as the sediment is no longer permanently under water, soil animals will start to inhibit the deposited material. According to DOEKSEN and MINDERMAN (1963) these pioneer animals will be *Tubifex* species in river sediments and *Nereis* species in estuary sediments. They give rise to the formation of the typical sponge structures. On top of this sponge structure new sediments will be deposited which will usually be more heavily textured. DOEKSEN and MINDERMAN (1963) stated that the soil will then bear a vegetation consisting to all probability of grasses. It is likely that the soil fauna will gradually include earthworms. A thin layer of sediments deposited from then onward will be mixed with the soil material present. A similar process occurs in the winter and spring in river foreland soils (cf. EDELMAN, 1950 and EDELMAN *et al.*, 1963). Finally the soil consists of a thick layer of sediments that tend to become more heavily textured from bottom to top. The upper part of the soil – which is what it has meanwhile become – shows a subangular blocky structure, possibly a granular structure, resulting from biological activity and desiccation. The lower part shows a sponge structure, resulting from the presence of biological activity outside the zone of regular desiccation. This sponge structure may be distinguished from sponge structures resulting from the activity of the *Tubifex* and *Nereis* species, the latter resembling more the inside of a walnut. EDELMAN *et al.* (1963) stated that all sponges in the river loam area should be regarded as *Tubifex* sponges. This statement should be considered as incorrect.

Soils with structural trends of type (2) result from the sedimentation of very fine particles from water which came to a stand still, generally in a depression. The soils were only slightly influenced by soil animals. The formation of soil structure almost exclusively depended on physical forces, resulting in a structural trend which includes physicogenic structures only.

(ii) Soil drainage. Soils like the Beuningen one are usually better drained than those like Opheusden 2. It was also observed that possible wet variants of the Beuningen soil are more readily improved by artificial drainage than soils like Opheusden 2. Living conditions for soil animals are better in soils of the first type than in soils of the second type, possibly after improvement of soil drainage. Consequently it is easier to improve the first type of soil than the second. The phenomenon is supposed of great value for selecting soils for soil improvement.

(iii) Biological activity and root development. Soils like Opheusden 2 are characterized by a minimum of biological activity resulting from a poor drainage. Consequently both homogenization and perforation (cf. section 2.5) are almost absent. The structural types are of physicogenic origin, except perhaps those occurring in a thin surface soil. Root development is scarce and shallow. These soils are mostly used as grassland. Soils like the Beuningen one are characterized by a relatively high biological activity, especially when it is a great distance from the soil surface to the upper boundary of the sandy subsoil. Generally they are more or less homogenized. Perforation is intense and continues to a great depth. The stratified sedimentation structures can only be observed at a great depth. The soil structural trend shows a succession of biogenic and geogenic structures. The pore-size distribution is fairly heterogeneous. These are some of the best agricultural soils in the Netherlands.

Preliminary studies revealed that the picture outlined might be completed with many other examples from alluvial soils from the Netherlands and abroad. Similar laws seem to govern structure formation in loess soils, which may also show a succession of biogenic and geogenic structures. If for defining the soil structural trend we use both the structural types and the heterogenity of the pore-size distribution, even sandy soils seem to fit into the picture. For these reasons the use of the structural trend is assumed to be of great value. It might be defined so far as we know at present for all soils and it presents the relation between the origin, the agricultural suitability and the possibilities for soil improvement.

Finally a relatively distinct correlation was observed in the river loam and river clay area in the central part of the Netherlands between soil structural trend, soil textural trend and natural soil drainage. This correlation enables the structure to be used as a criterion in soil survey (cf. chapter 6). By combining soil augerings with small profile pits of not more than some 50 centimetres depth, much more information can be collected than by using the soil auger only. This method might be considered as a synthesis of the study of soil structure and physiographic soil survey. In this way it should also be possible to obtain more information from soil maps concerning the possibilities of land use and soil improvement.

3 The influence of soil management on the properties of some tidal deposit soils

3.1 Introduction

It has often been stated that soils lose part of their production capacity some years after man starts to cultivate them. The decrease of the production capacity may be caused by erosion, resulting in many cases in loss of part of the surface soil and a decrease of the waterholding capacity of the soil. It may, however, also be caused by soil structure deterioration, which may be observed in many soils which have long been used as arable land. Soil structure deterioration has been described by several authors, e.g. HÉNIN (1960), GÖRBING (1947), KÖHLER (1949) and SEKERA (1950). It may be regarded as one of the most serious problems of soil management research.

Two examples of soil structure deterioration of arable land soils will be discussed in this chapter and some further examples will be presented in chapter 5. The examples will be used in this chapter as a contrast to the properties of some soils which improved greatly by being used very intensively by man. The latter soils have been used for at least some tens of years for growing horticultural crops under glass. These soils were introduced here to demonstrate the splendid properties which soils may acquire under certain management conditions.

To bridge the large differences in properties between the above mentioned arable soils and those under horticulture, two further examples were introduced concerning pasture soils which have intermediate properties.

3.2 Observations

The soil management studies which will be discussed in this chapter, were performed on a number of tidal deposit soils. These are situated in the west of the Netherlands, in the vicinity of Barendrecht and Zwijndrecht (the former Island of IJsselmonde). The soils, selected for these investigations, may be characterized as follows.

The Barendrecht soils (cf. profile descriptions P1, P2 and P3) consist of a moderately well-drained, calcareous, *silt loam*, which becomes lighter textured with increasing depth. The structural trend is of type 1 (cf. section 2.6) i.e. below the surface soil a sequence may be observed of biogenic and geogenic structural types (cf. section 2.4).

The Zwijndrecht soils (cf. profile descriptions P4, P5 and P6) consist of an imperfectly drained, noncalcareous, silty clay. The structural trend is of type 2 (cf. 2.6) i.e. below the surface soil a sequence may be observed of physicogenic structures only (cf. 2.5).

Differences between the properties of soils, subject to varying land use, may be caused by differences in soil management. As stated in section 2.1, however, in such cases it is important to pay special attention to the properties of the original soils. It is possible that some of the differences are not due to the differences in soil management, but to differences in geogenesis of the original soils. If the properties of the original soils are similar, we may be certain that the differences observed, are really caused by differences in the present soil management, at least if each of the soils has been subject for many years to the same cultural practice. The soils discussed below, have been subject to the same type of land use for at least some tens of years.

It was impossible in the two series under consideration to find three fully identical soils, in which the cultural practices differed. When a soil was chosen in the past for a particular type of land use, the soil topography was already taken into consideration. Since topography and geogenesis are closely interrelated in this area, soils in which the cultural practices differ, show smaller or larger differences in the properties of the original soils. In the Barendrecht sequence these differences were small. In the Zwijndrecht sequence they are larger. Such differences were only tolerated, if it was clear that they did not interfere with differences due to soil management and that they were not caused by soil management.

3.2.1 Barendrecht soils

This sequence consists of three soils. For profile descriptions and analytical data cf. Appendix II. One is used for growing horticultural crops under glass (P1). It is dressed year after year with vast quantities of organic manure. The glasshouse is sprinkled and heated. The soil is desinfected at regular intervals with steam.

The second soil is used as arable land (P2). This soil has a light dressing of organic manure. The croprotation scheme includes many times cereals and beets.

The third soil is under pasture (P3). The field, in which this soil is situated, is well managed.

The differences in sedimentological and hydrological properties of these three soils are small. The three soils have very similar textural and structural trends (cf. chapter 2). As stated above they may be characterized as moderately well-drained, calcareous, silt loams, becoming lighter textured with increasing depth.

The differences, with regard to soil physical and chemical properties, observed in these three soils with different cultural practices, are as follows.

The surface soil (0–26 cm) of the pasture soil (P3) shows with increasing depth first a compound platy structure, subdivided into subangular blocky elements; then a single subangular blocky structure and finally a compound prismatic structure, subdivided into subangular blocky elements. Hence the top of the structural trend of soil P3 consists of subangular blocky elements. The surface soil (0–30 cm) of the arable soil (P2) shows a sequence of angular blocky elements, the size of which increases with increasing depth. In the lower part of the surface soil (ploughsole) some of the angular blocky elements are characterized by partly shell-shaped pedfaces. Thus the top of the structural trend of soil P2 consists of angular blocky elements. The surface soil (0–35 cm) of the glasshouse soil (P1) shows a number of different structural types occurring at the same depth, ranging from granular via subangular blocky to dense clods. The lower part of the surface soil of P1 consists of granular elements only. Thus the top of the structural trend of soil P1 consists of granular, subangular blocky and cloddy elements.

Besides the above mentioned differences in soil structural type, obvious differences were noticed in the porosity (field observation) of the structural elements in the surface soil of P1, P2 and P3. In the surface soil of P3 the structural elements are characterized by a heterogeneous pore-size distribution and a relatively large number of pores per surface unit. The porosity of the structural elements shows no systematic change with increasing depth.

The structural elements in the surface soil of P2 are characterized by a change with increasing depth from a heterogeneous pore-size distribution via a relatively homogeneous pore-size distribution to an absence of pores. The latter is illustrated by the phenomenon that roots grow exclusively along the partly shell-shaped pedfaces and not through the peds.

The surface soil of P1 consists of structural types with a varying porosity. The granular elements have a heterogeneous pore-size distribution and a relatively large number of pores; the subangular blocky elements also have a heterogeneous pore-size distribution, though with a smaller number of pores per surface unit, while the clods have a relatively homogeneous pore-size distribution and a small number of pores.

The pore space (laboratory determination), on a depth varying from 5 to 12 centimetres below the surface in these soils, is 56% under pasture, 54% under arable land and 61% under horticulture. Greater differences in pore space were observed at a depth of 25 to 30 centimetres below the surface, viz., under pasture 53.5%, under arable land 46% and under horticulture 67%.

Unlike the basic differences in structural type and porosity of the surface soil of the three soils under consideration in which the cultural practices differ, the differences in properties of the sub-surface soil and subsoil are only gradual. The sub-surface soil and subsoil of the three soils show with increasing depth the following sequence of structural types: compound prismatic, subdivided into subangular blocky, porous sponge, partly disturbed stratified sedimentation structure and finally stratified sedimentation structure. The structural trends are very similar to the standard structural trend of type 1 (cf. section 2.6). In these soils the boundaries between two types of structural elements are gradual. The depth at which these boundaries are situated may vary slightly in different soils (gradual differences).

The structural types of the sub-surface soil and subsoil of soils P1, P2 and P3 show a heterogeneous pore size distribution and a fairly large number of pores per surface unit up to the undisturbed stratified sedimentation structure, which is characterized by a relatively homogeneous pore-size distribution. Pore space decreases with increasing depth, having about the same value at the same depth in the three soils.

Besides differences in structural properties (i.e. soil physical properties), manifest differences in soil chemical properties were observed in the surface soil of the three soils in which the cultural practices differed.

The organic matter content of the soil under pasture (P3) and that under horticulture (P1) are considerably higher than the organic matter content of the arable land soil (P2). The differences between the soils under pasture and under horticulture are slight. The calcium carbonate content of the upper part of the arable soil is higher than that of the two other soils. The differences between the soils under pasture and under glass are slight. The pH of the soil under arable land is higher than that of the other two soils. The differences in organic matter content, in calcium carbonate content and in pH occur not much deeper than the upper 50 centimetres of the soils.

To summarize it can be stated that the differences in properties of a relatively light textured, moderately well-drained, calcareous silt loam tidal deposit soil under horticulture, arable land and pasture, relate to: soil structural type, nature of the pore-size distribution, pore space, organic matter content, calcium carbonate content and pH. The differences in soil chemical properties seem to be restricted to the upper 50 centimetres, the differences in soil physical properties to an even thinner surface layer of the soil.

3.2.2 Zwijndrecht soils

This sequence also consists of three soils. For profile descriptions and analytical data cf. Appendix II. One is used for growing horticultural crops under glass (P4). This soil has been dressed for many years with large amounts of organic manure. It is sprinkled and heated. The soil is desinfected at regular intervals. The second soil (P5) is used as arable land. Like P2 it only has a light dressing of natural manure. Cereals and beets are the most important crops in the rotation system. The last soil of this sequence lies under pasture (P6). This pasture is well managed.

The hydrological and sedimentological properties of the soils of this sequence are in sharp contrast to those of the soils of the Barendrecht sequence. Distinct variations, however, occur between the soils of the Zwijndrecht sequence and attention is paid to them now. These variations relate to the depth of occurrence of the peaty subsoil, which begins in the subsoil of P6 at a much shallower depth than in P4 and P5. As far as can be concluded from the available data, the differences with regard to the depth of the peaty subsoil do not interfere with the differences due to differences in soil management. The main reason for this phenomenon is the imperfect drainage in all three soils under consideration, which inhibits the deep biological activity, normal in better drained soils.

The differences in soil management caused distinct differences in the properties of the three soils under consideration. The surface soil of the pasture soil (P6) shows with increasing depth first a single subangular blocky structure; then a compound prismatic structure subdivided into subangular blocky elements, changing at a depth of 15 centimetres below the surface into a compound prismatic structure, subdivided into angular blocky elements. The surface soil of the arable soil (P5) shows a sequence of angular blocky elements, the size of which increases with increasing depth. The upper part (Ap1) of the surface soil of the soil under glass (P4) consists of granular and subangular blocky elements side by side. The lower part (Ap2) of this surface soil consists of a compound prismatic structure, which is subdivided into granular, subangular blocky and angular blocky structural elements.

The differences in soil structural type are accompanied by differences in soil porosity. In P6 a gradual change takes place from a heterogeneous pore-size distribution in the sod layer to a relatively homogeneous pore-size distribution at a depth of 45 centimetres below the surface. This change is attended by a decrease of the porosity of the structural elements.

A similar change to a relatively homogeneous pore-size distribution with increasing depth and a decrease of pore space in the structural elements was observed in the arable soil P5.

The structural types of the surface soil of the soil under horticulture (P4) are, however, characterized by a heterogeneous pore-size distribution. The nature of this pore-size distribution does not change with increasing depth. A striking feature in this soil is the lower porosity of the angular structural elements in comparison with the porosity of the granular and subangular blocky structural elements.

The fieldobservations on the porosity of the structural elements are supported by the laboratory data on pore space in the total soil mass. At a depth varying from 7 to 13 centimetres below the surface the pasture soil (P6) has a pore space of 61.5%; the arable soil has a pore space of 48% at that depth, while the glass house soil (P4) has a pore space of 70%. The differences tend to become smaller with increasing depth.

Besides the above mentioned differences in structural properties occurring in the surface soil of the three soils under consideration, both basic and gradual differences occur in the sub-surface soil and in the subsoil.

The pasture soil (P6) shows a sequence of physicogenic structures in the sub-surface soil which rests on a macro-structureless subsoil.

In the glass house soil (P4) a sequence was observed consisting of prisms, subdivided into angular blocky elements (also physicogenic structures). The arable soil (P5) shows a sequence of physicogenic structures, the elements of which are, however, of slightly other types than in P4 and P6.

As in the soils of the Barendrecht sequence, considerable differences may be observed in the chemical properties of the three soils under consideration.

The organic matter content of the glass house soil is higher than that of the soil under pasture. In both soils, however, the organic matter content is much higher than in the arable soil. Moreover the high organic matter content in the glass house soil continues to a greater depth than in the pasture soil. The amount of calcium carbonate in the arable soil is higher than in the other two soils, but the differences are slight. The pH of the arable soil is higher than that of the glass house soil. The glass house soil in turn has a substantial higher pH than the soil under pasture.

To summarize it can be stated that the differences in properties of this imperfectly drained, relatively heavy textured, tidal deposit soil, in which three different cultural practices were employed, relate to: soil structural type, nature of the pore size distribution, pore space, organic matter content, calcium carbonate content and pH.

3.3 Interpretation

It seems possible to distinguish between differences resulting from minor differences in geogenesis and those due to a difference in soil management. Only those differences will be explained which result from differences in soil management.

3.3.1 Barendrecht soils

Since it is highly probable that the soils P1 (horticulture) and P2 (arable land) were originally also under pasture (as soil P3 at present), the properties of soils P1 and P3 will be explained against the background of the properties of soil P3.

The differences in soil structural properties between the surface soil of the soil under arable land and of that under pasture (P2 and P3 resp.) refer to: physicogenic structures in P2 with a relatively homogeneous pore-size distribution and a low soil porosity versus biogenic structures in P3 with a heterogeneous pore-size distribution and a higher soil porosity. Concerning the chemical differences: the organic matter content of P2 is lower than that of P3, the calcium carbonate content is higher, and the pH is also higher than in P3.

It is also clear that the compaction in the arable soil increases near the bottom of the surface soil (as demonstrated by the change from a heterogeneous pore-size distribution to a homogeneous one, by the decrease in the visible soil porosity and by the results of the pore space determination in the laboratory). Finally it is noticeable that as far as soil structure is involved, the different properties of the arable soil (P2) are restricted to a surface horizon with an abrupt lower boundary.

The differences may all be explained by the different soil management, applied to each of the soils under consideration. The properties of the arable land soil are the resultant of mechanical soil structure degeneration and suppression of the biological forces which should regenerate the soil structure.

The term mechanical soil structure degeneration stands for the totality of forces which induce the poor structural properties of many arable soils. Among these forces are: compaction and smearing of the soil material caused by soil tillage of too moist soils and driving heavy loads over the land surface.

The suppression of the biological regenerating forces is caused by: injury to soil animals (especially earthworms) by means of soil tillage implements and the supply of both quantitatively and qualitatively insufficient food for the soil animals (cf. Stöckli, 1958 and Finck, 1952).

In terms of the normal agricultural practices on arable land, the following factors are responsible for the formation of the unfavourable structural properties of the arable soil: soil tillage, driving over the land surface with the harvested crop, leaving insufficient plant material on the land surface after harvesting, applying a relatively insufficient amount of organic manure. The latter conditions are either absent in the pasture soil or they operate on a much smaller scale.

The mechanism of the biological regeneration of soil structure by means of earthworms will be discussed in greater detail in chapters 4 and 5, while mechanical degeneration of soil structure will be discussed again in chapter 5.

The higher pH, the higher calcium carbonate content and the lower organic matter content in soil P2 than in soil P3, are interrelated. They are also correlated to the differences in soil management. The higher root concentration and the higher carbon dioxide production in the surface soil of P3 seems to be responsible for these differences, from which a higher rate of decalcification under pasture may be concluded.

The differences in properties between the surface soil of the soil under horticulture and of the soil under pasture (P1 and P3 resp.) relate to: the simultaneous occurrence in one layer of very porous granular elements, porous subangular elements and dense clods, resting on a layer with very porous granular elements in P1, versus the occurrence of a continuity of porous subangular blocky elements in P3.

The occurrence of the cloddy elements and the occurrence of the granular elements in soil P1, need to be explained.

The differences between soils P1 and P3 result again from differences in soil management, applied to each of the soils. Many crops in the glass house are grown in rows or beds with small access paths in between. The soil under these paths was found to show distinct compaction phenomena. The paths are turned by soil tilth every year, bringing fresh soil material to the soil surface. The remnants of these paths were recovered in the Ap1-horizon in the form of cloddy elements. The only mechanical soil structure degeneration present in the soil under consideration is that caused by walking over these paths.

The soil under glass receives every year an extremely large amount of organic manure and large amounts of artificial manure are also added. The soil is tilled and the organic manure is introduced with a spade. The soil is steam-desinfected regularly. During the cold season the glass house is heated. During all periods of the year sprinkling is applied and excess of water is removed by artificial drainage.

There is few or no mechanical injury to soil animals. The regular soil desinfection, however, causes a selection among the species which together constitute the soil fauna of this soil. Earthworms, for example, are not present in large numbers. Where earthworms are present, they are mainly of the small types, operating in the surface soil. Large quantities of insects are, however, brought in with fresh manure every year. To summarize it can be stated that the vast amounts of good quality food stimulate the soil fauna, which may be active in this soil for most periods of the year, since it is subject to neither cold nor drought. The high biological activity is supposed to have caused the highly biogenic granular structures in soil P1 (cf. section 2.4).

Although the food supply for the soil animals in soil P3 (pasture) is good, it is smaller than in the glass house soil. Apart from the occurrence of the clods, resulting from the access paths, it can be stated that the main differences in soil management relate to a better cultivation of the soil fauna in the glass house soil, resulting in the formation of highly biogenic structural elements.

Starting from the point of view that soils P1 (glass horticulture) and P2 (arable land) were originally under pasture (as P3 at present) the following conclusions can be drawn from the above mentioned observations.

The arable soil has more physicogenic structures than the soil under pasture. Thus under the arable land practice, the soil deteriorated.

The soil under glass had, apart from the clods, more biogenic structures than the soil under pasture. Hence under the horticultural practice the soil was improved.

3.3.2 Zwijndrecht soils

Only one new element in the interpretation needs to be introduced in this sequence; it was absent in the Barendrecht sequence. Meant is the relatively high groundwater level which occurs in the winter in the Zwijndrecht soils, especially in the soil under pasture (P6).

The mode of formation of P3 (Barendrecht) was about the same as that discussed in section 2.6 for the soil, characterized by structural trend type 1. The mode of formation of P6 (Zwijndrecht), however, roughly corresponds to that of the soil, characterized by soil structural trend type 2 (cf. 2.6). The first type included a relatively high level of biological activity, the second type a low level of biological activity. The main cause of the difference in biological activity is the impossibility for the larger earthworms to flee downwards in case of cold or drought (cf. Stöckli, 1958). This problem will be discussed in detail in chapters 4 and 5. A consequence of the low biological activity in the heavily textured pasture soil (P6) is the occurrence of only a shallow layer of subangular blocky structural elements (biogenic structures) resting on a sequence of physicogenic structures.

The shallow ground water level and the resulting low biological activity had few consequences for the arable soil (P5). As in soil P6 the structures of the sub-surface soil and subsoil are distinctly physicogenic. The structures of the surface soil of P5 are also physicogenic. They are, however, not caused by the shallow groundwater level, but by the mechanical soil structure degeneration as in the Barendrecht sequence (cf. P2). To the forces suppressing biological soil structure regeneration, a third one has been added, viz., the shallow groundwater level.

The consequences for the soil under horticulture (P4) are also small, since the soil fauna here consists already of species operating in the surface soil with no reason to flee downwards on account of cold or drought.

There is no phenomenon of the clods, resulting from the compacted structures under the paths in the glass house (cf. 3.2.1). The main reason is assumed to be the location of the profile pit between two paths. Soil management is generally similar to that in the Barendrecht glass house. The quantities of organic manure are even greater than in soil P1.

Since it is highly probable that soil P4 was originally of about the same type as soils P5 and P6, a comparison of the properties of the present soils reveals that the structure changed in the top half metre from an almost fully physicogenic structure to a highly biogenic structure. The result is even more impressive than in the case of the Barendrecht soils, where the original soils started already with subangular blocky structures.

In the discussion of the structural types resulting from high biological activity (cf. 2.4) the granular structure has been almost entirely omitted. The main reason was that the granular structure is relatively rare. It seems that it results from a really very high level of biological activity. Apart from the mode of formation, the protection against climatical degenerating forces seems to be a factor of great importance.

Another interesting point is the phenomenon that the granular structure occurs both in the well-drained soil and in the imperfectly drained soil under horticulture. As will be pointed out in greater detail in chapters 4 and 5 the depth of the groundwater level is in many cases the factor which inhibits high biological activity. In this case, however, it does not, since the soil animals forming the granular structure mainly operate in the surface soil.

From the observations it is obvious, as in the Barendrecht sequence that the arable soil deteriorated, while the soil under horticulture was greatly improved. It should be noted further that the changes were restricted to a relatively shallow layer and that both the direction and the degree of the changes from the original soil are more or less independent of the depth of the groundwater level. Both the deterioration and the improvement were influenced more by soil management than by the depth of the groundwater level.

3.4 Summary and discussion

Man is said to start waste of soil productivity soon after he begins to cultivate the soil. The purpose of the investigations, the results of which were presented in this chapter, was to demonstrate that still examples may be found of soils which improved, because of their being used by man.

In this chapter six soils were discussed in two sequences and with three different cultural practices, viz., glass house culture with high quantities of organic manure, sprinkling, heating etc., arable land and pasture. The two soil types were a calcareous, moderately well-drained, silt loam and a non-calcareous, imperfectly drained, silty clay.

It has been shown that the differences resulting from differences in soil management tend to be restricted to the surface soil, possibly to the surface and to the subsurface soil.

The practice of the arable land management induced the formation of compacted surface soils with structures of distinctly physicogenic origin. The formation of such a compaction was said to result from mechanical soil structure degeneration together with the absence of biological soil structure regenerating forces. The cause of the latter's absence was said to be insufficient food for and mechanical injury to the larger soil animals.

The above mentioned soil management in glass houses induced the formation of structural types that exhibit very clearly their biological mode of formation. Causes of the formation of this favorable structure were said to be the large amounts of organic manure (soil animal food of high quality), sprinkling (absence of drought), heating (absence of cold) together with the absence of the severe mechanical soil structure degeneration that occurs in many arable soils.

The properties of the soils under pasture were shown to be intermediate between those of the other two soils. They can be explained by an equilibrium between soil structure regeneration and soil structure degeneration, which lies at a lower level than in the glass house soil, but at a higher level than in the arable soil.

Finally the above mentioned complexes of differences due to soil management seemed to be more or less independent of the depth of the groundwater level.

Some further observations may be made. Soils, like the ones under glass house horticulture, which were discussed above, are rare in the Netherlands. The total area, where they may be found is relatively small. They have not been deliberately improved. Mostly the dung was added in the form of hot dung for cultivating cucumbers. The soils acquired their present properties over a period of some tens of years. Their present condition is due to considerable labor and they are therefore really man-made soils (cf. EDELMAN, 1950). They tend to disappear, since the area where they are situated, will become a suburb of the Western Holland urban area.

Another remark concerns the rate of decalcification of soils in the Netherlands. Several studies have been published on the decalcification of the alluvial soils in the Netherlands. Some of these studies on decalcification of alluvial soils in the north of the Netherlands (EDELMAN and DE SMET, 1951) and (DE SMET, 1962) led to the conclusion that the rate of decalcification under Dutch climatic conditions cannot be more than 1% calcium carbonate in 65 to 90 years. The former publication in particular was widely criticized by HISSINK (1952) and by MASCHHAUPT (1952). The latter authors stated that it is incorrect to make general statements about the rate of decalcification in Dutch soils, since it depends on many factors. According to MASCHHAUPT (1952) the rate of decalcification is governed by three main factors, viz., drainage conditions, biological activity and the form in which the carbonates occur (either present as rather coarse shell fragments or precipitated as fine calcium carbonate).

HOEKSEMA (1953) stated that the rate of decalcification is lower in soils with biological activity than in soils without. PONS (1957) stated that the rate of decalcification depends on the water permeability of the soils, on the water holding capacity, on the biological activity and on the nature of the calcium carbonate occurring in the soils.

From the observations presented in this chapter, another element governing the rate of decalcification, may be derived, viz., the soil management or the nature of the vegetation. From a comparison of soils P2 and P3 the conclusion may be drawn that the rate of decalcification is higher under pasture than under arable land, notwithstanding the higher biological activity in the soil under pasture. Soils P2 and P3 are situated in the same polder and have identical textural trends, indicating that the original calcium carbonate content must have been the same in both soils. This observation supports a statement of MASCHHAUPT (1933) which reads: "It is possible that the rate of decalcification under pasture is larger than under arable land. Exact data in this respect, however, are not yet available."

Finally some remarks should be made on the changes in the soil suitability due to the different soil management practices discussed in the foregoing sections.

Since the soil management applied to the pasture soils seems to be the one intermediate between the two others, the soil structural changes will be discussed against the background of the properties of the soils under pasture.

The arable land soil management gave rise to: a lower water permeability, a lower amount of water available moisture, a more difficult gas transport and a lower soil volume which can be penetrated by roots, than in the soil under pasture. Thus it can be stated that the root development governing soil physical factors became more unfavourable in the soil under arable land than in the pasture soil. Changes in the opposite direction may be observed in the glasshouse soils.

The worse soil physical properties in the arable soil have certain consequences. One of them is pool formation on the land surface in the autumn and in the winter, giving rise to new structural degeneration and also preventing a good distribution of the precipitation over the depth of the soil.

A further consequence is the deformation of plant root systems, caused by mechanical resistance. KÖHLER (1949) presented some interesting examples of deformed sugar beets. The same pictures might, however, be observed in nature on arable land in the harvest season.

A final consequence is the phenomenon which KÖHLER (1949) also described, viz., organic manure stays in the soil without being broken down as it should be. Sometimes distinct reduction patches may be found around such manure masses.

The farmers opinion that certain arable land soils are becoming increasingly heavier (to plough) year after year, needs no further explanation. It only raises the question as to whether any methods are available for improving such arable land soils. The question will be discussed in detail in chapters 4 and 5. The results of the investigations presented in this chapter suggest a change of the landuse to pasture or to horticulture. Since the change in the specific way of horticultural landuse, discussed in this chapter, cannot be effectuated, it will be left out of discussion. A change to pasture, however, will be discussed again in chapters 4 and 5.

4 The influence of grass mulching on the properties of some fluviatile deposit soils

4.1 Introduction

Mulching has been defined by JACKS *et al.* (1955) as: "The use of crop residues, manure, leaves, peat and other litter as well as paper, glass wool, metal foil, cellophane, and other convenient manufactured materials as mulches with or without shallow tillage, for the purpose of increasing soil productivity". The discussion in this chapter will be limited to the use of grass as mulching material.

Previous to the Second World War fruit was grown in the Netherlands in orchards with long-stem trees. The soil was covered with grass undergrowth and cattle grazed in these orchards. After the war there was a change from long-stem trees to shorter ones. Cattle grazing then became impossible because of damage to the fruittrees. The removal of the grass growing in the orchard was particularly difficult on farms where no cattle was present. It was impossible to let the grass continue to grow infinitely. A new system was then introduced, viz., mowing the grass and leaving it on the soil surface. This management system, known as 'grass mulching' is now employed on a large scale in the Netherlands.

HOEKSEMA, JONGERIUS and VAN DER MEER (1957) and HOEKSEMA and JONGERIUS (1959) stated that the use of grass mulching greatly improves the structure of the underlying soil. OP 'T HOF (1959, 1960), EDELMAN and OP 'T HOF (1960) and EDELMAN *et al.* (1963) arrived at the same conclusion.

It is well known that some soils under grass mulching have favourable physical properties, but certainly not all. It was concluded that certain factors may restrict the soil-improving effect of grass mulching. It seemed important to study these factors. It also seemed worthwhile to try to differentiate in a number of cases between the physical properties induced by the grass mulching and those already present before the application of grass mulching.

4.2 Observations

Some evident examples were chosen from a larger number of investigated soils to illustrate the rules of soil structure improvement induced by grass mulching.

During the investigations it was found that the rate of modification of soil properties as result of the application of grass mulching is largely determined by the hydrological conditions of the soil. Consequently one sequence of soils will be discussed in this chapter which have favourable hydrological properties and one sequence of soils with unfavourable hydrological properties (too wet soils). All soils discussed in this chapter are under grass mulching.

4.2.1 Beuningen soils

The two soils in Beuningen are situated in the same orchard. The distance between the profile pits was less than 10 metres. The orchard which has long been used for growing long-stem trees with grass undergrowth and cattle grazing, has been used for the last 15 years as a grass mulch experimental field. The old trees were pulled up and younger ones planted. The field was divided into square plots, half of which were clean cultivated, the other half grass mulched. The grass was mown frequently and the plots were well dressed with fertilizers.

One soil (profile description P7) was chosen in a mulched plot, the other (profile description P8) in a clean cultivated plot. Previous to the use of the orchard as a grass mulch experimental field, the management of the two soils was the same. The management of the investigated soils only differs in the application of grass mulching on one of the soils for the last 15 years.

These soils only differ slightly as regards the sedimentological and hydrological properties. Both soils consist of a relatively heavy textured (but not water impermeable) river levee subsoil which was covered by a light textured, more or less coarse sandy, crevasse deposit. The light-textured surface soil does not give rise to undesirable drought phenomena. Both soils (*Typic Eutrochrepts*) (7TH APPROXIMATION, 1964) were described as well-drained (SOIL SURVEY MANUAL, 1962).

Judging from the available data (cf. profile descriptions P7 and P8) it is highly probable that the differences between the properties of these two soils with favourable hydrological properties are only caused by the difference in soil management, i.e. by the application of grass mulching on one of the two soils.

Some evident differences between the physical properties of these soils were observed. An evident difference in topography is present between the two plots which include the investigated soils, the mulched plot being about 8 centimetres higher than the clean cultivated one. The particle-size analyses (cf. Appendix II) show that in soil P7 all particle-size fractions in the layer between 0 and 50 to 60 centimetres below the surface, remain constant within 3%. The layer in soil P8, showing the same phenomenon, is about 20 centimetres thinner.

A comparison of the biopore trends (cf. section 2.5) of the two soils under discussion reveals that in soil P7 more biopores occur in the size class 2–4 mm to a depth of 40 centimetres below the surface than in soil P8. The difference is greatest near the soil surface and gradually decreases with increasing depth (cf. fig. 1). Deeper than 40 centimetres below the surface the differences are small and not systematic.

The numbers of biopores larger than 4 mm only differ slightly in the two soils.

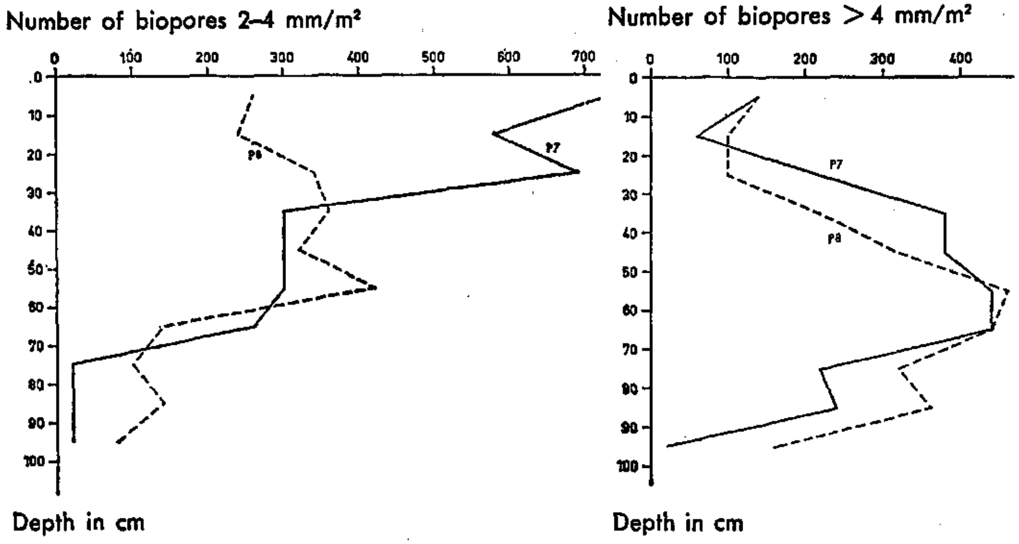


Fig. 1. Trends of biopores 2–4 mm/m² and larger than >4 mm/m² of the well-drained soils P7 (grass mulched) and P8 (clean cultivated)

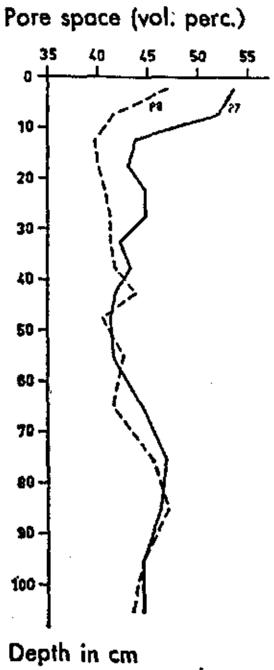


Fig. 2. Trends of pore space of soil P7 (grass mulch) and P8 (clean cultivated)

The pore space percentage near the soil surface in soil P7 is substantially higher than in soil P8 at the same depth. The difference gradually decreases with increasing depth becoming negligible at a depth of 30 to 40 centimetres and remaining so downwards (cf. fig. 2).

The structural trends show negligible differences. They are both of type (1) (cf. section 2.6).

The organic matter content of the upper 40 centimetres of soil P7 is somewhat higher than in the same layer in soil P8. Differences in pH are only small.

The calcium carbonate content is also about the same in the two soils, with a small difference in the layer between 60 and 70 centimetres below the surface.

4.2.2 Oosterhout soils

Unlike the soils of the Beuningen sequence, those discussed in this section have unfavourable hydrological properties. Like the Beuningen soils they are under grass mulch. Soils P9 and P10 are situated in a field used as pasture up to 1937. Later it became orchard with soil tillage and since 1948 with grass mulching.

These two soils show distinct differences in sedimentological and hydrological properties. Soil P9 (*Humic Normaquept*, 7TH APPROXIMATION, 1964) is imperfectly drained. It is situated in a former river stream-bed filled with heavy textured material (clayplug). Soil P10 (*Aeric Mollic Normaquept*, 7TH APPROXIMATION, 1964) is better drained than soil P9, but not so well as soils P7 and P8. Soil P10 lies on the levee of the former river in the streambed of which soil P9 is situated.

There are distinct differences in the physical and chemical properties of soils P9 and P10. The trends of the biopores between 2 and 4 mm and of those larger than 4 mm show higher values in soil P10 than in soil P9. The differences become smaller in the subsoil. It should be noted that only a few biopores occur in soil P9 (cf. fig. 3).

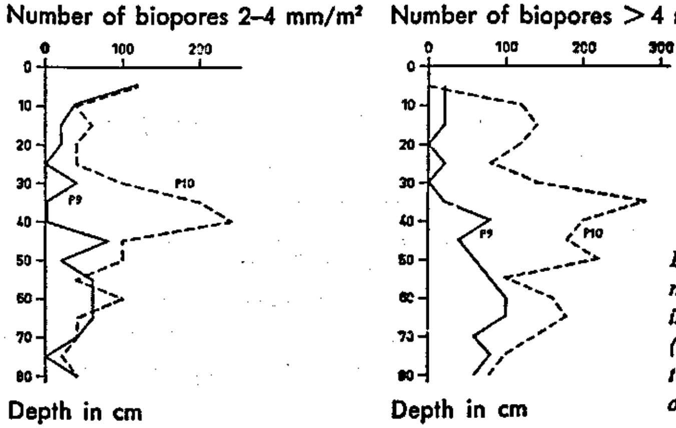


Fig. 3. Trends of biopores 2–4 mm/m² and >4 mm/m² of the insufficiently drained soils P9 (heavy textured) and P10 (light textured) under grass mulch orchard

Large differences were observed with regard to the structural trends of these soils. Soil P9 shows a thin layer (0–16 centimetres) of subangular blocky elements (biogenic structures, cf. section 2.4) resting on a sequence of angular blocky and prismatic structural elements (physicogenic structures, cf. section 2.4). Soil P10, however, shows a layer of 93 centimetres which consists of granular, subangular blocky and spongy structures, resting on a subsoil which consists of a more or less undisturbed, stratified sedimentation structure.

Soil porosity is also different in these two soils. In soil P9 it tends to increase, in soil P10 to decrease, with increasing depth. Calcium carbonate contents in soil P9 equal zero. In soil P10 calcium carbonate contents are high and they increase with increasing depth.

The pH in all horizons of soil P10 is higher than in soil P9. The organic matter content does not differ much in the two soils.

4.3 Interpretation of the observations

Several authors (e.g. HOEKSEMA, JONGERIUS and VAN DER MEER, 1957; HOEKSEMA and JONGERIUS, 1959) stated that on application of grass mulching earthworms play an important part in establishing soil structure improvement.

It is well known that a shortage of food keeps down the earthworm activity (cf. section 2.3). Probably starting from this point of view, the above-mentioned authors assumed that the addition of extra food stimulates the earthworm activity.

During the investigations reported in this chapter it was found that earthworms may, in fact, play an important part in improving soil structure upon application of grass mulching. The latter, however, does not always result in an improvement of the soil structure, especially not when earthworms cannot be active. Consequently in interpreting the observations, special attention will be given to the relationship between earthworm activity and grass mulching.

4.3.1 Beuningen soils

It was observed that the pore space of the surface soil of the mulched plot (P7) was substantially higher than that of the surface soil under clean cultivation (P8), and also that the surface soil of P7 was more intensively perforated with biopores between 2 and 4 mm than the surface soil of P8.

VAN RHEE and NATHANS (1961), who studied the same soils some years ago, stated that the numbers of the smaller earthworm species (e.g. *Allolobophora caliginosa*, *A. rosea* and *A. chlorotica*) showed a more marked response to the difference in soil management than the numbers of the larger earthworm species (such as *Lumbricus terrestris* and *Allolobophora longa*).

According to STÖCKLI (1958) the smaller earthworm species mainly live and burrow in the upper part of the soil. The larger species are said to burrow much more deeply. STÖCKLI (1958) also stated that the smaller earthworm species prefer fresh, young and albuminous grass-litter for nourishment. This food is available in relatively large quantities in grass mulch orchards which are well dressed with fertilizers and where the grass is frequently mown.

When these three statements, derived from literature, are compared with our own observations, the conclusion seems justified that the increased number of smaller biopores and the increased pore space in the surface soil of the mulched soil P7 result from an increased activity of the smaller earthworm species which live and burrow in that layer.

Soils P7 and P8 only differ in the application of grass mulching which results in the availability of larger amounts of plant material as food for the earthworms in soil P7. It was found that the application of grass mulching really stimulated the activity of the smaller earthworm species living and burrowing in the surface soil of P7. Consequently it can be concluded that previous to the application of the grass mulching the activity of the smaller earthworms was only hampered by a relative shortage of food (cf. 4.3.2).

Apart from the higher number of smaller biopores in the surface soil of the mulched soil, resulting from an increased activity of the smaller earthworms, a deeper homogenization was observed (cf. section 2.5). The latter may partly be attributed to a mechanical mixing resulting from an increased burrowing activity of the smaller earthworms and partly to a mixing via the digestion of the smaller and larger earthworms.

The higher pore space and the accompanying elevation of the soil surface of soil P7 are assumed to be direct consequences of the increased burrowing activities of the smaller earthworms which live in the surface soil.

Finally it should be noted that the application of grass mulching in soil P7 only improved the structural properties of the surface soil. Deeper than about 50 centimetres no systematic differences were observed between the properties of P7 and P8.

4.3.2 Oosterhout soils

When the observations of the Oosterhout sequence are compared with those of the Beuningen sequence it is evident that the grass mulched soils of the Oosterhout sequence show less traces of biological activity than the soils of the Beuningen sequence. The lower biological activity is reflected by lower pore space percentages, by lower numbers of biopores and by the occurrence at shallow depth of either physicogenic or geogenic structures (cf. sections 2.4 and 2.5).

Starting from the point of view that the soil structure improvement induced by grass mulching is realized by the earthworms, the problem is to discover which condition prevents the soil fauna from being as active in the Oosterhout soils as in the Beuningen soils.

Apart from enemies, earthworm activity may be reduced or terminated by lack of food or by poisoned food, by cold, by drought or by lack of oxygen (STÖCKLI, 1958; FINCK, 1952).

Lack of food of high quality may be translated as lack of young, fresh and albuminous litter. This condition is present in those grass mulch orchards where grass is not frequently mown. Poisoned food may be translated as grass with traces of poison which was sprayed to kill insects and moulds attacking the fruit trees. According to HIRST *et al.* (1961) spraying of certain copper compounds in the orchard may kill the earthworms to such an extent that the grass is no longer digested and remains as a mat on the soil surface.

Earthworms do not seem to be resistent to cold and drought. In case of cold or drought the smaller earthworms coil up in holes in the surface soil and the larger species retire to deeper parts of the soil. But the larger species can only retire up to the groundwater level or depth at which coarse sand occurs. The reason of the latter restrictions is that earthworms cannot live without oxygen and cannot burrow in coarse sandy materials.

When the above-mentioned factors which may inhibit the earthworm activity are applied on the problem under discussion the following can be stated. Observations revealed that little poison is found on the grass in the orchard where soils P9 and P10 were studied. Consequently the digestion of poisoned food can be left out of discussion. Observations revealed, however, that in this orchard grass is not frequently mown. It is also known that soils P9 and P10 have shallow groundwater levels in the winter. Finally the investigations showed that in soil P10 coarse sand occurs in the subsoil. Consequently it can be stated that the lack of possibilities to retire to greater depth and the lack of food of high quality restrict the biological activity in soils P9 and P10. The former factor restricts the activity of the larger earthworms, the latter the activity of both the smaller and larger ones.

Theoretically the soils of the Oosterhout sequence where the grass is not frequently mown, should not be compared with the soils of the Beuningen sequence, since not only the soil drainage is different, but also the frequency of mowing. On the other hand it should be realized that grass is not frequently mown on imperfectly drained soils under grass mulch. It should also be noted that even if the grass was frequently mown on soils P9 and P10, the soils still being insufficiently drained, the properties would be much similar to what they are now. In that case the biological activity would be inhibited by one factors instead of two.

To summarise it can be stated that both the fact that the grass is not frequently mown and the lack of possibilities to retire to deeper parts of the soils due to the imperfect soil drainage, restrict the biological activity in the soils P9 and P10. Consequently the Oosterhout soils show less traces of biological activity than those near Beuningen.

The two soils in Oosterhout (P9 and P10), however, also show substantial differences from each other. Some of these differences result from the fact that soil P10 is better drained than soil P9. The better drainage gave, via a higher biological activity, rise to a larger number of biopores in soil P10. The differences observed in structural trend are believed to originate on the one hand from a difference in soil drainage, on the other, however, from a difference in sedimentological properties. As stated in section 2.6, soil P9 has had little more than physicogenic structures from the beginning with only a shallow surface soil with biogenic structures. Soil P10, however, has had more biogenic structures from the beginning.

The granular structures occurring in the surface soil of P10 in particular reflect the higher biological activity in soil P10 in comparison to soil P9.

The differences in soil porosity, calcium carbonate content and pH are believed to result from differences in sedimentological properties.

To sum up it can be stated that the insufficiently drained soils under grass mulching (P9 and P10) show few traces of biological activity. Since such soils have always had little biological activity, it can be concluded that the grass mulching in such soils does not stimulate the biological activity and consequently does not greatly improve the soil structure. The observations showed that the soil which was best drained of the two (P10), contained more traces of biological activity than the other (P9). This observation does not prove, however, that soil structure was more improved in soil P10 than in soil P9. The difference is older than the application of the grass mulching. Comparison of the surface soil of P10 with its granular structures with similar soils under grass orchard with cattle grazing, however, did suggest that the grass mulching possibly effected a small improvement in the structure of soil P10.

4.4 Summary and discussion

From the observations it could be concluded that in the investigated well-drained soil P7 grass mulching resulted in an increase in soil porosity and the number of smaller biopores in the surface soil. These changes were attributed to the supply of albuminous grass which had a stimulating effect on the activity of the smaller earthworms living in the surface soil. It was stressed that the improvement of the soil structure was restricted to the surface soil.

It was also observed that in an imperfectly drained, heavily textured soil (P9) where grass mulching was applied, but where the grass was not frequently mown, fairly small numbers of biopores occurred. This could be explained on the one hand by the shallow groundwater level, on the other hand by the relatively unfavourable nourishment of the earthworms.

Finally it was observed that in a somewhat better drained, lighter textured soil (P10) under grass mulching, where the grass was also infrequently mown, a somewhat higher number of biopores occurred. The higher number of biopores in soil P10 than in soil P9 was attributed to a better soil drainage. The difference probably was present already previous to the application of the grass mulching, so that it does not indicate that grass mulching improved soil structure more in soil P10 than it did in soil P9. The number of biopores in the better drained soil P10 was considerably lower than the number of biopores in the well-drained soils P7 and P8. It was concluded that in the two insufficiently drained soils P9 and P10 grass mulching resulted in little or no improvement of soil structure.

Most of the authors cited in this chapter (HOEKSEMA, JONGERIUS, VAN DER MEER, EDELMAN *et al.*, OP 'T HOF, JACKS *et al.*) have stated that grass mulching improves the soil properties which are important for plant growth. According to these authors the improvement is due to the activity of earthworms. JACKS *et al.* (1955) for instance stated: "The relationship between earthworms and mulches is twofold. On the one hand mulching with plant remains provides the earthworms with readily available food, protects them from desiccation and, in cold climates from low soil temperatures. They are therefore able to remain active in the soil for longer periods and to maintain higher population levels than would otherwise be possible. On the other hand, earthworms, by their feeding and casting activities, accelerate the humification of organic mulches and deepen the zone of humification. From the point of view of raising the fertility of the topsoil, the effect of the earthworms on mulches is good".

From the observations made in the foregoing sections of this chapter, it can be concluded that:

(i) in well-drained soils grass mulching only improves the surface soil. Apart from an increase of porosity, the regular release of nitrate compounds (JACKS *et al.*, 1955) and an increase of soil structure stability (HOEKSEMA, JONGERIUS and VAN DER MEER, 1957) seem to play a part.

(ii) in insufficiently drained soils grass mulching does not improve soil structure or only to a very small extent.

The rule governing the above-mentioned observations can be described as follows. The application of grass mulching only stimulates the activity of earthworms if previous to the application of grass mulching the relative shortage of food was the only factor inhibiting the biological activity. If, however, the supply of food was not, or not only the limiting factor, supply of food, i.e. the application of grass mulching, fails to stimulate the earthworm activity. In this case the limiting factor should be removed before application of the grass mulching. In insufficiently drained soils, for instance, the application of grass mulching should always be preceded by improvement of soil drainage. In our opinion this rule is the key to 'grass mulching for the purpose of biological soil improvement' (cf. EDELMAN and OP 'T HOF, 1960).

The rule can be illustrated by the following examples. HOEKSEMA, JONGERIUS and VAN DER MEER (1957) stated that the increased earthworm activity on application of grass mulching gives rise to perforation of impermeable, waterlogging layers in the soil. Similar phenomena will be described in chapter 5 (cf. soils P11 and P13). By means of a combination of an improvement of soil drainage – which the above-mentioned authors did not refer to – and the application of grass mulching, many subsoils were disclosed for plant roots.

EDELMAN and OP 'T HOF (1960) stressed the great improvement of the heavily textured soil on the experimental field 'De Lange Ossekampen', which was due to the application of grass mulching. In this case too, the application of grass mulching could only result in such an improvement because the groundwater level had been considerably lowered in that soil.

Provided the soils are well-drained, grass mulching might also regenerate the compacted structures which occur in many arable land soils (cf. chapters 3 and 5). Pastures with temporary grass mulching might be more suitable than grass mulch orchards, for this purpose.

From the above observations on the influence of grass mulching on the properties of some fluviatile deposit soils it can be concluded that:

(i) in well-drained soils grass mulching results in an improvement of the surface soil only.

(ii) in imperfectly drained soils grass mulching does not improve the soil or only to a small extent.

(iii) in formerly imperfectly drained soils, in which soil drainage was improved, grass mulching may result in a considerable soil improvement.

5 The influence of soil management on the properties of some fluviatile deposit soils

5.1 Introduction

Two phenomena formed the motive for the investigations reported in this chapter. The first phenomenon is soil structure deterioration, which can be observed in permanent arable soils. It is of special interest to farmers endeavouring to increase crop yields, both quantitatively and qualitatively. Soil structure deterioration, or soil structure degeneration as it will be called hereafter, has been extensively described by several authors, e.g. SEKERA (1951), HÉNIN (1960), GÖRBING (1947) and KÖHLER (1949). These and other authors stressed the presence of soil structure degeneration in many arable soils. They described how it can be recognized and what the consequences are for root development. Finally they gave suggestions for the prevention and limitation of soil structure degeneration.

The second phenomenon is illustrated by the abnormally high yields of good quality which may be harvested from fields previously used as grass orchard. OP 'T HOF (1961) stated that 70 tons of sugar beets per hectare in such fields are not exceptional. Other authors (e.g. EDELMAN *et al.*, 1963) stated that in general soils under grass orchard have favourable soil structural properties. The structural properties of pasture soils seem not to be as favourable as those in similar soils under grass orchard. But according to OP 'T HOF (1961) and EDELMAN *et al.* (1963), the structural properties of grass orchard soils and pasture soils are much better than those in similar soils under arable land.

Characterization and prevention of soil structure degeneration in arable soils were widely discussed in literature (see above). But the improvement of arable land soils with highly degenerated soil structures, has been given little attention until now. Those degenerated soil structures might be improved in various ways. One way may be derived from a comparison of structural properties of soils under arable land with those in soils under grass orchard or under pasture. Some tens of soils under these cultural practices were therefore studied. Most of the investigations were performed on river clay and river loam soils in the central part of the Netherlands. Some additional investigations were performed on tidal deposit soils (cf. chapter 3) and on some marine deposit soils (used in section 5.4).

This chapter is subdivided in two parts. First some soils will be discussed in detail (sections 5.2 and 5.3). Then a summary will be given of similar investigations, without discussing, however, in detail the soils themselves.

5.2 Observations

The soil improvement method referred to above has been called biological soil improvement by some authors (e.g. EDELMAN *et al.*, 1963). It was believed that the best way to demonstrate that biological activity in soils under grass orchard and pasture is higher than in soils under arable land, was to present some soils which were originally insufficiently drained. It will be shown that after improvement of soil drainage the soils under grass orchard and pasture were considerably improved by biological activity whereas the arable soils did not change much.

The selected soils have a relatively complex sedimentological construction. They consist of a vertical succession of lighter and heavier textured layers. From a larger number of investigations some soils were chosen with a light textured subsoil and some with a heavy subsoil.

First an arable soil with a light textured subsoil will be compared with a similar soil under grass mulch orchard. Then an arable soil with a heavily textured subsoil will be compared with similar soils under grass mulch orchard and under pasture.

5.2.1 Slijk-Ewijk soils P11 and P12

Two examples were chosen (cf. P11 and P12, Appendix II).

Soil P11 lies in a field which has long been used as grass orchard. At first cattle was grazing in this field, but for the last twenty years it has been grass mulched (cf. chapter 4). Grass is mown frequently in this field.

Soil P12 lies in a field which has been used as arable land for at least some decades. To this arable land little organic manure is applied and cereals and beets account for a considerable part of the crop rotation.

To answer the question whether these soils had originally similar properties, attention was paid to the soil textural trend and the soil drainage. A small difference in soil textural trend was observed. The highest and lowest groundwater level occur at similar depths in the two soils under consideration. Consequently it is believed that the observed differences in soil structural properties between soils P11 and P12 result from differences in soil management only.

Obvious differences in soil structural properties were found between soils P11 and P12. In the grass orchard soil (P11) a weak plate was observed which was subdivided into subangular blocky elements. Below this plate a layer followed with prismatic structures subdivided into holoedrical elements. The latter were intergrade types between subangular and angular blocky elements. With increasing depth they gradually change into angular blocky elements.

The arable soil (P12) shows from the surface downwards first a layer with distinct, small, angular blocky elements, followed by a layer with a relatively massive structure. This massive structure was described as a thick plate, characterized by a few shell-shaped pedfaces and distinct rootprints.

At a depth greater than 33 centimetres below the surface, structures show only minor differences in soils P11 and P12. At a greater depth in both soils a vertical succession was observed, consisting of physicogenic structures (cf. section 2.4, angular blocky and prismatic structures). These structures rest on a subsoil characterized by a stratified sedimentation structure which is partly disturbed.

Apart from differences in soil structural type, differences were noticed with regard to the biopore trends (cf. section 2.5) in the soils P11 and P12. In the tilled layer of soil P12 (arable land) only a fraction occurs of the number of biopores noticed in soil P11 (grass orchard) at the same depth. Below the plough sole the number of large earthworm burrows remains considerably lower than that in the soil under grass orchard. The number of small earthworm burrows at that depth, however, is about the same in the two soils under discussion.

A third difference in structural properties between soils P11 and P12 concerns the pore space in the surface soils. In the tilled layer of P12 pore space is 8–14% lower than in the surface soil of P11. Below the plough sole the differences in pore space between soils P11 and P12 are negligible.

5.2.2 Slijk-Ewijk soils P13, P14 and P15

From the soils with a heavily textured subsoil three examples were chosen, viz., P13, P14 and P15. Soil P13 is in the same field as P11 (grass orchard) and soil P14 is in the same field as P12 (arable land). Soil P15 is in a field which has been used as pasture for at least some decades.

The soils P13, P14 and P15 are discussed seperately from the soils P11 and P12, since they have a different geological construction. The heavily textured subsoil starts at a somewhat greater depth in soil P13 than in soils P14 and P15. Soil P13 originally was also somewhat better drained. Soil drainage was improved, however, to such an extent that it is believed that the differences in soil drainage did not cause the large differences in structural properties observed between soils P13, P14 and P15. Consequently the differences in structural properties between soils P13, P14 and P15 are considered as consequences of differences in soil management.

The following obvious differences in structural properties were noticed between the three soils under consideration. In the grass orchard soil (P13) a subangular blocky structure was observed which changed with increasing depth into an angular blocky structure.

The arable soil (P14) consists of an angular blocky structure which rests on a thick plate with shell-shaped pedfaces and distinct rootprints.

Near the soil surface of the pasture soil (P15) an angular blocky structure was observed which is part of a weakly developed compound platy structure. Below this plate a compound prismatic structure follows which consists of angular blocky elements again.

At a depth greater than 25 centimetres below the surface no basic differences in structural types were noticed in these soils with varying soil management. The three soils then show a succession of physicogenic structures (cf. section 2.4, angular blocky and prismatic structural elements).

The surface soils of P13, P14 and P15 also show large differences in pore space. In the arable soil P14 at a depth of 5–10 centimetres below the surface pore space is 14% lower than in the orchard soil P13 at the same depth. Pore space in the pasture soil P15 at that depth was 8% higher than in the arable soil. At a depth greater than 25 centimetres below the surface no systematic differences in pore space were observed.

The biopore trends also show considerable differences in the three soils under consideration. At every depth the arable soil P14 has a smaller number of biopores than soil P15 under pasture. This is true for both small and large biopores. The numbers of biopores at each depth and in both size classes (2–4 mm and larger than 4 mm) in the orchard soil, however, are much greater than those in the two other soils.

5.3 Interpretation

The above observations will be discussed against the background of two contrasting processes, viz., soil structure degeneration due to mechanical forces and soil structure regeneration due to biological activity.

5.3.1 Slijk-Ewijk soils P11 and P12

It was observed that, with exception of the subsoils, soils P11 and P12 are relatively heavily textured. They contain iron mottles from shallow depths downwards, but soil drainage was improved to such an extent that part of the mottling is fossile. These soils consist of physicogenic structures (with exception of the structures occurring in the surface soil of P11) which rest on geogenic structures. A small number of biopores was observed in soil P12 (arable land) and a large number in soil P11 (grass orchard). From these data it may be concluded that soils P11 and P12 had rather little biological activity in the beginning.

From the relatively large number of biopores observed in the soil under grass orchard (P11) and the fact that the structural elements near the soil surface show a trend to become more and more of the subangular blocky type, it may be concluded that biological activity increased substantially in soil P11 after improvement of soil drainage (cf. chapter 2 and 4). In the beginning soil drainage was so poor that, notwithstanding a good nutrition of the soil fauna, no intensive biological activity was able to develop (cf. chapters 2, 3 and 4). The improvement of soil drainage stimulated the biological activity, resulting in an intense perforation (formation of biopores by earthworms) and a rounding of the angular blocky structural elements in the surface soil. The increasing rounding of the structural elements in the surface soil of P11 is accompanied by an increase of pore space. This phenomenon which has also been discussed in chapter 4, is mainly due to the activity of the smaller earthworms which live and burrow in the surface soil.

In soil P12 (arable land), which has about the same textural trend as soil P11 (grass orchard) and a similar soil drainage, the number of biopores did not increase after improvement of soil drainage or only very little. Before improvement of soil drainage the activity of the earthworm fauna in soil P12 was inhibited by lack of food, by injury caused by soil tillage implements and by the shallow groundwater levels. Lack of food resulted from insufficient organic matter supply on the arable soil. The shallow groundwater levels prevented the soil animals from fleeing downwards into the subsoil in periods of severe cold. When the groundwater level was lowered, one inhibiting factor disappeared, the two others, however, remained, viz., the lack of food and the mechanical injury by soil tillage implements. According to STÖCKLI (1958) and to FINCK (1952) these are the reasons why in most arable soils, either well or imperfectly drained, only 10–25% of the number of earthworms occur which can be observed in pasture soils.

The relatively high numbers of biopores in the orchard soil (P11) and the presence of subangular blocky structures in the surface soil of P11 and the absence of both in the arable soil P12 reflect the difference in soil improvement of the same soil under different soil management. The difference in structural change has the following consequences. The intense perforation of soil P11 results in a much higher air and water permeability than in soil P12. The higher permeability prevents waterlogging and stimulates aeration, enabling plants to develop a deeper root system and soil animals to burrow deeper and more intense. The whole process gives rise to a further improvement of soil P11. In soil P12 little has changed up till now and little will change in future as long as it is under arable land.

Soil P11 is a fine example of biological soil improvement which only became possible after improvement of soil drainage. The improvement obtained is of much higher value than the improvement resulting from a lower groundwater level only. The latter condition was observed in soil P12, which has a lower groundwater level, but with the same unfavourable structural properties as before.

After discussing soil structure improvement of soil P11 and the absence of it in soil P12, the soil structure degeneration of soil P12 should be discussed. The latter is reflected by a relatively low pore space and by physically unfavourable structural types in the surface soil. The soil structure degeneration is a compaction which might be observed in many arable soils. It might be caused by driving with heavy machines over the soil when it is too moist or by tilling the soil under similar conditions. The factors which gave rise in each case to the unfavourable structural properties will not be discussed in detail. As stated in section 5.1 these factors have been extensively discussed in the literature. A further discussion of these factors was considered to be beyond the scope of our investigations. The process will be referred to as mechanical soil structure degeneration, designating the totality of factors which gave rise to unfavourable changes in structural properties of surface soils under arable land.

For the benefit of a later discussion (cf. section 5.4) it should be stressed that in soils P12 and P14 an extreme soil structure degeneration occurs, where the plough sole (cf. chapter 3) grew to a fully compacted tilled layer.

Finally it should be noted that the perforating activity of earthworms in soil P11, might also occur in well-drained arable soils (cf. P12) if the earthworms were provided with enough food and were not injured by soil tillage implements.

5.3.2 Slijk-Ewijk soils P13, P14 and P15

After the relatively extensive discussion in paragraph 5.2.2, below only a few additional remarks will be made on the observed differences in soil structure of the three soils under varying soil management under discussion.

From the observations it may be concluded that the soil structure improvement of soil P13 (heavy subsoil) under grass mulch orchard differs slightly from the structural improvement of soil P11 (light subsoil) under the same cultural practice. This uniform reaction to soil management of soils with heavily and light textured subsoils is not often observed. Differences in subsoil textures are usually accompanied by differences in the depth of the groundwater level. In the case under discussion the uniform reaction to soil management results from a substantial improvement of soil drainage in the two soils. It should be stressed that the soil drainage is improved by lowering the groundwater levels. If tile drains only had been used in each of the two soils under discussion, the soil drainage would have been improved more in the soil with a light textured subsoil than in that with a heavily textured subsoil.

The properties of the surface soils of the two arable soils (P12 and P14) appeared to differ very little. This is not surprising when it is realized that the soils are situated in the same field, that they were subject to the same soil management and have about the same texture in the surface soil. Consequently soil structure degeneration is the same in the two soils. Soil structure regeneration as result of biological activity is practically impossible in both soils. Lack of food and injury caused by soil tillage implements restrict the biological activity in both soils. The differences in subsoil texture do not play a part. This fact was observed in many cases. Soil structure degeneration in surface soils of arable soils was also found to be independant of subsoil structures and soil drainage.

The pasture soil P15 has properties which differ both from the properties of the arable soil (P14) and from those of the soil under grass mulch orchard (P13). The number of biopores was found to be intermediate between the numbers of the two other soils, as are also pore space and structural types of the surface soil. At a depth greater than 25 centimetres below the surface the pasture soil has about the same structural trend as the two other soils. The above data show that the biological activity in the pasture soil (P15) is lower than in the soil under grass mulch orchard (P13), but higher than in the soil under arable land (P14). Mechanical soil structure degeneration seems to be absent in soil P15. Since differences in soil drainage between soils P13 and

P15 are negligible, the difference in biological activity should be attributed to differences in nutrition of the earthworms. In the field where soil P13 is situated, the grass is frequently mown and the grass is spread as a mulch on the soil surface. The field is well dressed with fertilizers. Cattle graze in the field where soil P15 is situated and relatively small amounts of fertilizers are applied.

It can also be concluded that the differences in soil management of the soils P13 and P15 give rise to a substantial difference in the rate of soil improvement. Soil improvement in both soils started at the same moment, viz., when the groundwater level was lowered. The progress in soil improvement is obviously greater in soil P13 than in soil P15.

Finally, the following conclusions of more general character may be drawn from the observations.

Soil structure degeneration of arable soils is restricted to the surface soil. A similar phenomenon was observed in chapter 3. Soil structure improvement, as discussed above, embraces both changes in the surface and in the sub-surface soil, possibly even in the subsoil. In the beginning changes in structural type and an increase in soil porosity are restricted to the surface soil. But the increase in the number of biopores, had already been observed at a deeper level.

5.4 Observations on other soils and their interpretation

Arable land, pasture and orchard may be found in the Netherlands on various soils. The detailed investigations for this study were mainly restricted to river loam and river clay soils. Some detailed (cf. chapter 3) and many preliminary studies on other alluvial soils in the Netherlands revealed that the rules of soil structural changes, found in the fluviatile deposit soils, might also be valid for other alluvial soils. In this section a summary will be given of the results of investigations in various alluvial soils in the Netherlands, including fluviatile, estuary and marine soils. The conclusions are not as reliable as those resulting from the detailed investigations and they should be checked in future.

The remarks about the common properties of arable soils on clay and loam in the Netherlands should be preceded by two reservations.

The examples given, may be thought to give a rather too pessimistic view of the structural properties of these arable soils. In selecting soils for investigations, extreme examples were chosen rather than average ones. On the other hand it should be stressed that considerable soil structure degeneration in arable soils on clay and loam in the Netherlands can often be observed. It is easier to find such soils with compaction than soils without. A second reservation refers to the period of the year in which the investigations were performed. Owing to soil tillage the structural properties of the tilled layer change during the course of the year. Only a momentary picture is presented, viz., the condition at the end of the summer or in autumn. In the first place this minimized crop damage and secondly the structural properties which were investigated were most pronounced.

The properties investigated in these arable soils refer to the degree of soil structure degeneration of the tilled layer and to the absence of natural regenerating forces of the whole soil.

The soil structure degeneration generally manifests itself as a relative compaction of the tilled layer or of parts of it (plough sole). In the beginning the compaction was generally noticed in the plough sole only, i.e. in a thin layer at the bottom of the tilled layer.

In a light textured soil the structure of this thin layer is often impossible to distinguish in the field from the structure of the overlying and underlying layers. Pore space, however, was generally found to be lower. In heavier soils the above-mentioned band soon has an angular blocky structure contrasting to the structures of the overlying and underlying layers.

In a further stage of soil structure degeneration, the pore space of the tilled layer as a whole tends to become lower than that of the underlying layers. In light textured soils no aberrant structures, which can be distinguished as such in the field, need to be present. Such structures will be found in somewhat more heavily textured soils. The tilled layer then consists of less porous subangular blocky elements or already of angular blocky, prismatic or platy elements. As soil structure degeneration proceeds the angular blocky character increases and visual porosity decreases. The angular blocky elements gradually acquire shell-shaped faces and rootprints, and the roots will tend to grow along and not through the structural elements.

Extreme examples of soil structure degeneration in the tilled layer are presented by the descriptions of the relatively heavily textured soils P12 and P14. A thick compound plate was observed in these soils which showed only shell-shaped fissures. This platy element showed rootprints, a very low visible porosity, a low pore space and roots growing exclusively along the structural elements and not through them. These characteristics are often accompanied by blue-black reduction mottles around dead roots and undecayed organic manure.

The rate at which soil structure degeneration proceeds may be fairly high, as will be demonstrated with the following example. In a former grass mulch orchard, used one year as arable land, and which formerly had very favourable structures, soil structure degeneration was already visible. After 7 years a compacted plough sole was present.

Soil structure regeneration is generally absent in arable soils on clay and loam in the Netherlands. If present at all, it is too weak to prevent soil structure degeneration. The fact that the biological activity which should result in soil structure regeneration is small, can be demonstrated by the low numbers of biopores in arable soils. Lack of food and injury caused by soil tillage implements are assumed to be the causes of the low biological activity and consequently of the low soil structure regenerating capacity of arable soils (cf. STÖCKLI, 1958; FINCK, 1952).

It has been observed that highly degenerated soil structures resulting from arable land practice can be regenerated by means of high biological activity. In well-drained soils under grass mulch orchard such structures are found to disappear in a few years, but in imperfectly drained soils they were sometimes noticed twenty years after land had ceased to be used as arable land.

It is rather difficult to give a summary of structural properties of clay and loam soils under pasture and orchard, since these cultural practices include a large number of variants such as grass orchard with cattle grazing, grass orchard with grass mulching, clean cultivated orchard, pasture with cattle grazing and pasture with haymaking. The structural properties of clay and loam soils under pasture and orchard range from those observed in the grass mulch orchard where soil P7 is situated to those observed in the arable soils P12 and P14. The former soil had a high pore space in the surface soil which gradually decreased with increasing depth, a relatively high number of biopores and subangular and spongy structures up to a great depth. The latter soils are characterized by a compacted surface soil with low pore space, few biopores and physicogenic structures.

The most favourable structures are to be found in well-drained soils under grass mulch orchard. They resemble those of soil P7. Less favourable structures, however, may also be observed in grass-mulched orchards. They may be due to several factors, such as imperfect soil drainage, the fact that grass is not frequently mown and the presence of certain poisonous compounds on the soil surface and driving of machines through the orchard.

If the soil under grass mulch orchard, for instance, is more imperfectly drained, less favourable structural properties will be observed than in soil P7. There is less pore space and there are less biopores; the subangular blocky and spongy structures will change at a shallower depth into angular blocky, prismatic or stratified sedimentation structures.

Remnants of poisonous compounds, such as copper oxychloride and Bordeaux mixture used to control plant diseases may kill many earthworms, resulting in the formation of a mat of undigested grass on the surface of the soil (cf. HIRST, LERICHE and BASCOMB, 1961). It is believed that the modern method of spraying such compounds causes less harm than the older methods, since less spraying material now falls on the soil surface.

Driving with heavy machines over the soil surface in the orchard causes compaction of the surface soil. It may be observed in many orchards. The characteristics resemble those observed in arable soils. In orchards, however, it only occurs under paths used for driving.

The soil under clean cultivated orchard usually has less favourable properties than that under grass mulched orchard. No grass is supplied to the soil animals and soil tillage is applied. Consequently biological activity is less intense and there is mechanical soil structure degeneration. In extreme cases soil structure under clean cultivated orchard is not much better than under arable land.

The structural properties of soils under grass orchard with cattle grazing may resemble the properties under grass mulch orchard. Mechanical soil structure degeneration due to soil tillage is absent. The organic matter influx may be at the same level as in the grass-mulched orchard.

The properties of soils under pasture with cattle grazing or haymaking are less favourable than those under grass orchard. The difference is not due to a difference in soil management in the first place, but to a selection of soils for various cultural practices. In general, soils used for pasture are more or less imperfectly drained, resulting in a low biological activity. It was observed that if a pasture soil is well-drained, the structural properties are almost as good as in grassorchard soils. Apart from soil drainage a lower organic matter influx is believed to cause a lower biological activity. In pastures with haymaking, moreover, the severe desiccation during summer seems to be harmful.

5.5 Summary and discussion

The investigations reported above were started on the following considerations:

(i) soil structure degeneration is one of the factors that reduce crop yield increase on arable soils.

(ii) fields formerly used as grass orchard tend to produce very high crop yields.

(iii) grass orchard soils and pasture soils are said to have more favourable structural properties than arable soils.

The purpose of the investigations reported in this chapter was to collect information on the differences in soil structural properties of clay and loam soils under arable land, orchard and pasture for the purpose of soil improvement.

The investigations were restricted to some young alluvial soils mainly situated in the central part of the Netherlands. The observations showed that arable soils generally have surface soils with unfavourable structural properties. These properties were said to be due to mechanical soil structure degeneration and the absence of sufficient biological activity which should regenerate soil structure. The cause of the low biological activity was said to be lack of food for the soil animals and injury caused to the animals by soil tillage implements.

It was also shown that in general soil structural properties in the surface soil of grass orchards and pastures were better than in arable soils. Mechanical soil structure degeneration under grass orchards is restricted to the paths where tractors are driven. In pastures it was generally found that the soil structure degeneration is fairly slight. If the grass orchard is well-drained a high biological activity may develop because of a high organic matter influx and the absence of injury to earthworms caused by soil tillage. In pasture soils biological activity is generally lower because of more or less imperfect soil drainage.

With the use of some soils which were formerly insufficiently drained, but where groundwater levels were substantially lowered, it was shown that soils under grass mulch orchard and under pasture acquire favourable soil structural properties sooner than in arable soils.

From the above data the following conclusions may be drawn which are of importance for the use and improvement of soils of the types under consideration.

(i) It was shown that improvement of soil drainage alone, does not improve soil structure. Soil structure improvement is enabled by lowering the groundwater level, but not effected by this, but by biological activity. The soil animals, however, can only improve the soil structure, provided that the soil is well-drained and they receive a good nutrition. Hence the conditions for soil structure improvement are better under grass orchard or pasture than under arable land.

(ii) Following the above-mentioned principles it should be possible to improve compacted soil structures resulting from arable land practices, provided the soils in which they occur are well-drained. Probably it might be more suitable to use the former arable land field for some years as pasture than as grass mulch orchard. The use of grass mulches during part of the year in such pastures will probably accelerate the improvement.

(iii) Finally it should be noted that from the point of view of soil structure conservation when planting a new orchard the system of grass mulch orchard is preferable to that of the clean cultivated orchard.

6 Soil morphology and soil survey

6.1 Introduction

6.1.1 Soil survey

In chapter 2 some physical and morphological characteristics were discussed together with methods to study them. In chapters 3, 4 and 5 the occurrence of the above-mentioned physical and morphological characteristics were discussed in relation to the mode of formation of the soil in which they occur and in relation to the applied cultural practices. By means of the used methods it was possible to compare and to collect soils which have a similar response to soil management. Some important conclusions could be drawn concerning soil suitability and soil improvement. The used methods, however, were very timeconsuming. Since soil survey is interested to group soils which have a similar response to soil management, it was thought worthwhile to simplify the methods, used in the foregoing chapters, in such a way that these methods can be used in the future for soil survey purposes.

In this chapter a demonstration will be given of the incorporation of the working methods of the foregoing chapters in soil survey work. Two detailed soil surveys will be discussed. In each of the main mapping units a pit was described and sampled in the way discussed in the foregoing chapters. Before discussing the results of the two soil surveys, one paragraph will be dedicated to a survey of the methods used in the foregoing chapters in order to simplify them for soil survey work.

6.1.2 Classification of biopores

The morphological and physical characteristics discussed in chapter 2 and used in chapters 3, 4 and 5 are only partly applicable in the field. It is the purpose of this paragraph to decide which of the above mentioned characteristics are directly applicable in soil survey work.

None of the soil physical methods can directly be used in the field. In chapter 2 the following morphological characteristics were discussed, viz., macro-structure and its trend in the soil, biological homogenization, perforation and the number of biopores and the disturbance of stratified sedimentation structures.

Macro-structure can be described in the field according to the scheme of JONGERIUS

(1957). Special attention should be paid to the difference between biogenic, physicogenic and geogenic structures (cf. section 2.4).

Further the soil structural trend may be described according to one of the three types defined in section 2.6, viz.,

type (1) biogenic on geogenic structures
type (2) physicogenic on geogenic structures
type (3) combinations of type (1) and (2).

In type (1) a surface soil of less than 30 centimetres may be present with physicogenic structures, caused by soil tillage. In type (2) a surface soil of less than 30 centimetres may be present with biogenic structures, caused by shallow biological activity.

As described in section 2.5 the depth and intensity of biological homogenization cannot be defined in the field. For the classification of the stages of homogenization many timeconsuming laboratory data are required.

Observations about the disturbance of stratified sedimentation structures are possible in some soils, in many other soils, however, not. If possible the depth of the undisturbed subsoil should be reported and the depth where the first traces of undisturbed stratification are observed. As stated in section 2.5 roots usually do not penetrate into stratified layers. The main reason is that biopores are absent in stratified sedimentation structures. This means that the counting of the numbers of biopores at different depth levels in the soil is essentially more important than observations about the stratification.

Therefore in this paragraph attention will only be paid to biopores, in particular to their recognition in the field and to their classification.

Several groups of biopores have been discussed in the foregoing chapters, viz., the biopores larger than 200 microns, occurring in sandy soils and the biopores larger than 2 mm occurring in heavier textured soils. Biopores of the former group were counted on soil peels by means of stereo-microscope with a magnification of 50 times, biopores of the latter group were counted in the field. It was found recently that it is possible to count all biopores with diametres exceeding 200 microns in the field. The accuracy of the countings increases as the diameter of biopores increases. The smaller biopores (up to 2 mm) can be counted by means of the naked eye or by means of a handglass with a magnification up to 10 times in undisturbed soil fragments taken from the soil profile wall. Their abundance is expressed in numbers per square centimetre. The biopores larger than 2 mm are counted in horizontal sections of 20 × 25 cm cut in the soil profile wall. Till now their abundance was expressed in numbers per square metre (cf. section 2.5). We suggest to express the abundance of the biopores larger than 2 mm in numbers per square decimetre. It was found that for biopores smaller than 2 mm a surface area of at least 5 sq. centimetre should be counted at each depth level in order to obtain reproduceable results. This value is 5 sq. decimetre for biopores larger than 2 mm.

The following tentative names are suggested for the size classes of biopores:

Size class in mm	*Name*
<1	very fine
1–2	moderately fine
2–4	moderately large
>4	very large

It was found that in sandy soils, biopores usually are smaller than 1 mm. In heavier textured soils biopores in all size classes may occur. The size class subdivision has been based upon the existing classification of biopores (cf. HOEKSEMA and OP 'T HOF, 1960; section 2.5). It has been completed with a class smaller than 1 mm for the biopores occurring in sandy soils. The lower limit of very fine biopores was found to be about 30 microns and the upper limit of the very large biopores was found to be about 1 centimetre.

The following tentative abundance classes are suggested. For biopores smaller than 2 mm (fine biopores):

Abundance in numbers per cm²	*Name*
0–5	few
5–10	common
10–15	many
>15	abundant

For biopores larger than 2 mm (large biopores)

Abundance in numbers per dm²	*Name*
0–2	few
2–5	common
5–10	many
>10	abundant

The abundance classification has been based on experience with some 60 sandy soils and some 150 heavier textured soils in the Netherlands. The highest abundance class (abundant) has been defined in such a way that it corresponds with numbers of biopores per surface unit which are rarely found in the Netherlands. The groupname 'many' has been used for numbers of biopores occurring in soils where conditions are presumed to be or to have been favourable to form many biopores. The groupname 'few' has been used for numbers of biopores in soils where conditions are presumed to be or to have been unfavourable to form many biopores.

In very detailed profile descriptions, for each soil horizon each size class of biopores may be described with its abundance. Usually it will be satisfactory, however, to present only two size classes (fine and large biopores) with their abundance. More details may be given then with the detailed description of soil structure. The following suggestions are given for the adaption of the detailed description of soil structure.

Behind the soil structural type code a combination of 4 arabic numerals is given which from left to right indicate the abundance of very fine, moderately fine, moderately large and very large biopores .To present an example: A4a 1243 IV ½ means in this conception: very weak, fine, subangular blocky, with few very fine, common moderately fine, abundant moderately large and many very large biopores (cf. Appendix I for the code of soil structure).

6.2 Soil survey and additional investigations of some river deposit soils

The first soil survey which will be discussed in this chapter is a detailed soil survey of 50 hectares of soils in the holocene river deposit area of the central part of the Netherlands (Betuwe, Opheusden). The results are presented on a 1 : 10.700 scale map in fig. 4.

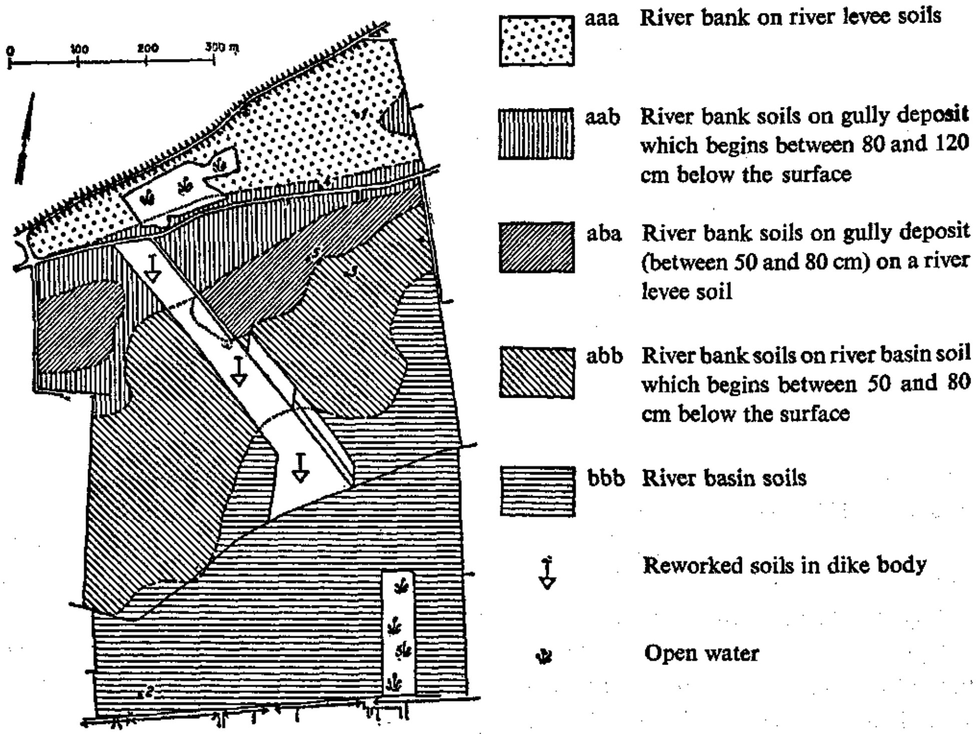


Fig. 4. Soil map of the investigated Opheusden area. Arabic numbers refer to situation of profile pits. Approx. scale 1 : 10.700

The observations have been performed by means of a spade and an auger of 1.20 m length. Small soil profile pits up to a depth of about 50 centimetres, have been dug (cf. section 2.6) while the deeper parts of the soils were studied by means of a soil auger. The observation points were arranged in a grid with intervals of 50 metres. Additional observations have been made where necessary. Some twenty augerings have been done up to about 4 metres. Some deep profile pits have been studied morphologically and physically. The observations totalled 200.

The area was selected for investigations because of the small number of soil types which occur here with very divergent soil properties.

6.2.1 Mapping legend, hydrology and land use

The mapping legend has mainly been based on textural trends. In the area under consideration, with minor exceptions, only two classes of soil texture occur, viz., sandy clay loam and loam on the one hand and clay on the other. The first textural class has been called *a*, the second textural class *b*. A threefold notation was given for each soil, showing from left to right the textural class of the layers between 0 and 50, 50 and 80 and 80 and 120 cm.

Consequently the relatively light textured soils in the North were labelled *aaa*, the heavily textured soils in the South *bbb*. According to this scheme the light textured soils in the centre of the surveyed area which contained between 50 and 80 cm below the surface a heavily textured layer, were called *aba*.

The hydrological conditions have changed in this area in the course of years. A gradual lowering of the groundwater levels, resulting from the lowering of the water level in the river Rhine, was followed during the last decade by a sharp lowering of the groundwater levels, resulting from the river Linge improvement.

The actual hydrological conditions may be characterized as follows. The northern part of the area in particular has been drained much better than before (mapping units *aaa* and *aab*). The area of mapping unit *aba* and of part of mapping unit *abb* were originally already better drained than the areas of the other types because of their higher topography. The southern part of the type *abb* and the area of type *bbb*, periodically suffer from excess of water.

Artificial drainage by means of tile drains has not been found in this area; the land, however, is drained by open drains (ditches). Moreover the area is protected by dikes against flooding.

The differences in land use more or less correspond to differences in hydrological conditions and to the differences in soil conditions. The northern part of the area is used as orchard, tree nursery or arable land. The central part of the area is used as orchard or tree nursery. More to the south pasture appears, while in the southern basinclay area only pasture occurs.

6.2.2 Results of morphological and physical investigations

Five soil profiles were investigated in detail in this area. They are assumed to be representative of the mapping units in which they are situated. The location of the profile pits is indicated on the soil map (fig. 4) by arabic numerals. The soil profile descriptions follow below. To enable the reader to compare the analytical data, they are reproduced graphically in figures 5 to 8.

Profile descriptions

Opheusden 1

Location: N 439.125 — E 173.050 (Betuwe, Opheusden)
Land use: grass mulch orchard
Parent material: Holocene river deposit (Rhine), (sandy clay) loam, river bank deposit on river levee deposit
Hydrology: moderately well-drained
Classification: Normaqueptic Eutrochrept (7TH APPROXIMATION, 1964)

PROFILE DESCRIPTION

A11,	0– 15 cm	10 YR 3.5/1.5, moist; sandy clay loam; granular on subangular blocky; common to many fine and few large biopores; friable; diffuse and smooth on
A12,	15– 60 cm	10YR 3.5/2.5, moist; sandy clay loam; compound prismatic subdivided into subangular blocky; common fine and few large biopores; friable to firm; diffuse and smooth on
B2,	60–110 cm	10YR 4.5/1.5, moist; clay loam; compound prismatic subdivided into subangular blocky on sponge; common fine and common to few large biopores; slightly sticky and non plastic; common, fine, distinct, strong brown and black mottles; diffuse and smooth on
B3g,	110–160 cm	2.5Y 5/1, moist on wet; clay loam on sandy clay loam; sponge structure; many fine and few or no large biopores; sticky and slightly plastic; many, medium, prominent strong brown and black mottles.

DETAILED DESCRIPTION OF SOIL STRUCTURE AND BIOPORES

A11, 0–5 cm, A3a 3311 II 3
A11, 5–15 cm, A4a 2211 II–III 2½
A12, B2, 15–110 cm, B3a III–IV 1/A4a 2211 III 1½
B3g, 110–160 cm, G1b

The structural trend is of type (1)
Biopore trends of large biopores: cf. fig. 5
Analytical data: cf. fig. 7
pF and soil-water-air-ratios: cf. fig. 8

Opheusden 2

Location: N 438.225 — E 172. 875 (Betuwe, Opheusden)
Land use: pasture
Parent material: holocene river deposit (Rhine), clay, river basin deposit
Hydrology: poorly drained
Classification: Humic Normaquept (7TH APPROXIMATION, 1964)

PROFILE DESCRIPTION

A1,	0– 42 cm	10YR 3.5/1.5, moist; clay; granular on compound prismatic subdivided into angular blocky; few fine and large biopores; friable on very firm; few, fine, faint, strong brown mottles; clear and wavy on
IIA1g,	42– 58 cm	2.5Y 3.5/1, moist; clay; single prisms and angular blocky elements; few fine and large biopores; very firm; few, fine, faint, strong brown mottles; gradual and wavy on
IIB2g	58– 97 cm	2.5Y 4.5/1, moist; clay; angular blocky; few fine and few or no large biopores; sticky and plastic; many, medium, prominent, strong brown mottles; diffuse and smooth on
IIIA1g,	97–120 cm	2.5Y 4/0, wet; clay; angular blocky; few fine and no large biopores; very sticky and very plastic; common, faint, medium, yellowish brown mottles.

DETAILED DESCRIPTION OF SOIL STRUCTURE AND BIOPORES

A11, 0–3 cm, A3 2211 II 3
A12, 3–42 cm, B3a III–IV 2/A5a 1111 III 2½
IIA1g, 42–58 cm, B5c 1111 III 2½ + A5a 1111 IV 1
IIB2g, 58–97 cm, A5a 1100 IV 2½ → ½
IIIA1g, 97–120 cm, A5a 1100 III ½

The structural trend is of type (2)
Trends of large biopores: cf. fig. 5
Analytical data: cf. fig. 7
pF and soil-water-air ratios: cf. fig. 8

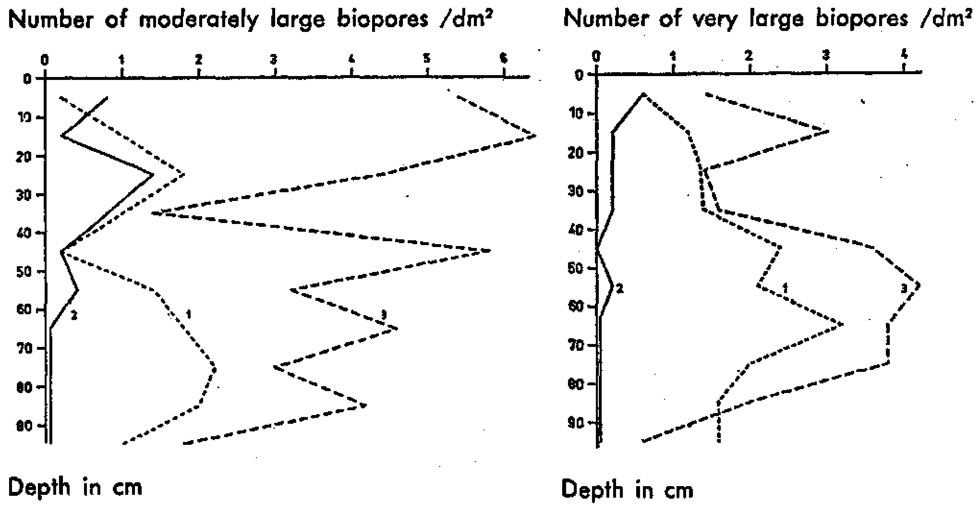


Fig. 5. Trends of large biopores of soils Opheusden 1, 2 and 3

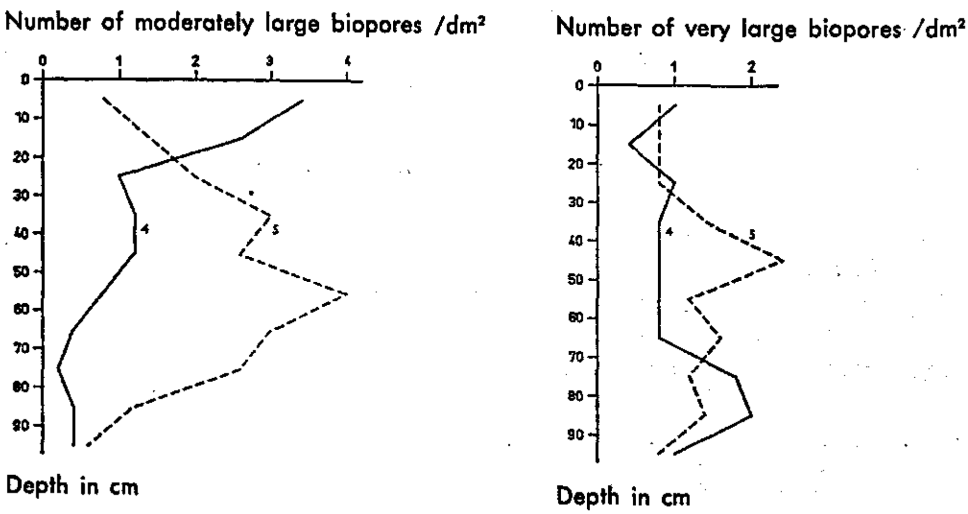


Fig. 6. Trends of large biopores of soils Opheusden 4 and 5

Opheusden 3

Location: N 438.875 — E 173.075 (Betuwe, Opheusden)
Land use: grass mulch orchard
Parent material: holocene river deposit (Rhine), (sandy) clay loam on clay, river bank deposit on river basin deposit
Hydrology: moderately well-drained
Classification: Normaqueptic Eutrochrept (7TH APPROXIMATION, 1964)

PROFILE DESCRIPTION

A11,	0– 30 cm	10YR 3.5/3, moist; (sandy) clay loam; granular on subangular blocky; common fine and large biopores; firm; diffuse and smooth on
A12,	30– 50 cm	10YR 4/2.5, moist; sandy clay loam; subangular blocky; common fine and large biopores; friable; many, medium, distinct, strong brown and black mottles; gradual and smooth on
B2,	50– 65 cm	10YR 4.5/2, moist; clay loam; subangular blocky; common fine and large biopores; friable to firm; many, medium, distinct, strong brown and black mottles; gradual and smooth on
IIB2,	65–110 cm	10YR 5/2.5, wet; clay; compound prismatic subdivided into angular blocky; common fine and large biopores; sticky and plastic; common, fine, faint, brown and black mottles; gradual and smooth on
IIIA1g,	110–115 cm	2.5Y 4/0, wet; clay; compound prismatic subdivided into angular blocky; few fine and no large biopores; very sticky and very plastic; common, fine, faint, brown and black mottles.

DETAILED DESCRIPTION OF SOIL STRUCTURE AND BIOPORES

A11, 0–5 cm, A4a 2231 II 3
A11, 5–30 cm, A4a 2222 IV 2½
A12, B2, 30–65 cm, A4a 2222 III 2½
IIB2, 65–110 cm, B3a III 2/A5a 2222 III–IV 2½
IIIA1g, 110–115 cm, B3a III 3/A5a 1100 IV ½

The structural trend is of type (3)
Trends of large biopores: cf. fig. 5
Analytical data: cf. fig. 7
pF and soil-water-air-ratios: cf. fig. 8

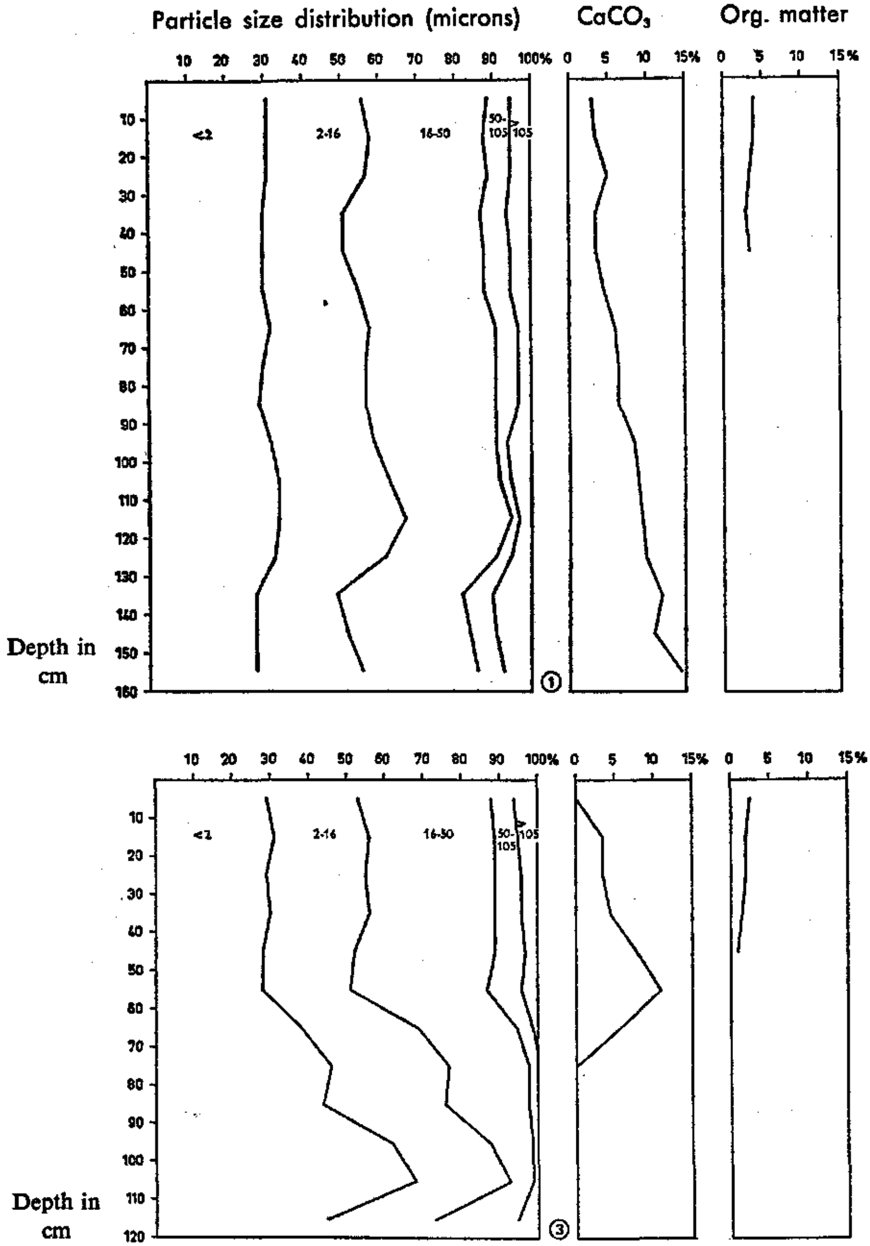
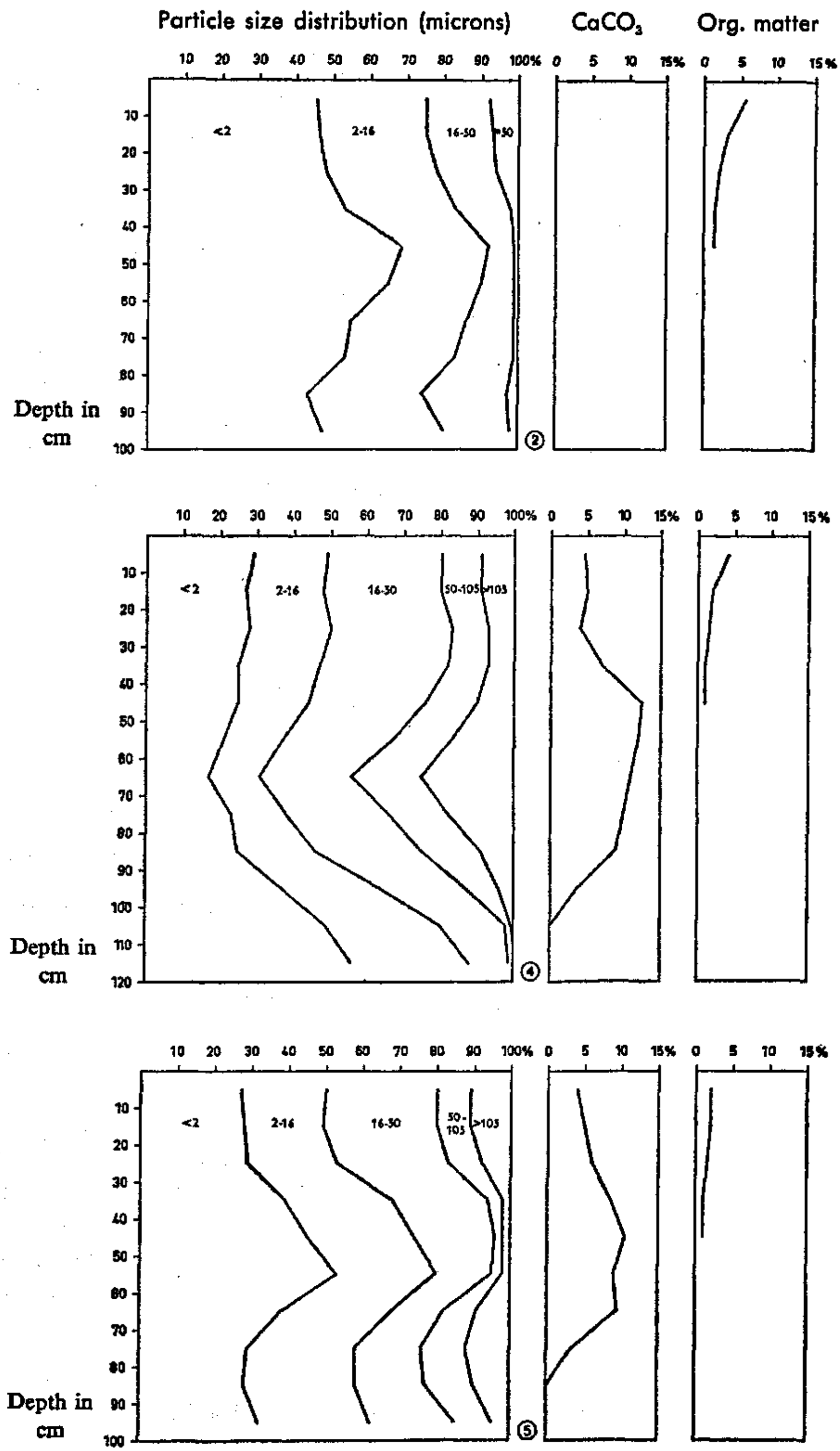


Fig. 7. Trends of soil texture, of calcium carbonate and organic matter content of soils Opheusden 1, 2, 3, 4 and 5. Particle size distribution in cumulative weight % of fraction <2000 micron



Particle size distribution (microns)
CaCO$_3$
Org. matter
Depth in cm
<2
2-16
16-50
>50
2-16
16-50
50-105
>105
②
④
⑤

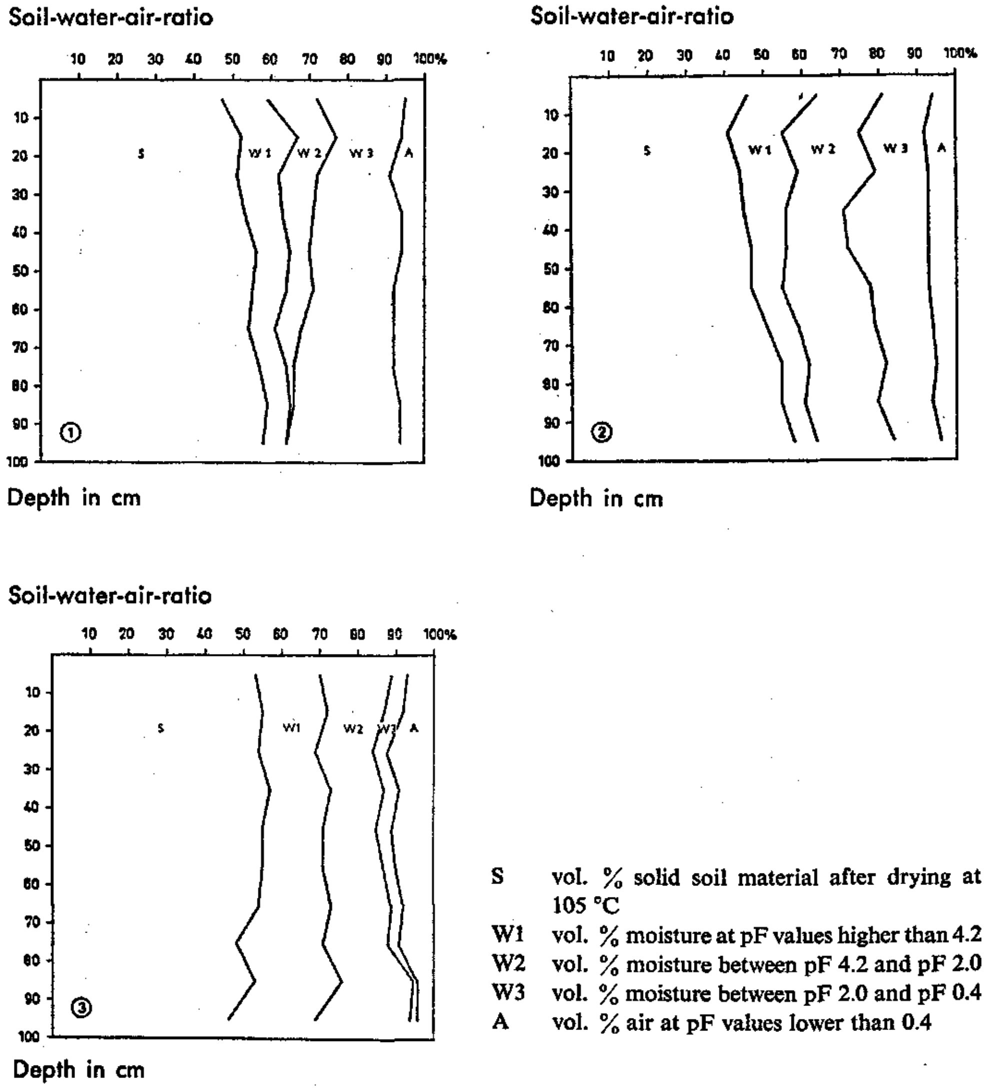


Fig. 8. Trends of soil-water-air-ratios at various pF-values of soils Opheusden 1, 2 and 3. Cumulative volume % of soil volume at pF 2.0

Opheusden 4

Location: N 439.025 — E 173.025 (Betuwe, Opheusden)
Land use: grass orchard with cattle grazing
Parent material: holocene river deposit (Rhine), sandy clay loam on clay, river bank deposit on streambed deposit
Hydrology: somewhat imperfectly drained
Classification: *Normaqueptic Eutrochrept* (7TH APPROXIMATION, 1964)

PROFILE DESCRIPTION

A1,	0– 16 cm	10YR 3.5/3, moist; sandy clay loam; compound platy subdivided into granular on subangular blocky; common to few fine and large biopores; friable to firm; clear and wavy on
B1,	16– 30 cm	10YR 4.5/4, moist; sandy clay loam; compound prismatic subdivided into subangular blocky; common fine and few large biopores; friable; gradual and smooth on
B2,	30– 53 cm	10YR 5/3, moist; sandy clay loam; subangular blocky; common fine and few large biopores; very friable; clear and wavy on
IIB2,	53– 70 cm	10YR 4.5/2, moist; sandy loam; sponge; many fine and few large biopores; very friable; common, medium, prominent, black and common, medium, very faint, yellowish brown mottles; clear and wavy on
IIIB2g,	70–100 cm	2.5Y 4/2, moist; (sandy) clay loam; subangular blocky; common fine and few large biopores; slightly sticky, non plastic; common, fine, distinct, yellowish brown and black mottles; clear and smooth on
IVA1g,	+ 100 cm	2.5Y 3/0, moist; clay; prismatic; few fine and no large biopores; sticky and plastic.

DETAILED DESCRIPTION OF SOIL STRUCTURE AND BIOPORES

A11, 0–2 cm, C2 V 1/A3a 2221 II 1½
A12, 2–16 cm, C2 V 1/A4a 1121 III–IV 1½
B1, 16–30 cm, B3a III 1/A4a 2211 III 2½
B2, 30–53 cm, A4a 2211 III 2½
IIB2, 53–70 cm, G1b
IIIB2g, 70–100 cm, A4a 2211 III 1½
IV A1g, + 100 cm, B5a 1100 IV ½

The structural trend is of type (3)
Trends of large biopores: cf. fig. 6
Analytical data: cf. fig. 7

Opheusden 5

Location: N 438.900 — E 173.010 (Betuwe, Opheusden)
Land use: tree nursery
Parent material: holocene river deposit, (Rhine), sandy clay loam on clay on sandy clay loam, river bank deposit on river streambed deposit on river levee deposit.
Hydrology: moderately well-drained
Classification: Typic Normaquept (7TH APPROXIMATION, 1964)

PROFILE DESCRIPTION

Ap1,	0–16 cm	10YR 4/3, moist; sandy clay loam; few fine and large biopores; angular blocky; friable on firm; clear and smooth on
Ap2,	16–30 cm	10YR 4/2, moist; sandy clay loam; subangular blocky; common fine and few to common large biopores; friable to firm; common, fine, faint, black mottles; abrupt and wavy on
B2,	30–40 cm	10YR 5/3, moist; clay loam; subangular blocky; common fine and few to common large biopores; friable; common, fine, faint, black mottles; gradual and smooth on
IIB2g,	40–56 cm	2.5Y 5/1, moist; clay; compound prismatic subdivided into subangular blocky; common fine and large biopores; common, fine, faint, black mottles; gradual and smooth on
IIIA1g,	56–67 cm	2,5Y 3/0, moist; single prisms; clay; sticky and plastic; common fine and common to few large biopores; few, fine, faint, black mottles and many, fine, faint, yellowish brown mottles; gradual and smooth on
IVB2g,	67–100 cm	10YR 5/0, moist; sandy clay loam; sponge structure; many fine and few large biopores; slightly sticky and slightly plastic; few, fine, faint, black mottles and many, fine, faint, yellowish brown mottles.

DETAILED DESCRIPTION OF SOIL STRUCTURE AND BIOPORES

Ap11, 0–5 cm, A5a 1111 II–III 2½
Ap12, 5–16 cm, A5a 1111 IV 2
Ap2, 16–30 cm, A4a 2221 III 1½
B2, 30–40 cm, A4a 2221 IV ½
IIB2g, 40–56 cm, B3a III 3/A4a 2222 IV 2½
III A1g, 56–67 cm, B5a 2221 III 3
IV B2g, 67–100 cm, G1b

The soil structural trend is of type (3)
Trends of large biopores: cf. fig. 6
Analytical data: cf. fig. 7

The results of the morphological and physical investigations of samples of the five above-mentioned soils led to the following comments.

The textural trend of soil Opheusden 1 (cf. fig. 7) evidently shows that this soil is not a regular river levee soil. The textures would become lighter with increasing depth in that case. A deep biological homogenization is also out of question (cf. section 2.5), because of the past excess of water in this soil. Moreover stratified subsoil structures which generally occur in river levee soils, are absent to a depth of over 1.60 m in soil Opheusden 1. It is assumed to be a river bank soil which rests on a river levee soil. EDELMAN *et al.* (1950), labelled such soils as crevasse deposits resting on river levee soils. PONS (1953) stated that the covering deposit probably does not originate from a dike-burst, but from a levee which was broken. According to the latter author such soils should consequently be labelled as river bank deposits resting on river levee soils.

It is also striking that the texture of the surface soil of the soil types which bear the river bank deposit (cf. fig. 4) is similar within narrow limits (cf. fig. 7).
A close correlation has been noticed in this area between the soil macro-structures and the textural classes of the parent material. Apart from the structures occurring in the surface soil which structures have been influenced by the soil management, it appeared that the main structural types correspond to different soil textural classes. Those structures, for instance, which have been called biogenic (cf. section 2.4) only occur in the relatively light textured river bank and river levee soils. The physicogenic structures (cf. section 2.4), however, have only been noticed in the heavily textured basin clay and streambed material. Stratified subsoil structures have not been noticed in this area.

The correlation between the occurrence of the two main types of soil structure on the one hand and the soil textural classes on the other is so close that each soil textural trend might be replaced by a standard soil structural trend (cf. section 2.6).

The close correlation in this area between soil structural type and soil texture means (cf. profile descriptions Opheusden 1–5) that the numbers of fine biopores are also correlated with the differences in soil texture. It was found that, apart from the numbers of biopores occurring in the surface soils, in the biogenic structures in the studied soils common to many fine biopores occur. In the physicogenic structures, however, only few fine biopores occur. The observation means that from the soil map (cf. fig. 4) important data about the root potentialities can be derived.

The trends of the biopores larger than 2 mm (cf. figures 5 and 6) do not show much correlation with differences in soil texture. Soil Opheusden 2 shows a low number of large biopores, because of the poor drainage in this soil in the past and in the present. Soils Opheusden 1 and 4 show a fairly low biopore trend because of their relatively poor drainage, which has only quite recently been improved in such a way that biological activity may increase. Notwithstanding the differences in soil texture between soil Opheusden 2 on the one hand and soils Opheusden 1 and 4 on the other, the differences in the trend of the larger biopores are relatively small. The reason is the insufficient soil drainage of the three soils under consideration.

Soils Opheusden 3 and 5 are better drained than the other three soils. Still there is a substantial difference in biopore trend of the earthworm burrows larger than 2 mm between soils Opheusden 3 and 5. Soil Opheusden 3 has a soil management which stimulates the biological activity, while in soil Opheusden 5 both lack of food and the presence of mechanical injury to earthworms restrict their activity.

Concerning the results of the pF- and soil-water-air-ratio determinations (cf. fig. 8), performed on samples of three of the five soils, the following remarks should be made.

The accumulated amounts of moisture between pF 2.0 and pF 4.2 over a depth of 1 metre, only differ very slightly. The differences in the trends of the biopores smaller than 1 mm in the different Opheusden soils raise the expectation that after lowering of the groundwater levels in the soils under consideration large differences in depth of root development will occur. Then also large differences will be found in the amounts of plant available water over the rooted zone.

Important differences have been found in the volume percentages of air present at pF 2.0. As stated in chapter 2 (cf. section 2.2) BUTIJN (1961) assumed that an air percentage of 10 at pF 2.0 was required for roots of fruit trees to enter a soil layer. In the soils investigated it seemed that in the basin clay less than 10% gaseous phase at pF 2.0 occurs, whereas the lighter textured river bank and river levee material contained more than 10%. This observation has a more general meaning since it is supported by some tens of determinations on similar samples which all showed the same result.

6.2.3 Geogenesis

The soil map (cf. fig. 4) shows that the mapping units are arranged in a West-East direction. The collected data gave rise to the following hypothesis on the genesis of the area investigated. In the North, near the river dike (of the river Rhine), a strip with relatively light textured soils occur (type *aaa*). They are river levee soils which were covered by a river bank deposit (cf. EDELMAN *et al.*, 1950; PONS, 1953). South of it lies a strip of type *aab*. This is a former river bed which was originally filled up with fairly heavy clay and which was in turn covered by the above-mentioned river bank deposit.

Surrounded by the mapping unit *aab* and south of it, are two remnants of the former levee of the above-mentioned river bed (type *aba*). The subsoil of this type consists of river levee material which was covered by a fairly heavy clay which was again covered by the above-mentioned river bank deposit. More to the South a river basin deposit follows which was also covered by the river bank deposit (type *abb*). Finally in the most southern part of the area a basin clay follows which was not covered with the river bank deposit.

The dike, which intersects the area from NW to SE and which is said to date from the 16th century, contains soils which are man-made.

6.3 Discussion

It has been stated that the relatively light textured soils contain biogenic structures with 'common' or more fine biopores. It has also been stated that the heavily textured soils contain physicogenic structures with 'few' fine biopores. Exceptions were found in the surface horizons of all soils investigated in the Opheusden area.

The abundance of the large biopores was found to vary much. In general, however, few large biopores occurred, due to the more or less insufficient drainage of the soils in the area under consideration.

Finally it has been stated that root penetration in the heavily textured soils is difficult since these soils contain less than 10% of gaseous phase at fieldcapacity, resulting in lack of oxygen or excess of carbondioxide at fieldcapacity.

The above data give rise to the following remarks. The soils in the area under consideration are mainly used for two cultural practices, viz., the soils with less than 50 cm river bank deposit on basin clay as pasture and the other soils for horticulture. Horticulture here comprises cultivation of cherries, apples, pears, plums and black and red currants. Moreover part of the land is used for tree nursery. The plants cultivated in the above-mentioned branches of horticulture develop a deep root system. This means that they demand a soil in which they can develop a deep root system. The Opheusden soils, as they are now, do not permit plants to develop a deep root system, since they are insufficiently drained. The first step towards soil improvement in this area should be lowering of the groundwater levels.

After lowering the groundwater levels some soils in this area will become well-suited for deep rooting crops, others, however, not. The soils of the mapping unit *aaa* (cf. fig. 4) which have fine biopores till at least 1.50 m and no stratification within that depth, will be well-suited for deep rooting crops. The soils of the mapping units *aab* and *aba* are less suited although they may improve much by means of grass mulching applied after lowering the groundwater levels (cf. chapters 4 and 5). The soils of the mapping units *abb* and *bbb* will be more or less unsuited after lowering of the groundwater levels for deep rooting crops. The heavily textured subsoils of the latter two groups of soils are either too wet or too dry. It should be stressed that for deep rooting crops only those soils should be improved by lowering the groundwater levels which are either relatively light textured or those which have a light textured subsoil and only finally those which have a deeper subsoil which is heavily textured.

The above remarks on the Opheusden soils have a more general meaning if it is realized that many soils in the Netherlands which are used for cultivating deep rooting crops, are insufficiently drained. For deep rooting crops primarily those soils should be selected which enable these crops to develop a deep root system. In case of soil improvement for those crops, primarily those soils should be improved which acquire after being improved, good root potentialities. In terms of soil drainage and abundance of biopores this means that firstly those soils should be selected which are well-drained and contain many biopores till great depth. In the second place those soils should be selected in which larger numbers of biopores become available after lowering the groundwater level (cf. soils of the mapping unit *aaa*, cf. fig. 4). Finally those soils should be selected in which a considerable increase of the number of biopores is to be expected after lowering the groundwater level.

It is evident that the above remarks on soil suitability are mainly based on the abundance of biopores. Using the concept of biopores more information can be collected for soil suitability than by means of the conventional items used in profile descriptions hitherto. That is why we suggest to use in soil survey work the concept of biopores.

It is because of the great importance of biopores for soil suitability that the presented mapping legend was chosen for the soil map of the Opheusden area. Knowing the relation in this area between soil texture and the abundance of fine biopores, it is possible to read directly from the soil map which soils will be suited for deep rooting crops after improvement of soil drainage in this area.

It might be questioned whether a survey of the actual root system in a soil profile wall does not give enough information about the root potentialities. It is true that roots, if they are present are the best indicators for root potentialities. In many cases, however, roots are not present or the root system is not at its maximum development when the soil is investigated. Moreover different crops have different root systems. In insufficiently drained soils, finally the root system does not indicate much about root potentialities; the biopores, however, do.

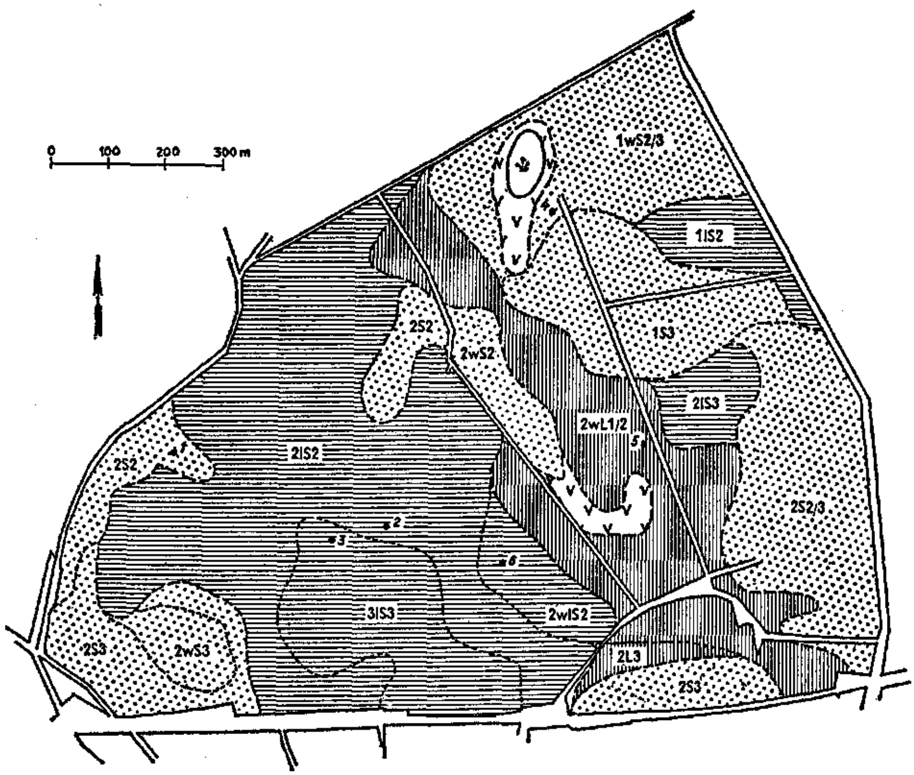
6.4 Soil survey and additional investigations of some sandy soils

The second soil survey which will be discussed in this chapter concerns a detailed soil survey of 100 hectares of soils in the pleistocene sandy area in the Northeast of the Netherlands (Province of Drente, municipality of Rolde). The result of this soil survey is reproduced on a 1 : 13.300 mapping scale in fig. 9.

This soil survey was performed by means of profile pits up to a depth of about 50 cm and soil augerings in these pits up to a depth of 1.20 m. The observation points were arranged in a grid with intervals of 100 m. Additional observations were made where necessary. The total number of observations was about 250.

This area was selected for investigation because a small number of soil types occur here on a small surface area. Moreover the soil types showed quite different soil properties.

Fig. 9. Soil map of the investigated Rolde area. Arabic numbers refer to situation of profile pits. Approx. scale 1 : 13.300



	S	Excessively drained sandy soils
	wS	Imperfectly drained sandy soils
	2S2	Old arable soil (*Plaggen soil*), thick epipedon, solum 60–90 cm
	2S3	Old arable soil (*Plaggen soil*), thick epipedon, solum >90 cm
	2S2/3	Soil complex of 2S2 and 2S3
	1S3	Arable soil, thin epipedon, solum >90 cm
	2wS3	Old arable soil (*Plaggen soil*), thick epipedon, solum <90 cm
	2wS2	Old arable soil (*Plaggen soil*), thick epipedon, solum 60–90 cm
	1wS2/3	*Umbraquept*, thin epipedon, solum 60–120 cm
	lS	Somewhat excessively drained loamy sandy soils
	wlS	Somewhat imperfectly drained loamy sandy soils
	1lS2	Arable soil, thin epipedon, solum 60–90 cm
	2lS2	Old arable soil (*Plaggen soil*), thick epipedon, solum 60–90 cm
	2lS3	Old arable soil (*Plaggen soil*), thick epipedon, solum >90 cm
	3lS3	Old arable soil (*Plaggen soil*), very thick epipedon, solum >90 cm
	2wlS2	Old arable soil (*Plaggen soil*), thick epipedon, solum 60–90 cm
	L	Somewhat imperfectly drained sand on loam soils
	wL	Imperfectly drained sand on loam soils
	2L3	Old arable soil (*Plaggen soil*), thick epipedon heavily textured subsoil beginning between 90 and 120 cm
	2wL1/2	Old arable soil (*Plaggen soil*), thick epipedon, heavily textured subsoil beginning between 30 and 90 cm
	M	Soils with a cover of 30 to 60 cm of muck
		Open water

6.4.1 Mapping legend, hydrology and land use

The soil map (fig. 9) shows three main soils, viz., the sandy soils (S), the slightly loamy sandy soils (1S) and the loamy soils (L). Each of these soils has been subdivided into a dry or moist and into a wet phase. The wet phases are characterized by 'characteristics associated with wetness' (7th Approximation, 1960), occurring within 50 to 75 cm below the surface. These soils are indicated on the soil map (cf. fig. 9) by means of a 'w' before the main symbol. At the right and the left side of each symbol, given on the soil map, an arabic numeral will be found. The left hand numeral indicates the thickness in centimetres of the Ap or A1 horizon in three classes, viz., 1. 0–30; 2. 30–60; 3. 60–90 cm. The right hand numeral indicates the depth at which the C-horizon begins in three classes, viz., 1. between 30 and 60; 2. between 60 and 90; 3. deeper than 90 cm below the surface.

Soils with a cover of 30 to 60 cm. of muck were indicated on the soil map (cf. fig. 9) with the symbol M.

The hydrological conditions in this area changed in the course of time. A very gradual lowering of the groundwater levels has taken place. The present hydrological conditions may be characterized as follows. The dry sandy soils (S) periodically contend with a lack of water. The wet sandy soils (wS) periodically suffer of an excess of water. The slightly loamy sandy soils (lS) are well-drained to somewhat excessively drained. The wet loamy sandy soils (wlS) have some excess of water in the winter and spring. The loamy soils (L and wL) are characterized by a low water permeability, resulting in a periodical excess of water.

Artificial drainage by means of tile drains has not been observed in the Rolde area. The wet soils in this area are usually drained by open drains (ditches).

The land use has more or less been adapted to the soil conditions and to the hydrological conditions. The dry sandy soils are used as arable land for the growth of crops which do not demand much water (here mainly rye and potatoes). The wet sandy soils are mostly used as pasture. The loamy sandy soils are all under arable land. A relatively large variety of crops are grown there (e.g. barley, oats, beets and potatoes). Part of the loamy soils are used as arable land. Here crops are grown which need much water, e.g. wheat and beets. Another part of the loamy soils lies under pasture. Only a small part of the area is woodland.

6.4.2 Results of the morphological and physical investigations

Six soil profiles have been described and sampled in the investigated Rolde area. The location of the profile pits has been indicated on the soil map (cf. fig. 9) by means of arabic numerals. The profile descriptions follow below.

The analytical data are presented graphically (cf. figures 10 to 13).

Profile descriptions

Rolde 1

Location: N 557.075 — E 239. 210 (Drente, Rolde)
Land use: arable land.
Hydrology: (somewhat) excessively drained
Parent material: young cover sand, loamy sand on sand, Würm glaciation.
Classification: Plaggept (7TH APPROXIMATION, 1964)

PROFILE DESCRIPTION

Ap1,	0– 20 cm	10YR 2.5/1.5, moist; loamy sand; few very fine biopores; very friable to loose; clear and smooth on
Ap2,	20– 54 cm	7.5YR 2.5/1.5, dry; loamy sand on sand; few very fine biopores; very friable; clear and smooth on
B2hb,	54– 62 cm	5YR 2.5/2, dry; sand; common very fine biopores; slightly hard; gradual and smooth on
B2b,	62– 80 cm	7.5YR 3.5/2, dry; sand; common to few very fine biopores; slightly hard; diffuse and smooth on
B31b,	80–125 cm	10YR 5/6, dry; with humus fibers of 5YR 3/2, dry; sand; few very fine biopores; very friable; diffuse and smooth on
B32b,	+ 125 cm	10YR 7/4, dry; sand; few to no very fine biopores; loose.

Trends of the very fine biopores: cf. fig. 10
Analytical data: cf. fig. 11
pF and soil-water-air-ratios: cf. fig. 12

Rolde 2

Location: N 556.920 — E 239.670 (Drente, Rolde)
Land use: arable land
Parent material: old cover sand on glacial till, sandy loam on gravelly sand; Würm on Riss Glaciation
Hydrology: somewhat excessively drained
Classification: Plaggic Normorthod (7TH APPROXIMATION, 1964)

PROFILE DESCRIPTION

Ap1,	0– 20 cm	10YR 3.5/1, dry; sandy loam; common very fine biopores; very friable; clear and smooth on
Ap2,	20– 32 cm	10YR 3/1, dry; sandy loam; few very fine biopores; friable; clear and wavy on

B21b,	32– 55 cm	10YR 3.5/3, dry; sandy loam; many to abundant very fine biopores; friable; diffuse and smooth on
B22b,	55– 73 cm	10YR 4.5/4, dry; gravelly sandy loam; common very fine biopores; friable; diffuse and smooth on
IIB23b,	73– 85 cm	2.5Y 7/4, dry; gravelly loamy sand; common to few very fine biopores; very friable; clear and irregular on
IIIB3b,	85–90/100 cm	2.5Y 7/4, dry; sand; loose; few very fine biopores; clear and wavy on
IIICb,	+ 90/100 cm	2.5Y 7/5, dry; sand; few to no very fine biopores; loose.

Trends of very fine biopores: cf. fig. 10
Analytical data: cf. fig. 11
pF and soil-water-air-ratios: cf. fig. 12
Water permeability: cf. fig. 13

Rolde 3

Location: N 556.850 — E 239.640 (Drente, Rolde)
Land use: arable land
Parent material: old cover sand on glacial till; loamy sand on gravelly sand; Würm on Riss glaciation
Hydrology: somewhat excessively drained
Classification: Plaggept (7TH APPROXIMATION, 1964)

PROFILE DESCRIPTION

Ap1,	0– 20 cm	10YR 4.5/1, dry; loamy sand; few very fine biopores; very friable; clear and smooth on
Ap2,	20– 40 cm	10YR 4.5/1.5, dry; loamy sand; few to common very fine biopores; friable; clear and smooth on
Ap3,	40– 59 cm	10YR 5/2, dry; loamy sand; common very fine biopores; friable; gradual and wavy on
B1b,	59– 68 cm	10YR 4/1.5, dry; loamy sand; many very fine biopores; friable; gradual and wavy on
IIB2b,	68– 84 cm	10YR 4.5/3, dry; slightly gravelly loamy sand; abundant very fine biopores; friable; diffuse and smooth on
IIB3b,	84–130 cm	10YR 6/4 → 10YR 7/3, dry; gravelly sand; many to common very fine biopores; loose; clear and wavy on
IICb,	+ 130 cm	10YR 7.5/3, dry; with fibers of iron coated sand with colour 7.5YR 6/7, dry; slightly gravelly sand; common to few very fine biopores; slightly hard.

Trends of very fine biopores: cf. fig. 10
Analytical data: cf. fig. 11
pF and soil-water-air-ratios: cf. fig. 12

Rolde 4

Location: N 557.550 — E 240.030 (Drente, Rolde)
Land use: arable land
Parent material: colluvium of cover sands and prae moraine sand; loamy sand on sand; Würm glaciation on older deposits
Hydrology: imperfectly drained
Classification: *Normaquod* (7TH APPROXIMATION, 1964)

PROFILE DESCRIPTION

Ap,	0– 19 cm	10YR 3.5/1, dry; loamy sand; common very fine biopores; friable; abrupt and smooth on
A2g,	19– 38 cm	10YR 6/1, dry; loamy sand; few very fine biopores; friable; gradual and smooth on
IIB1g,	38– 47 cm	7.5YR 5/2 → 7.5YR 3/3, dry; loamy sand; few very fine biopores; compact and hard; clear and wavy on
IIB21g,	47–57/68 cm	7.5YR 3.5/3, dry; loamy sand; few to no very fine biopores; very compact and hard; clear and smooth on
IIB22g,	+57/68 cm	7.5YR 5/4, dry; with humusfibers of 7.5YR 3.5/3, dry; sand; no very fine biopores; compact and slightly hard.

Trends of very fine biopores: cf. fig. 10
Analytical data: cf. fig. 11
pF and soil-water-air-ratios: cf. fig. 12
Water permeability: cf. fig. 13

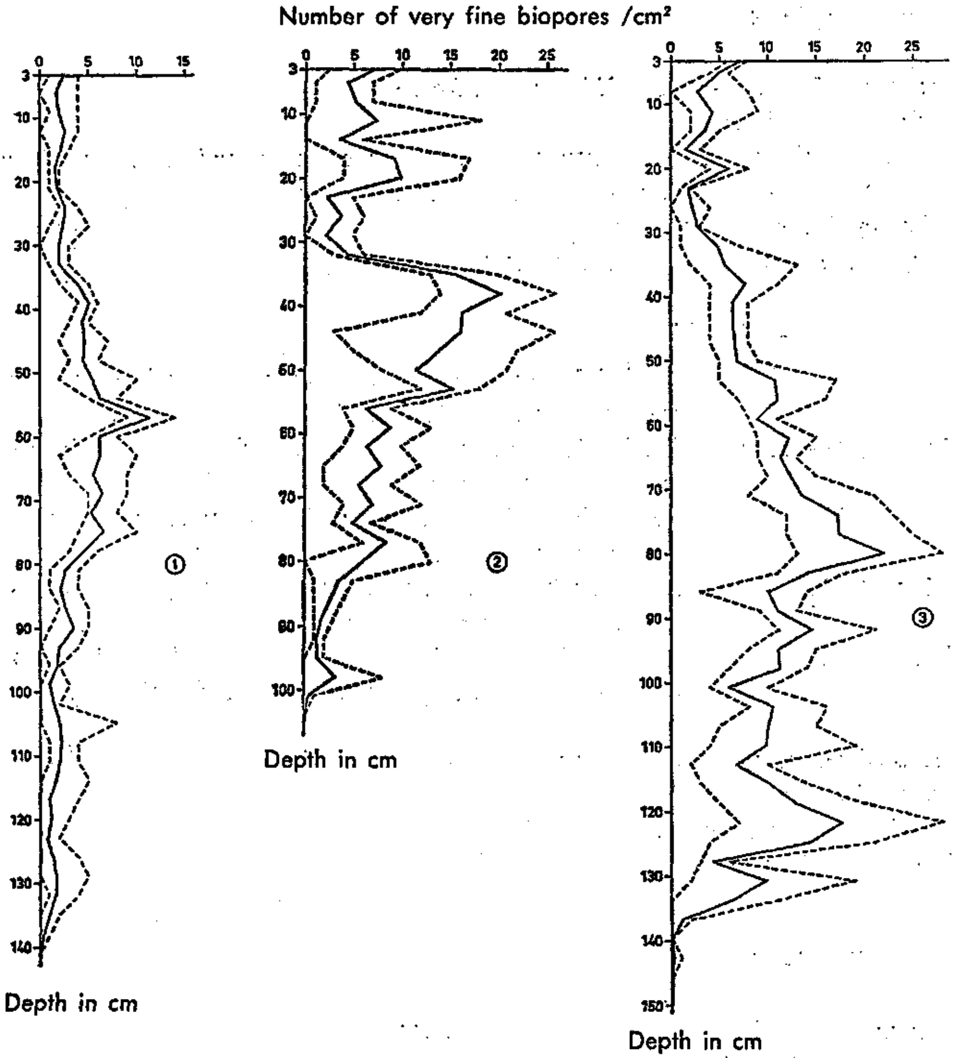
Rolde 5

Location: N 557.100 — E 240.180 (Drente, Rolde)
Land use: arable land
Parent material: old cover sand on glacial till; sandy loam on silty clay loam; Würm Glaciation on Riss Glaciation
Hydrology: somewhat imperfectly drained
Classification: *Typic Humaquept* (7TH APPROXIMATION, 1964)

PROFILE DESCRIPTION

Ap1,	0–20 cm	10YR 5/1, dry; sandy loam; few very fine biopores; friable; clear and smooth on
Ap2,	20–35 cm	10YR 5/1, dry; sandy loam; few very fine biopores; friable; common, fine, faint, yellowish brown mottles; gradual and irregular on

(continued on page 86)


Number of very fine biopores /cm²
Depth in cm
Depth in cm
Depth in cm
①
②
③

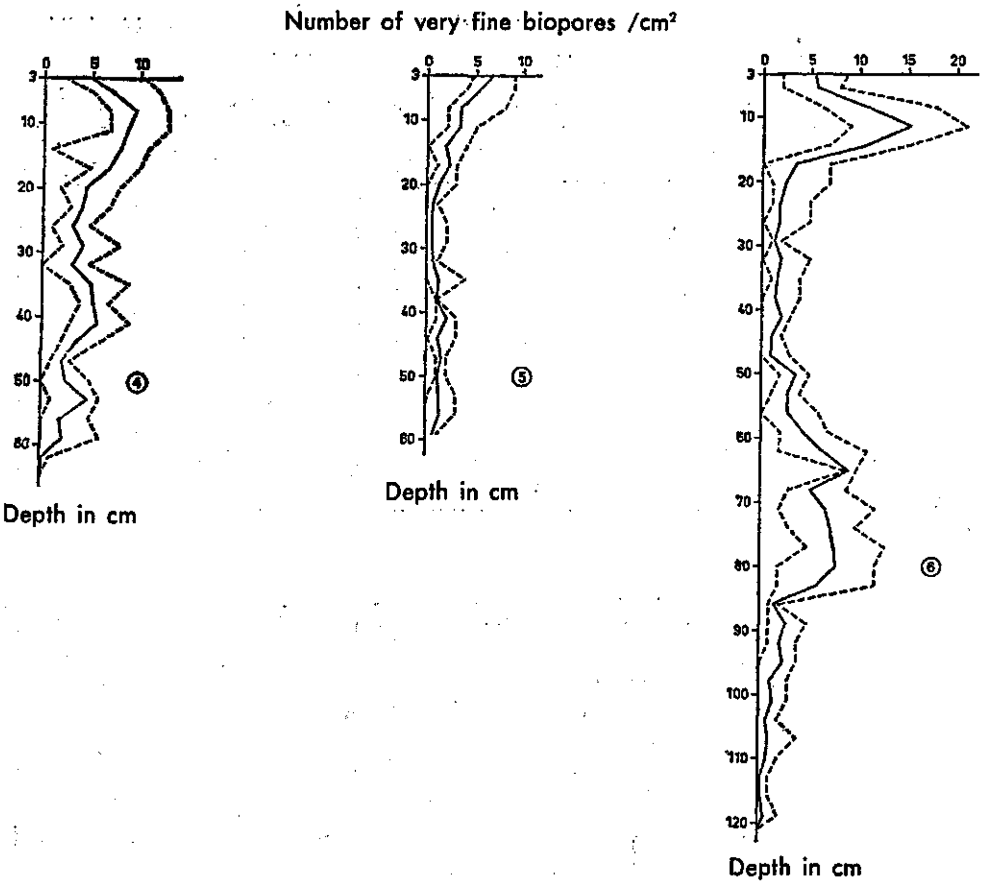
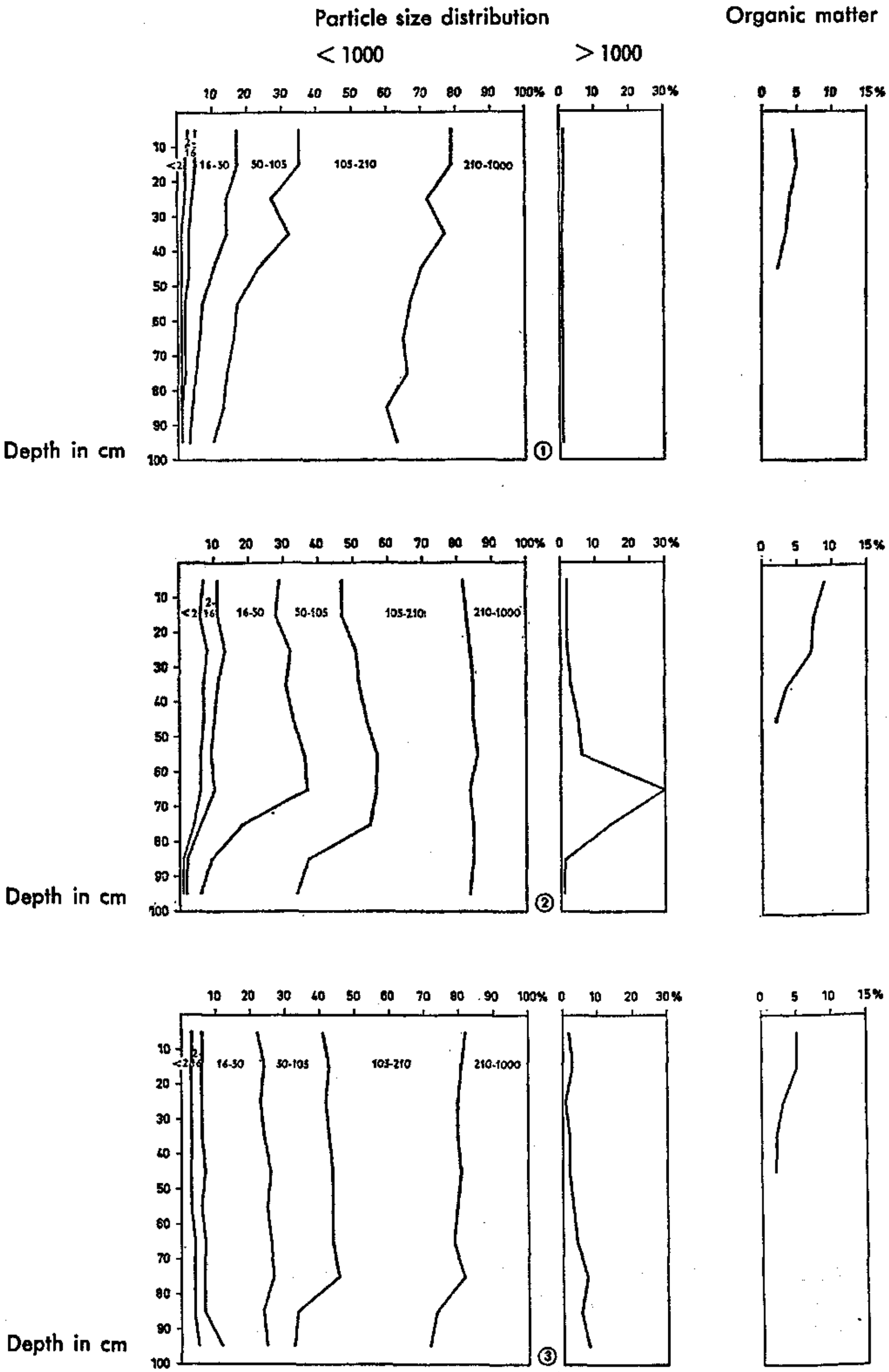


Fig. 10. Biopore trend and spread of soils Rolde 1, 2, 3, 4, 5 and 6. The solid line connects the arithmetic averages of a set of five observations at one depth level. The dotted lines on both sides of the averages connect the extreme values observed in each set of five observations (cf. VAN DER PLAS and SLAGER, *1964)*



Particle size distribution
Organic matter
< 1000
> 1000
10 20 30 40 50 60 70 80 90 100%
0 10 20 30%
0 5 10 15%
<2
2-16
16-50
50-105
105-210
210-1000
10 20 30 40 50 60 70 80 90 100
Depth in cm
①
②
③

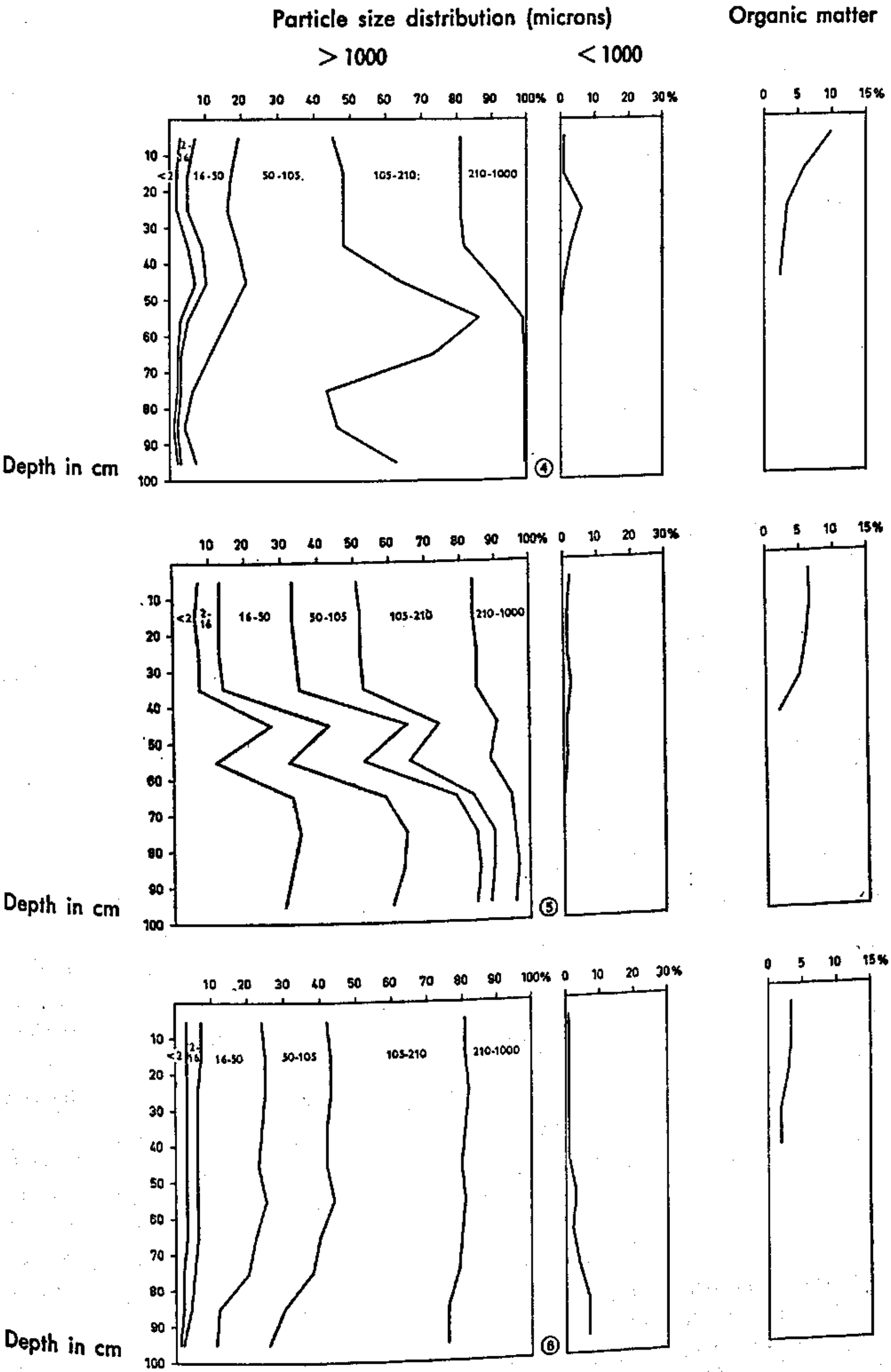


Fig. 11. Trends of soil texture and organic matter of soils Rolde 1, 2, 3, 4, 5 and 6. Particle size distribution of fractions <1000 micron in cum. wt. %. Fractions >1000 micron in wt. % of fractions <1000 micron

(continued from page 81)

IIA1gb, 35–55 cm	10YR 6/2, moist; loam; few very fine biopores; slightly sticky and slightly plastic; compound prismatic subdivided into subangular blocky to angular blocky structural elements; many, fine, distinct, reddish yellow mottles; gradual and wavy on
IIB2gb, 55–80 cm	10YR 7.5/2, moist; clay loam; few very fine biopores; prismatic; sticky and plastic; many, medium, prominent, reddish yellow mottles.

Trends of the very fine biopores: cf. fig. 10
Analytical data: cf. fig. 11
pF and soil-water-air-ratios: cf. fig. 12
Water permeability: cf. fig. 13

Rolde 6

Location: N 556.900 — E 239.950 (Drente, Rolde)
Land use: arable land
Parent material: old cover sand on glacial till; loamy sand on sand; Würm on Riss Glaciation
Hydrology: well drained
Classification: Plaggept (7TH APPROXIMATION, 1964)

PROFILE DESCRIPTION

Ap1,	0– 25 cm	10YR 4.5/1, dry; loamy sand; many to few very fine biopores friable; abrupt and smooth on
Ap2,	25– 50 cm	10YR 5/2, dry; loamy sand; few very fine biopores; friable; clear and smooth on
A3b,	50–68/80 cm	10YR 4.5/2, dry; loamy sand; few to common very fine biopores; friable; clear and wavy on
IIB2b,	68/80–81 cm	10YR 7/6, dry; slightly gravelly loamy sand; common very fine biopores; slightly hard; gradual and smooth on
IICb,	81–104 cm	10YR 7/4, dry; gravelly sand; few very fine biopores; slightly hard; many, coarse, prominent, strong brown mottles.

Trends of very fine biopores: cf. fig. 10
Analytical data: cf. fig. 11
pF and soil-water-air-ratios: cf. fig. 12
Water permeability: cf. fig. 13

The above-mentioned results of the morphological and physical investigations give rise to the following remarks.

The textural trends (cf. fig. 11) show some characteristic differences. In Rolde soil 1 the fractions smaller than 105 microns decrease rapidly with increasing depth, while gravel is absent in the subsoil. In the Rolde soils 2, 3 and 6, the fractions smaller than 105 microns decrease at a deeper level, the decrease being accompanied by an increase of the gravelly fraction. Soil Rolde 4 shows in the top of the profile the same trend as Rolde soils 2, 3 and 6 and at a greater depth the fraction larger than 210 microns is absent. The top of the soil Rolde 5 has about the same composition as the top of the Rolde soil 2. Between 40 and 60 cm below the surface, however, a transitional layer follows, while at 60 cm below the surface a relatively heavily textured layer follows.

The differences between certain particle size-distributions were found difficult to observe in the field. The differences between some sandy and some slightly loamy sandy materials gave special difficulties. When it was impossible to differentiate on basis of differences in soil texture, differences in soil development were used as a second differential criterion. In the above-mentioned case these developments were one which resembles a *Humod* and one which resembles an *Orthopsammentic Dystrochrept* (cf. 7TH APPROXIMATION, 1960).

The trends of the biopores larger than 200 microns (cf. fig. 10) (cf. VAN DER PLAS and SLAGER, 1964 and SLAGER, 1964) may be grouped according to three types, viz.,

(i) a relatively low number of biopores which continues till a relatively great depth.

(ii) a relatively high number of biopores which continues till a relatively great depth.

(iii) a relatively low number of biopores which continues till a shallow depth.

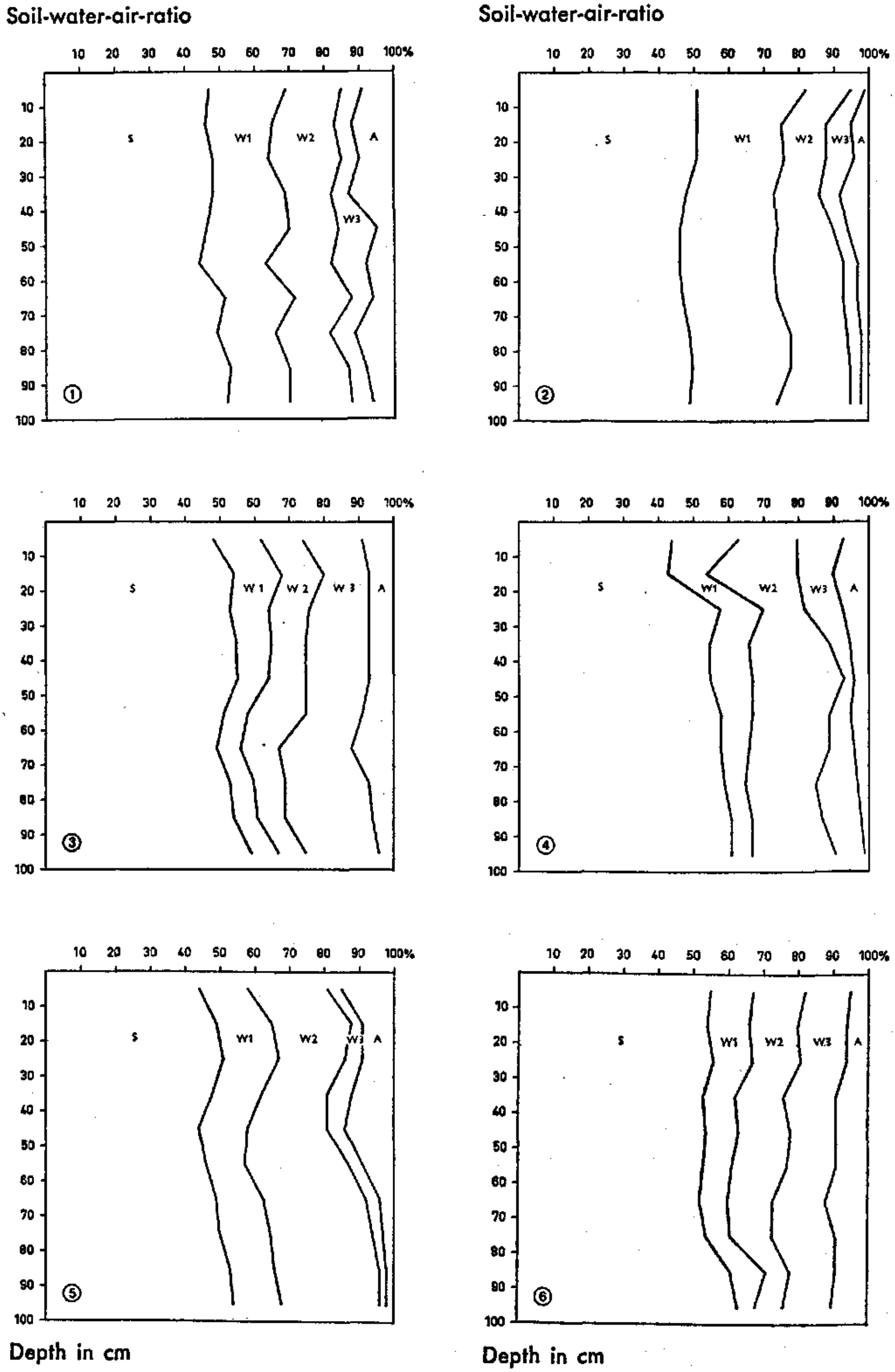
The biopore trends of the Rolde soils 1 and 6 belong to the first type. Rolde 1 contains a small number of biopores larger than 200 microns because of lack of moisture, Rolde 6 on the other hand shows a small number of biopores because this soil was relatively wet in the past.

The biopore trends of the soils Rolde 4 and 5 belong to the third type. The low numbers of biopores in these soils result of periodical excess of moisture.

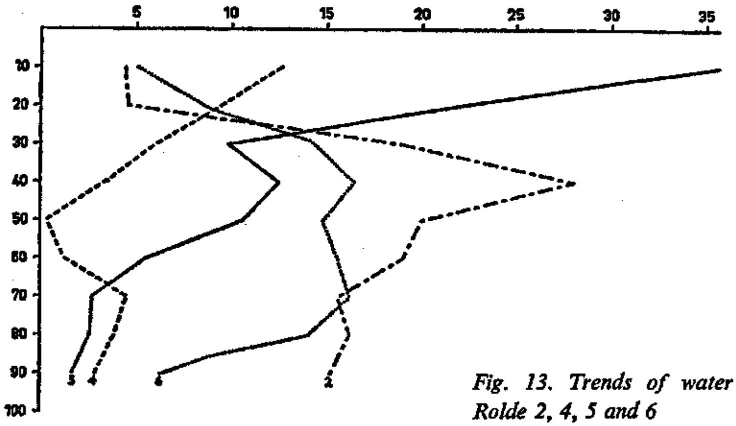
The biopore trends of the soils Rolde 2 and 3 belong to the second type. The high numbers of biopores larger than 200 microns result from a combination of a good drainage and a good water retentivity.

pF and soil-water-air-ratio determinations have been performed on samples of the six soils of the Rolde sequence (cf. fig. 12). From these determinations it was found that only certain parts of the soils Rolde 4 and 5 contain less than 10% by volume of gaseous phase at pF 2.0. In soil Rolde 4 this phenomenon may be correlated with the occurrence of compact fine sand which compactness is very noticeable in the field (cf. profile description Rolde 4). In soil Rolde 5 the same phenomenon is to be correlated with the presence of a compact heavily textured glacial till.

The accumulated amounts of moisture present between pF 2.0 and pF 4.2 in the


Soil-water-air-ratio
Soil-water-air-ratio
10 20 30 40 50 60 70 80 90 100%
10 20 30 40 50 60 70 80 90 100
S
W1
W2
W3
A
①
②
③
④
⑤
⑥
Depth in cm
Depth in cm

Water permeability in cm/h



Depth in cm

Fig. 13. Trends of water permeability of soils Rolde 2, 4, 5 and 6

layer between 0 and 100 cm below the surface and the accumulated amounts of moisture between pF 2.0 and pF 4.2 over the zone which may be penetrated by roots have been presented in the following table.

It may be concluded from this table that the moisture reserve of soil Rolde 1 is small. Additional supply by means of capillary rise is not possible in this soil. The moisture reserve of the soils Rolde 4 and 5 over the rooted zone is also small. Additional supply by means of capillary rise should not be ignored, however, in these soils. The soils Rolde 2, 3 and 6 have about the same moisture reserve over the rootable zone and an additional supply by means of capillary rise is improbable.

Soil	*Rootable zone in cm*	*mm/metre*	*mm/rootable zone*
Rolde 1	100	64	64
Rolde 2	95	139	134
Rolde 3	140	110	142
Rolde 4	47	212	98
Rolde 5	55	242	96
Rolde 6	100	129	129

Fig. 12. Trends of soil-water-air-ratios at various pF values of soils Rolde 1, 2, 3, 4, 5 and 6. Cumulative vol. % of soil volume at pF 2.0

S vol. % of solid soil material after drying at 105 °C
W1 vol. % of moisture at pF values higher than pF 4.2
W2 vol. % of moisture between pF 4.2 and pF 2.0
W3 vol. % of moisture between pF 2.0 and pF 0.4
A vol. % of air at pF values lower than 0.4

Finally investigations have been performed about the water permeability of saturated undisturbed samples of four of the six soils under consideration (cf. fig. 13).

The results show that the water permeability of the Rolde soils 4 and 5 decreases with increasing depth. It may be correlated with an increasing compaction which has been observed in the field. In the Rolde soils 2 and 6 water permeability first increases with increasing depth. These data correspond to the biopore trends of the same soils.

6.4.3 Geogenesis

The following hypothesis on the geogenesis of the investigated area is partly derived from the following publications: DE ROO (1952), EDELMAN and MAARLEVELD (1958) and DE ROO and HARMSEN (1959). According to these authors the substratum of this area consists of glacial till. Its nature varies from loamy (silty clay loam) to sandy or gravelly. This deposit, originating from the Riss Glaciation, has been affected by erosion. During the Würm Glaciation it was covered by the older cover sands, which have generally a slightly loamy nature in this area. Locally this deposit has also been eroded. In part of the area the older cover sand was covered by younger cover sand. The surface of the latter deposit shows a somewhat pronounced relief. The younger cover sands have a less loamy nature than the older cover sands.

The soils, designated on the soil map (cf. fig. 9) with the type symbol S are the younger cover sands. The lS-soils consist of older cover sand which rests on a porous, more or less gravelly glacial till. The L-soils consist of older cover sand (possibly with a thin cover of young cover sand) resting at shallow depth on a non-porous, heavily textured glacial till.

6.5 Discussion

It was shown that the Rolde soils 2 and 3 are well-drained, have many very fine biopores, a good water retentivity and a good water permeability. Soil Rolde 1 has a low water retentivity and a low number of biopores. Soil Rolde 6 has a relatively low number of biopores. Soils Rolde 4 and 5 have an insufficient soil drainage and a low number of biopores.

Most of the soils in Rolde are used as arable land or pasture. In the investigated Rolde area very little or no horticulture is present. Some of the soils of the Rolde sequence, however, are well-suited for cultivating deep rooting horticultural crops.

If the soils are studied in relation to their suitability for horticulture, it is evident that the Rolde soil 3 is best suited for deep rooting crops. In other parts of the Netherlands, soils of this type are preferred for glasshouse horticulture including heating and sprinkling irrigation. Soils of type Rolde 2 are also suited for deep rooting crops. The depth to which roots may develop is smaller than in Rolde 3. Soils of the type of Rolde 6 may be used for the same purpose, but they are less favourable than soils similar to Rolde 2. Soils similar to Rolde 1 are more or less unsuited for cultivating deep rooting crops, because of their low number of biopores and their low water retentivity. Soils like Rolde 4 and 5 are unsuitable for deep rooting crops, because of low numbers of biopores and their insufficient drainage.

It is important to note that in the Netherlands soils similar to those of Rolde 3 are chosen more and more for the cultivation of horticultural crops. In practice they were found to be among the best sandy soils in the Netherlands. When asking soil scientists, what the attractive properties of these soils are, the answer will be: a good water retentivity, a good water permeability, a good soil drainage and the experience that plants develop a deep root system in these soils. When asking how these soils are recognized the answer will be: an old arable land cover on a slightly loamy subsoil with an Acid Brown Forest or a Brown Podzolic profile. When these soils are studied in soil profile pits, their common property appears to be: a high number of very fine biopores which can readily be seen and quantified in the field, without the use of a handglass or microscope. These biopores indicate that these soils will enable plants to develop a deep root system.

As stated in chapter 2, the description of soil structure in sandy soils in the field is rather difficult. Instead of describing structures as very weak subangular blocky as is often done in the field in sandy soils, it is proposed to describe in future the abundance of biopores, being the ways roots will follow in the soil.

In a similar way as in the heavier textured soils of Opheusden, biopores prove to be important for soil suitability and soil improvement. In selecting soils in sandy regions for deep rooting crops, primarily deeply drained soils should be selected which contain many biopores till great depth.

6.6 An estimate of the storage factor μ

An application of the study of biopores in sandy soils is the estimate of the storage factor μ. This application will be demonstrated by means of the soils studied in the Rolde area.

In a method to calculate the spacing of tile drains, the parameter 'total storage' has been introduced (DE JAGER, 1965). The total storage is the volume in the soil which is allowed to be filled with water under certain conditions. This total storage (μy) is calculated by multiplying the difference in depth of the actual groundwater level and the depth of the permissible highest groundwater level (y) by the air volume at field-capacity (μ). DE JAGER (1965) stated that in imperfectly drained sandy soils, the total storage strongly depends on the depth of the groundwater level, that means that it strongly depends on 'y'. In better drained soils (groundwater levels deeper than 1 m below surface) the total storage, (μy) depends on the storage factor μ which is equal to the total pore space minus the volume of water at pF 2.0, i.e. the air volume at pF 2.0. DE JAGER (1965) stated also that the storage factor in well-drained sandy soils may be calculated from pF data. This method, however, against the background of the inaccuracy of the information required (cf. DE JAGER, 1965), is rather cumbersome. In well-drained or excessively drained slightly loamy sandy or non-loamy sandy soils, the storage factor μ can be estimated from the abundance of biopores in combination with soil texture.

The relation between the air volume at pF 2.0 on the one hand and on the other the abundance of the very fine biopores and soil texture, may be explained as follows.

As stated in chapter 2 mainly two types of pores occur in sandy soils, viz., the primary pores and the biopores. The primary pores depend on the particle-size distribution, the biopores on the conditions governing biological activity.

According to JONGERIUS (1957) a pF-value of 2.0 corresponds to pores with diameters of 30 microns. According to WIERSUM (1957) primary pores with diameters of 30 microns can only occur in sands with a considerable fraction coarser than 120 microns, combined with an absence of clay and silt. This implies that in deeply drained sandy soils with a small clay and silt fraction, but with a substantial percentage of coarser sand material, the air percentage at pF 2.0 may be rather high. In this case the sandy soil is dry and a low number of biopores is present. Soil Rolde 1 demonstrates this situation. The air volume at pF 2.0 increases with increasing depth in this soil till some 25%, and only few very fine biopores are present. When a deeply drained sandy soil contains both coarser and finer components (cf. soils Rolde 2 and 3), the contribution of the primary pores to the total volume of pores larger than 30 microns decreases. Then conditions are favourable to the formation of biopores and generally large numbers of biopores are present. In those cases numbers of more than 15 very fine biopores per square centimetre correspond to air volumes at pF 2.0 of 25–35%.

When soils of the textural composition of soils Rolde 2 and 3 contain 5–15 very fine biopores per square centimetre, the air volume at pF 2.0 will be lower (15–30%). The cause generally is a former poor drainage, which resulted in the formation of less biopores. But also parts of soils Rolde 2 and 3 which are characterized by relative compaction (e.g. plough soles) and consequently contain less biopores, have a lower air volume at pF 2.0.

In soils which contain much fine sand or silt and which have always been imperfectly drained (cf. soils Rolde 4 and 5) a low number of biopores will be found (0–5/cm²). These values correspond to low air volume at pF 2.0 (10–20%). If in the latter soils groundwater levels are lowered till below one metre below surface, the above correlation will hold for a considerable time.

The above correlation has been tested on some twenty soils from sandy regions, including those of the Rolde series. These correlations will have to be controlled in future. In the following table the above correlations have been brought together.

Numbers of very fine biopores/cm²	*Volume of air at pF 2.0* %	*Estimate of μ* (cf. DE JAGER, *1965*)
LOAMY SANDY SOILS		
0–5	<20	<0.20
5–10	15–25	0.15–0.25
10–15	20–30	0.20–0.30
>15	25–35	0.25–0.35
SANDY SOILS		
0–5	25–35	0.25–0.35

6.7 Soil phases

In chapter 2 it has been stated that plants can only develop a wide branched and deep root system if a permanent heterogeneous pore-size distribution occurs in the soil which continues to rather great depth. It has also been stated that usually a pore-size distribution is only permanent heterogeneous if biopores occur. Biopores usually were only noticed in biogenic structures. Apart from minor exceptions they are absent in physicogenic structures and they are always absent in geogenic structures.

Consequently, in discussing the investigated soils in chapters 3, 4, 5 and 6, biogenic structures were contrasted to physicogenic and geogenic structures and the abundance of biopores was emphasized. Each of the soils was still treated as a separate unit. It is possible, however, to group soils according to the degree and depth of occurrence of the permanent heterogeneous pore-size distribution, using the type of soil structure, the abundance of biopores and the depth of occurrence of undisturbed stratified sedimentation structures. The result of such a classification is a number of classes (phases) which indicate the suitability of soils for deep rooting crops. This classification is meant to group soils which enable plants to develop a deep root system and to separate these soils from those which prevent plants to develop a deep root system.

A tentative proposal for such a classification is presented below. Three differential criteria are used, viz., (i) the depth to which biopores occur in the soil (perforation), (ii) the depth to which biogenic structures occur in the soil (biostructuration) and (iii) the depth to which stratified sedimentation structures are disturbed in the soil (disturbance). Four tentative depth classes are distinguished, viz., 0–30 cm (shallow), 30–60 cm (moderately deep), 60–100 cm (deep) and more than 100 cm (very deep).

For this classification biopores are considered to be present, if more than 5 fine biopores per cm^2 or more than 2 large biopores per dm^2 were observed. Subclasses might be based in future on the abundance of biopores. Not enough data are available now to establish such subclasses.

Depth in cm	*Phases according to biostructure, perforation, disturbance*
0–30, shallowly 30–60, moderately deeply 60–100, deeply >100, very deeply	biostructured, perforated, disturbed

This classification might be illustrated with the following examples. When soil P1 (Barendrecht) is contrasted to soil Opheusden 2, the following evident differences are observed.

Biopores are found in soil P1 at depths greater than 104 cm; in soil Opheusden 2 deeper than 58 cm very few or no biopores occur. Biostructures occur in the Barendrecht soil P1 at depths greater than 104 cm, in the Opheusden soil they are not found deeper than 3 cm below the surface. The Barendrecht soil lacks stratification to depths greater than 104 cm, although stratification might be observed at greater depths in this soil. In the Opheusden soil no stratification can be noticed. In terms of the classification presented above, the Barendrecht soil is grouped as very deeply perforated, very deeply biostructured and very deeply disturbed. The soil Opheusden 2 is classified as shallowly biostructured and moderately deeply perforated. The Barendrecht soil is well-suited for the cultivation of deep rooting crops, the Opheusden soil is unsuitable for this purpose.

When soils Rolde 2 and 3 are compared, it is observed that in Rolde 3 very fine biopores occur to a depth greater than 130 cm, while in Rolde 2 very fine biopores only occur to about 95 cm below the surface. Rolde 3 is consequently classified as very deeply disturbed and very deeply perforated, and soil Rolde 2 is classified as deeply disturbed and deeply perforated. Soil Rolde 3 is well suited for cultivating deep rooting crops and soil Rolde 2 has less favourable properties in this respect.

7 Some remarks on the soil classification of cultivated soils

7.1 Introduction

Since the early stages of development of pedology, soil scientists have been engaged in preparing soil classification schemes. Until quite recently, however, these schemes referred in particular to non-cultivated soils. This is surprising if it is realized that most scientists study soils from the viewpoint of suitability for agriculture.

In the Netherlands with its intensive agricultural practices it is difficult to find virgin soils. Soil survey and additional investigations in the Netherlands were therefore focused from the beginning on the problems of cultivated soils. Soil classification schemes developed abroad for non-cultivated soils were difficult to apply in the Netherlands.

Another complication was due to the fact that most soils in the Netherlands which are important for agriculture, as they produce high crop yields, belong to the Great Soil Group of the Alluvial soils, i.e. they are built up by material transported by water and they are generally young from the soil genetical point of view and consequently show almost no profile development. Pedological investigations which were performed during the last 10 to 15 years in the Netherlands, however, revealed that these soils are interesting from the viewpoint of initial soil genesis. The changes which may be noticed in the above mentioned soils and which originate in many cases from soil management, especially after improvement of soil drainage, are among the first rate soil genetical phenomena (e.g. homogenization, perforation or the formation of biopores, disturbance of stratified sedimentation structures etc., cf. chapter 2).

Some years ago a new scheme for soil classification was introduced in soil science which enables its user to classify almost all soils. We mean the 7th Approximation of the scheme for soil classification developed in the United States (U.S.D.A., 1960, 1964). An attempt was made to classify the soils which were discussed in the foregoing chapters by means of this scheme. The 1960 edition was used, together with the additions and changes proposed in 1964.

7.2 Classification by means of the 7th Approximation

It seemed interesting to investigate to what extent the discussed soils fit into the scheme referred to above and to what extent the differences in nomenclature reflect the differences in soil properties as noticed during the investigations. Only those soils will be discussed of which the complete profile descriptions were presented (cf. Appendix II, profile descriptions 1–15).

Difficulties have been encountered in classifying, according to the 7th Approximation, the soils under glass, labelled Barendrecht and Zwijndrecht (Profiles P1 and P4). They evidently show the consequences of intense human influence on the soil genesis and they should therefore be called anthropogenic soils. The 7th Approximation recognizes such soils, without, however, 'characteristics associated with wetness'. According to this scheme the soils under discussion should be classified as *Aquepts*, but classification below suborder level is impossible then. We suggest for the soils under consideration the name *Anthraquepts*, stressing both the man-made features and 'the characteristics associated with wetness'. MÜCKENHAUSEN (1962) already recognized the discussed wet subtype of the anthropogenic soils. He mentioned besides the terrestric anthropogenic soils (*Anthrumbrepts*) the wet subtype, viz., the semiterrestric anthropogenic soils.

The soils in Barendrecht and Zwijndrecht (profiles P2 and P5) under arable land, were classified as *Typic Normaquepts*. The difference in nomenclature between these soils and those mentioned above, reflects the absence of the thick, dark surface soil, rich in phosphate compounds, which has been observed in the soils P1 and P4.

The pasture soils in Barendrecht and Zwijndrecht (profiles P3 and P6) were classified as *Humic* and *Thapto Histic Normaquepts* respectively. In this case the 7th Approximation stresses the accumulation of organic matter near the soil surface under wet conditions under pasture.

The well-drained soils P7 and P8 with and without grass mulching respectively, were both classified as *Typic Eutrochrepts*. Since the differences in soil genesis between these two soils are rather small, the uniformity in nomenclature at this level of classification seems satisfactory.

A fine example of suggestive nomenclature was noticed with the relatively wet river loam and river clay soils P9 and P10. Both soils are grass mulched; P9 is heavily textured, P10 is relatively light textured. Both soils are more or less imperfectly drained. In soil P9 organic matter accumulates near the soil surface without being broken down and without being mixed properly into the surface soil by the soil animals. The accumulation of organic matter is reflected by the adjective *Humic* in combination to the great group name *Normaquept*. In the somewhat better drained soil P10 a mixing of organic matter and mineral particles occurs near the soil surface to such an extent that a more or less thick, dark surface horizon may be observed. The better drainage and the presence of the dark A1-horizon are reflected by the adjectives *Aeric* and *Mollic* respectively, in combination to the great group name *Normaquept*.

Finally some remarks will be made about the classification of soils P11 till P15. They all are river loam and river clay soils which were formerly improperly drained. Groundwater levels were gradually lowered in these soils. They all are classified as *Normaquepts*, though at subgroup level different adjectives were added.

The soils P11 and P12 consist of a heavily textured deposit which rests on a lighter textured subsoil. The soils P13, P14 and P15 are heavily textured throughout the soil profile. The improvement of soil drainage gave rise to more changes in soil properties in the soils P11 and P12 than in the soils of the latter group. This difference is stressed by the adjective *Aeric* given to the great group name of soils P11 and P12. Moreover an extra adjective is added to the great group name of soil P11 under grass mulching, viz., *Mollic*, stressing the deeper mixing of organic material with the mineral particles near the soil surface. This extra adjective is absent for the arable soil P12.

Such differences of mixing the organic matter in the surface soil are smaller in the more imperfectly drained soil P13 (grass mulching) and P14 (arable land) resulting in a uniform classification as *Typic Normaquepts*. The soil P15, under pasture, was classified as *Humic Normaquept*, because of the accumulation of organic matter under wet conditions near the soil surface.

7.3 Discussion

Apart from the fifteen soils discussed above, some tens of soils in the Netherlands were classified in a similar way. The conclusions from the classification by means of the 7th Approximation are the following.

Almost all cultivated soils which were studied, fitted into the scheme of soil classification.

The investigated alluvial soils were generally classified by means of the 7th Approximation in such a way that important agricultural differences resulted in differences in nomenclature on subgroup or higher levels of classification. An exception should be made here for differences in drainability which are correlated with differences in texture (cf. profiles P2 and P5). On family level, however, these differences will result in differences in classification.

Until family level the 7th Approximation primarily deals with morphological soil characteristics resulting from soil genesis. On family and lower levels agricultural criteria will also be used. It has been announced that subdivisions will be based on, for instance, textural classes and on permeability classes. This means that at the lower levels root potentialities of soils will be included. The great advantage of the soil classification system under consideration is the fact that at each level an unambiguous classification is possible if all required data are available. A serious disadvantage of this system, however, is that many of the required data can only be obtained by laboratory analyses. Consequently each soil characteristic which can be measured in the field and which is considered to be important for classification should be used.

From the characteristics mentioned in chapter 2, the depth of disturbance of stratified sedimentation structures and the abundance of biopores meet the above mentioned requirements. In a number of cases differences in the depth of disturbance or in the abundance of biopores already result at a higher level of classification in different names of soils. Sometimes, however, soils with differences in these morphological characteristics are classified under the same name till family level. They might be subdivided on family level according to, for instance, soil texture or water permeability. But in many cases such subdivisions cannot be made in the field. Therefore we suggest to use among others soil structure, the depth of disturbance of stratified sedimentation structures and the abundance of biopores as factors for differentiation at lower levels of classification. These morphological characteristics can readily be observed in the field and they allow a decision for classification in the field. The following two examples might illustrate the possibilities.

Sandy soils with a *Plaggen* epipedon of more than 50 centimetres thickness are classified as *Plaggepts*. Within the *Plaggepts* distinct variations occur in root potentialities. Till now these differences could only be determined in the field by means of the abundance of biopores.

Many river levee soils in the Netherlands are classified as *Typic Eutrochrepts* (like profiles P7 and P8). Distinct variations, however, occur in root potentialities in these soils. These variations might easily be determined by measuring the depth of the undisturbed stratified subsoil and by counting the numbers of biopores.

The soil phases defined in section 6.7 are proposed to be used at lower levels of soil classification. According to this proposal soil P1 (Barendrecht) may be classified as an *Anthraquept*, very deeply perforated, biostructured and disturbed phase. Soil Rolde 2 is classified according to the above scheme as a *Plaggic Normorthod*, deeply disturbed and perforated phase. Soil Rolde 3 finally may be classified as a *Plaggept*, very deeply disturbed and perforated phase.

Samenvatting

In Nederland is, vooral na de Tweede Wereldoorlog, een grote vraag ontstaan naar gegevens over de bodemgesteldheid in verband met de geschiktheid van de bodem voor verschillende takken van landbouw. Het merendeel van de uitgevoerde bodemkarteringen had tot doel aan deze vraag te voldoen. Hoewel deze onderzoekingen vele inlichtingen hebben verschaft, hebben zij enerzijds bepaalde vragen onbeantwoord gelaten en hebben zij anderzijds nieuwe vragen doen ontstaan. Deze problemen kunnen in het algemeen slechts opgelost worden door toepassing van gedetailleerder onderzoeksmethoden.

Nieuwe problemen resulteren veelal uit de toenemende rationalisatie in verschillende takken van de Nederlandse landbouw en vooral uit een intensivering van het bodemgebruik. Zij betreffen vooral de bodemgeschiktheid en de bodemverbetering.

Het doel van deze studie was enige aspecten van de bovengenoemde problemen nader te onderzoeken door beschrijving van profielkuilen en met behulp van bepalingen aan ongestoorde monsters. Het onderzoek is beperkt tot een studie van enige gevolgen van de ontstaanswijze en gebruikswijze voor de landbouwkundige geschiktheid van een aantal Nederlandse gronden. Een tweede beperking geldt de methode van onderzoek. In het algemeen zijn slechts die morfologische en fysische eigenschappen van de bodem beschreven, die voor beworteling van belang geacht moeten worden.

Met betrekking tot de methode van onderzoek kan voorts opgemerkt worden, dat in vele gevallen gebruik is gemaakt van een vergelijking van gronden in groepen van twee of drie. Deze gronden zijn zodanig gekozen, dat aangenomen kan worden dat zij oorspronkelijk dezelfde eigenschappen hadden. De verschillen in eigenschappen, die nu voorkomen zouden uitsluitend een gevolg zijn van verschillen in bodembehandeling.

In hoofdstuk 2 is aannemelijk gemaakt, dat planten slechts een diep en wijdvertakt wortelstelsel kunnen ontwikkelen als de grond tot relatief grote diepte een zogenaamd permanent heterogeen poriënstelsel bevat. Een poriënstelsel is permanent heterogeen genoemd als daarin gedurende het gehele jaar zowel kleine als grote poriën voorkomen.

Een groot deel van hoofdstuk 2 wordt in beslag genomen door de beschrijving van de omstandigheden, waaronder het permanent heterogeen poriënstelsel ontstaat en door de beschrijving van methoden om zulk een poriënstelsel te karakteriseren.

Het permanent heterogeen poriënstelsel is een gevolg van biologische activiteit

(de vorming van bioporiën). Daarom is aandacht besteed aan enkele factoren, die de activiteit van bodemflora en bodemfauna beïnvloeden. Gebleken is, dat in het algemeen bodemdieren en plantenwortels dezelfde levensomstandigheden vereisen. De bodemdieren zijn onder bepaalde omstandigheden in staat ondergronden voor plantenwortels te ontsluiten door het wegnemen van mechanische wortelweerstanden. Bodemdieren zijn voor hun voeding echter weer afhankelijk van de plant.

In verband met het bepalen van de bewortelingsmogelijkheden van een grond, is het belangrijk te weten in hoeverre en tot welke diepte een poriënstelsel permanent heterogeen is.

Soms is het mogelijk de heterogeniteit van een poriënstelsel direct te meten bijvoorbeeld in zandgronden (vergelijk VAN DER PLAS en SLAGER, 1964; SLAGER, 1964; BOUMA en HOLE, 1965). De meting werd uitgevoerd met behulp van een stereomicroscoop op lakfilms. Vaak was de directe meting op lakfilms onmogelijk (bijvoorbeeld in kleigronden) en had gebruik gemaakt moeten worden van omslachtiger methoden zoals slijp- en polijstplaten.

Wanneer een directe meting van de heterogeniteit onmogelijk was is gebruik gemaakt van het feit, dat biologische activiteit niet slechts het poriënstelsel, doch ook de structuurvorm beïnvloedt. Daarom is de morfologische beschrijving van de bodemstructuur uitgebreid besproken. Bij deze onderzoekingen is gebruik gemaakt van de door JONGERIUS (1957) ontworpen morfologische structuurindeling. Nadruk is gelegd op het verschil tussen enerzijds de biogene structuren, gekenmerkt door een min of meer heterogeen poriënstelsel en anderzijds de fysicogene en geogene structuren, die gekenmerkt zijn door een meer homogene poriënverdeling. In een aantal gevallen kon het verband tussen de heterogeniteit van het poriënstelsel en de aard van de bodemstructuur niet gebruikt worden. In die gevallen is meer aandacht besteed aan andere gevolgen van biologische activiteit, zoals homogenisatie, perforatie en verstoring. Het begrip biologische homogenisatie (HOEKSEMA, 1953) is opnieuw gedefiniëerd en een ontwerp van een methode om homogenisatie meetbaar te maken, is besproken. Voor de bepaling van de nieuw ingevoerde begrippen diepte en mate van homogenisatie is het lutumverloop gebruikt. Gebleken is echter, dat de meting van de homogenisatie van ondergeschikt belang is in geval van verandering van biologische activiteit op korte termijn. In die gevallen spelen perforatie en verstoring een belangrijke rol. De term 'perforatie graad' is vervangen door de term 'verloop van het aantal bioporiën' ('biopore trend'). De meting van de perforatie en verstoring zijn besproken. Beide processen kunnen aanleiding geven tot ontsluiting van de ondergrond voor de plantenwortels.

Tot slot is in hoofdstuk 2 aandacht besteed aan het structuurverloop ('structural trend'). Deze term, ingevoerd ter vervanging van het begrip 'structuurprofiel' (VAN DER KLOES, 1961), is gebruikt om de verticale opeenvolging aan te duiden van verschillende structuurtypen in een bodem. Het structuurverloop is van grote waarde gebleken, wanneer een overzichtsbeeld gewenst is van het verloop van de heterogeniteit van het poriënstelsel. Vooral wanneer de bewortelbaarheid van een bodem bepaald dient te worden, is het structuurverloop een belangrijke grootheid. Twee typen van structuurverlopen, die veelvuldig in Nederlandse alluviale gronden voorkomen, zijn besproken, te weten, de verticale opeenvolging van biogene en geogene structuren, voorkomend in vele oeverwalgronden en het verticale verloop van fysicogene structuren, voorkomend in komkleigronden. Hierbij zijn ook de geogenese van de gronden, waarin de genoemde structuren voorkomen en hun ontwateringsmogelijkheden besproken. Tot slot is gewezen op de mogelijkheden om via het structuurverloop te komen tot structuurkartering, die is op te vatten als een synthese tussen de studie van de bodemstructuur en de fysiografische bodemkartering.

In de hoofdstukken 3, 4 en 5 is de invloed besproken, die een aantal bodemverzorgingsmaatregelen hebben op de eigenschappen van enige Nederlandse alluviale gronden.

In hoofdstuk 3 is de invloed beschreven, die drie wijzen van bodemverzorging hebben op twee sterk verschillende estuariumgronden. De bodembehandelingen kunnen alsvolgt omschreven worden:

1. glastuinbouw met grote organische mestgiften, kunstmatige beregening, kunstmatige ontwatering en grondontsmetting
2. bouwland met relatief kleine organische mestgiften en veelvuldige teelt van granen en bieten
3. weiland.

De onderzochte bodemtypen waren:

1. een vrij goed ontwaterde, kalkrijke, lichte zavelgrond met aflopend profiel
2. een slecht ontwaterde, kalkloze, zware kleigrond.

Het onderzoek heeft uitgewezen, dat de verschillen in bodembehandeling slechts aanleiding geven tot verandering van de eigenschappen van de bovengrond.

Het gebruik van de grond als bouwland gaf aanleiding tot een verdichte bovengrond, opgebouwd uit fysicogene structuren. De vorming van deze verdichting werd toegeschreven aan de activiteit van (mechanische) structuur-degenererende krachten, die niet gecompenseerd werden door (biologische) structuur-regenererende krachten. Als structuur-degenererende krachten zijn onder andere genoemd: bewerking van te vochtige gronden en rijden over te vochtige gronden. Als oorzaken van de afwezigheid van regenererende krachten zijn onder andere genoemd: relatief geringe organische mestgiften en verwonding van bodemdieren tijdens de bodembewerking. Het jarenlange gebruik van de grond voor de teelt van tuinbouwgewassen onder glas gaf aanleiding tot de vorming van een zeer poreuze bovengrond bestaande uit sterk biogene structuren. In dit geval waren de mechanische structuur-degenererende krachten vrijwel afwezig, terwijl veel bodemdieren actief waren, als gevolg van onder andere de zware organische bemestingen.

De eigenschappen van de grond onder grasland bleken intermediair te zijn tussen de eigenschappen van de gronden onder de beide andere bodembehandelingen. Dit was te verklaren met behulp van een combinatie van een geringere structuur-degeneratie dan in het bouwland en een geringere structuur-regeneratie dan in de kasgrond. Daar waarschijnlijk alle in dit hoofdstuk genoemde gronden vroeger onder weiland hebben gelegen, kon uit de waarnemingen worden geconcludeerd dat de bouwlandgronden verslechterd zijn, terwijl de kasgronden verbeterd zijn.

Tot slot bleken zowel de aard als de mate van de bovengenoemde verschillen gelijk te zijn in de goed ontwaterde en in de slecht ontwaterde grond.

In hoofdstuk 4 zijn de resultaten meegedeeld van enige onderzoekingen over de gevolgen van het toepassen van grasmulch op bepaalde bodemeigenschappen in rivierkleigronden.

Gebleken is, bij vergelijking van een goed ontwaterde lichte grond onder grasmulch met een zelfde grond, die zwart was gehouden, dat toepassing van grasmulch aanleiding geeft tot een hoger poriënvolume en tot een groter aantal bioporiën in de bovengrond. Als oorzaak van de verandering kon worden aangewezen de aanvoer van eiwitrijk voedsel, dat de activiteit van de in de bovengrond levende kleine regenwormen stimuleerde.

In een slecht ontwaterde, zware kleigrond, onder grasmulch, waar het gras te weinig werd gemaaid, was slechts een gering aantal bioporiën aanwezig. Dit was een gevolg van de ondiepe grondwaterstand en van de slechte voeding van de regenwormen.

In een wat beter ontwaterde, lichtere grond onder grasmulch, bleek een wat hoger aantal bioporiën aanwezig te zijn.

Uit de bovengenoemde waarnemingen werd geconcludeerd, dat grasmulch slechts in die gevallen aanleiding geeft tot bodemverbetering, waar relatief voedselgebrek van de regenwormen de enige oorzaak vormde van de geringe biologische activiteit voor de toepassing van de grasmulch. Dit impliceert, dat grasmulch op onvoldoend ontwaterde gronden geen aanleiding geeft tot bodemverbetering, terwijl anderzijds verdichte, doch goed ontwaterde, bouwlandgronden door toepassing van grasmulch te verbeteren zouden zijn.

In hoofdstuk 5 is de invloed besproken, die enige bodemverzorgingsmaatregelen uitoefenen op de eigenschappen van een aantal rivierkleigronden, waarvan de ontwatering recent verbeterd was. De onderzochte bodembehandelingen waren grasland, bouwland en grasboomgaard. Gebleken is, dat ontwatering alleen, geen aanleiding geeft tot structuurverbetering. Het aantal bioporiën bijvoorbeeld onder bouwland bleek ook na verbetering van de ontwatering nog laag te zijn. Het aantal bioporiën in dezelfde grond onder weiland of onder boomgaard was beduidend hoger. Hoewel de verbetering eerst mogelijk was na verbetering van de ontwatering, werd zij gerealiseerd door de bodemfauna. Uit de waarnemingen kon geconcludeerd worden, dat bij bodemverbetering van slecht ontwaterde gronden, na verbetering van de ontwatering, veel aandacht besteed moet worden aan een goede voedselvoorziening van de bodemdieren.

Uit de waarnemingen, vermeld in de hoofdstukken 3, 4 en 5, konden enige belangrijke conclusies worden getrokken betreffende bodemgeschiktheid en bodemverbetering. De morfologische en fysische methoden, die in bovengenoemde hoofdstukken gebruikt werden, waren nogal gedetailleerd en tijdrovend. Daarom is getracht deze methoden te vereenvoudigen teneinde ze toepasbaar te maken voor praktische doeleinden, zoals de bodemkartering. De resultaten van deze vereenvoudiging en de toepassing daarvan in de bodemkartering zijn vermeld in hoofdstuk 6.

Eerst is een overzicht gegeven van de gebruikte morfologische en fysische methoden en is een scheiding gemaakt tussen de methoden, die direct in het veld toepasbaar zijn en degenen, die dat niet zijn. Tot de eerste groep behoren de macrostructuur en het verloop daarvan in de bodem, de distributie van de bioporiën en de diepte van verstoring van de gelaagde sedimentatie structuren. Speculatieve schema's zijn gegeven voor de classificatie van bioporiën volgens grootte en aantal. Tot slot zijn enige suggesties vermeld in verband met waarneming en telling van bioporiën in het veld.

De resultaten zijn weergegeven van twee gedetailleerde bodemkarteringen, waarin het concept van de bioporiën is toegepast. Eén van deze karteringen betreft 50 ha rivierkleigronden in de Betuwe. De andere kartering betreft 100 ha zand- en leemgronden in Drente.

In beide karteringen zijn de waarnemingen verricht met behulp van spade en boor. In de onderzochte gebieden zijn enige diepe kuilen uitgekozen voor gedetailleerde morfologische beschrijvingen en voor bemonstering ten behoeve van fysische onderzoekingen. Voor aanvullende morfologische onderzoekingen zijn vele kleine kuilen gegraven tot een diepte van ongeveer 50 cm, waarna de diepere delen van de bodem onderzocht zijn met behulp van een boor.

Door het invoeren van het concept van de bioporiën in de beide genoemde bodemkarteringen was het mogelijk enige aanwijzingen te geven betreffende de geschiktheid van de onderzochte gronden voor de teelt van diepwortelende gewassen. In ieder van de twee karteringsgebieden kwam één grond voor waarvan aangenomen kan worden, dat zij potentiëel geschikt is voor diepwortelende gewassen. In het rivierkleigebied is dit de oevergrond op oeverwalondergrond. Na ontwatering is in deze grond een beworteling mogelijk tot tenminste 1,50 m, omdat tot die diepte bioporiën aanwezig zijn. Van de bestudeerde zand- en leemgronden wordt de zwaklemige oude zandbouwlandgrond de meest geschikte geacht voor diepwortelende gewassen. Als deze grond beregend wordt is een diepe beworteling mogelijk.

De uitspraken over de bodemgeschiktheid zijn allen gebaseerd op de actuele beworteling of op degene, die te verwachten is na verbetering van de water- en luchthuishouding. In het tweede geval is het voorkomen van bioporiën als criterium gebruikt.

Door toepassing van het concept van de bioporiën kon meer informatie verkregen worden, die van belang is voor bodemgeschiktheid en bodemverbetering. Daarom is gesteld, dat het zinvol is de meting van de distributie van de bioporiën in de bodem in de toekomst toe te passen bij de bodemkartering.

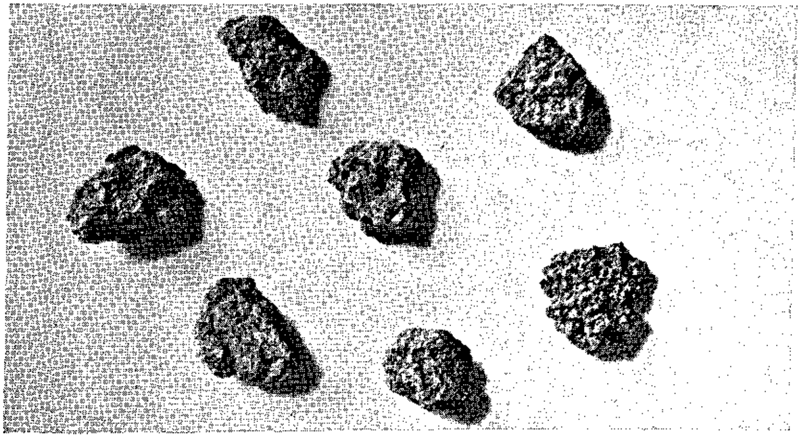
Enige opmerkingen over de bodemclassificatie van de onderzochte alluviale cultuurgronden zijn vermeld in hoofdstuk 7. Gebleken is, dat de 7th Approximation van het in de U.S.A. ontwikkelde schema voor bodemclassificatie (U.S.D.A. 1960, 1964) toepasbaar is voor vrijwel alle bestudeerde alluviale cultuurgronden. De meeste van de verschillen in bodemeigenschappen, die tijdens het onderzoek zijn vastgesteld, resulteerden in verschillen in naamgeving. Enkele belangrijke bodemkundige verschillen, die geen aanleiding gaven tot verschil in naamgeving zullen dat alsnog doen op een lager niveau van classificatie.

Gesteld is, dat een groot voordeel van de 7th Approximation is, dat een éénduidige classificatie mogelijk is, wanneer alle vereiste gegevens beschikbaar zijn. Veel van deze gegevens moeten echter nog ontleend worden aan laboratoriumanalyses. Daarom is gesuggereerd gebruik te maken van de diepte van de gelaagde, ongestoorde ondergrond en van het aantal bioporiën als criteria bij de differentiatie op lagere niveau's van classificatie. Het voordeel van het gebruik van deze morfologische grootheden is, dat zij in het veld kunnen worden waargenomen en kunnen worden gekwantificeerd. Daardoor maken zij een éénduidige classificatie in het veld mogelijk.

Photographs

On the following pages some photos are shown which are meant to visualize some of the characteristics discussed in the foregoing chapters. Most of the photos deal with the contrast biogenic to physicogenic structures or with biopores. The photos were not mentioned in the foregoing chapters since references to them should have been made then on almost every page.

The first five photos show structural elements and their relation to root development. Photos 6, 7 and 8 show earthworm burrows (biopores) as they may be observed in the field. Photos 9 to 12 are included to stress the great differences in structural properties between the light textured Barendrecht soils with different soil management. Photos 13 to 19 show views of biopores as they occur in thin sections of various soils. Finally photos 20 to 24 show biopores as they occur in soil peels of sandy soils.



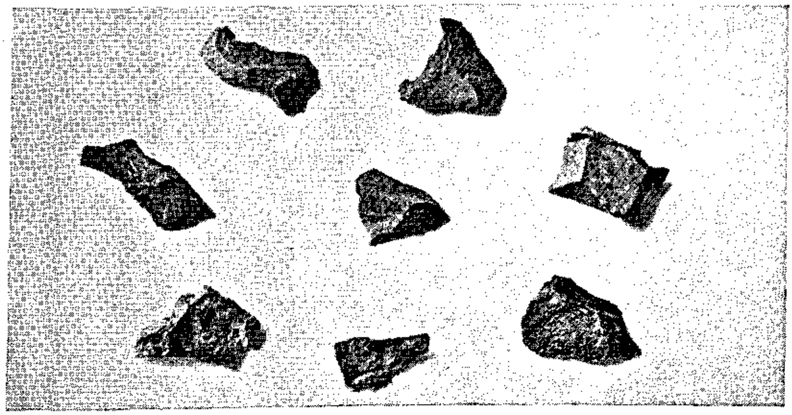
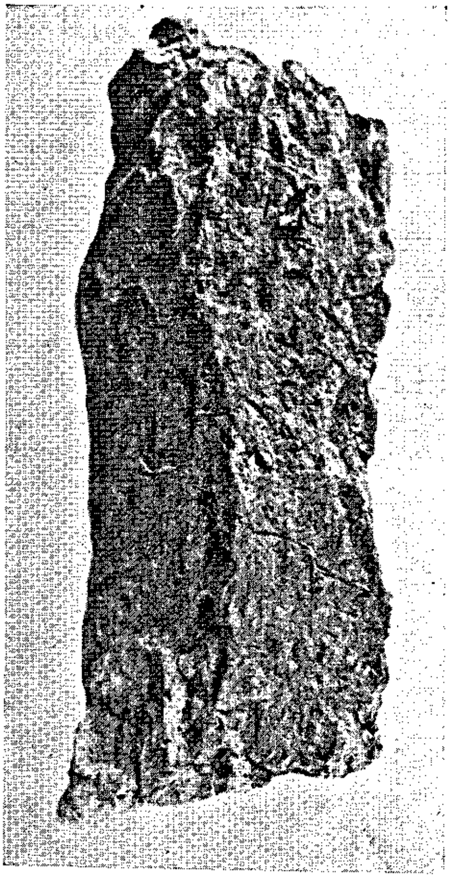


Photo 1 (top). Subangular blocky structural elements, favourable towards root development (biogenic structures with a heterogeneous pore-size distribution). About natural size

Photo 2. Angular blocky structural elements, unfavourable towards root development (physicogenic structural elements, with a relatively homogeneous pore-size distribution). About natural size (cf. 2.4)



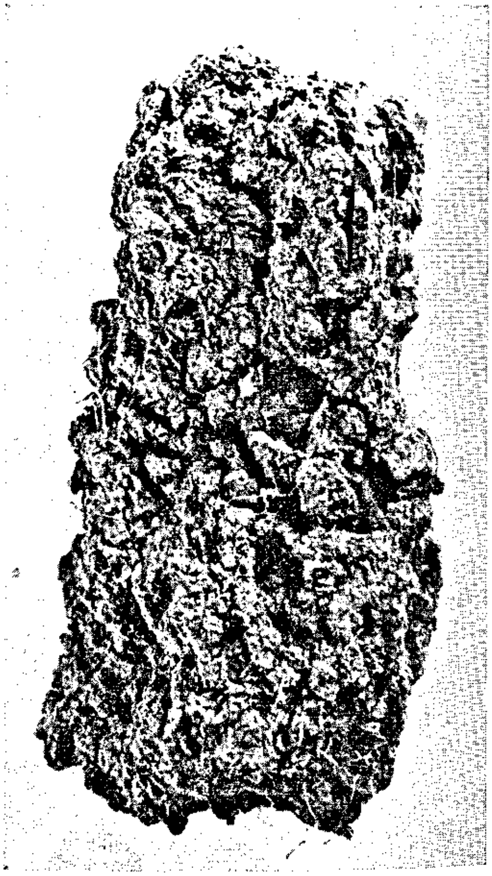
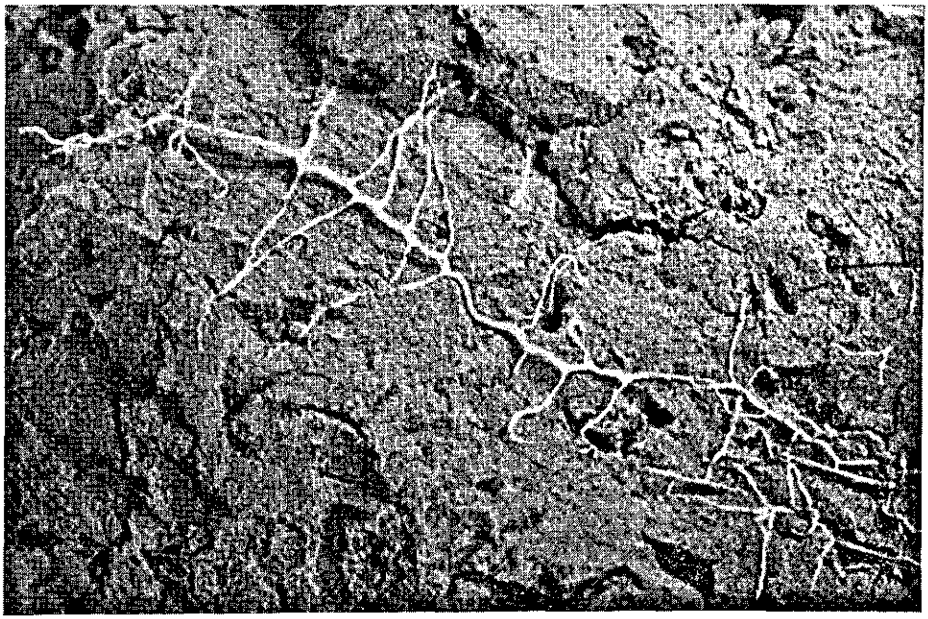


Photo 3 (left). Single prism. Roots seldom penetrate such a physicogenic structural element. Magn. 2/3×

Photo 4. Compound prism, subdivided into subangular blocky elements. Roots penetrate the prism in large numbers. Magn. 2/3× (cf. 2.4)



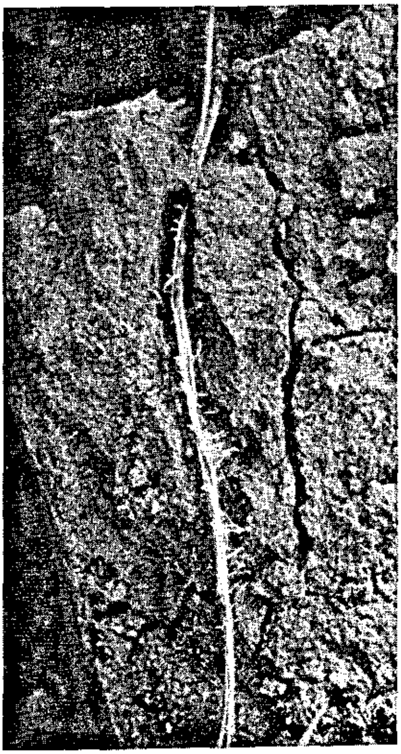


Photo 5 (top). Roots growing over the surface of a physicogenic structural element which they could not penetrate. Magn 3×

Photo 6. A bundle of roots growing through a biopore (here an earthworm hole) in a physicogenic structural element. Magn. 1× (cf. 2.4)

Photo 7 (top). Interior of a prism which was perforated by an earthworm. The wall of the biopore was plastered with dark colored material. Magn. 2/3×

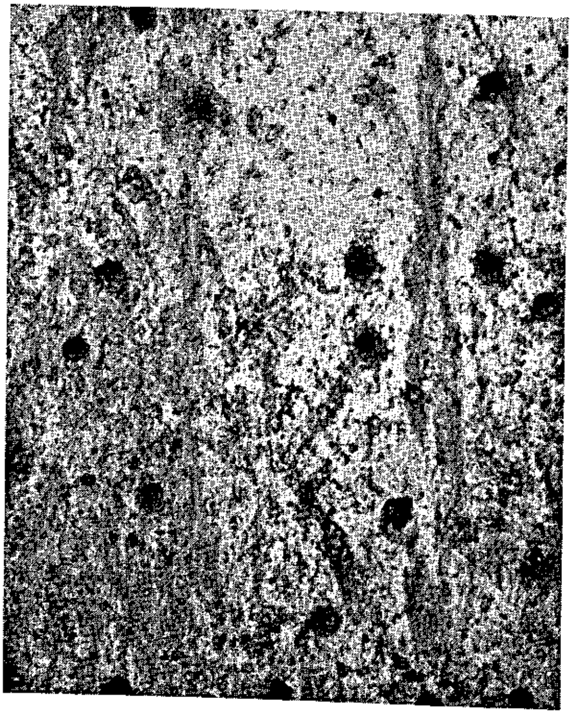
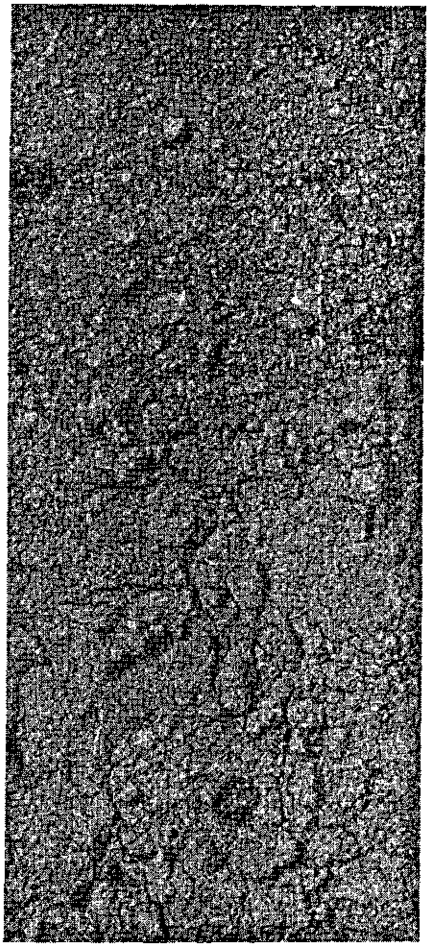


Photo 8. Biopores (here earthworm holes) with diameters exceeding 4 millimetres in horizontal section in profile pit. River clay soil with improved soil drainage under grass-mulch orchard, depth 50 cm. Magn. 1/3× (cf. 2.5 and 5)



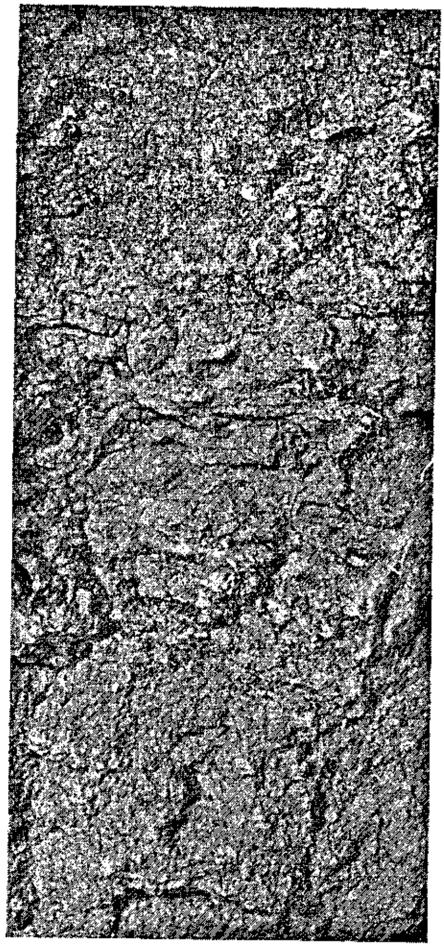
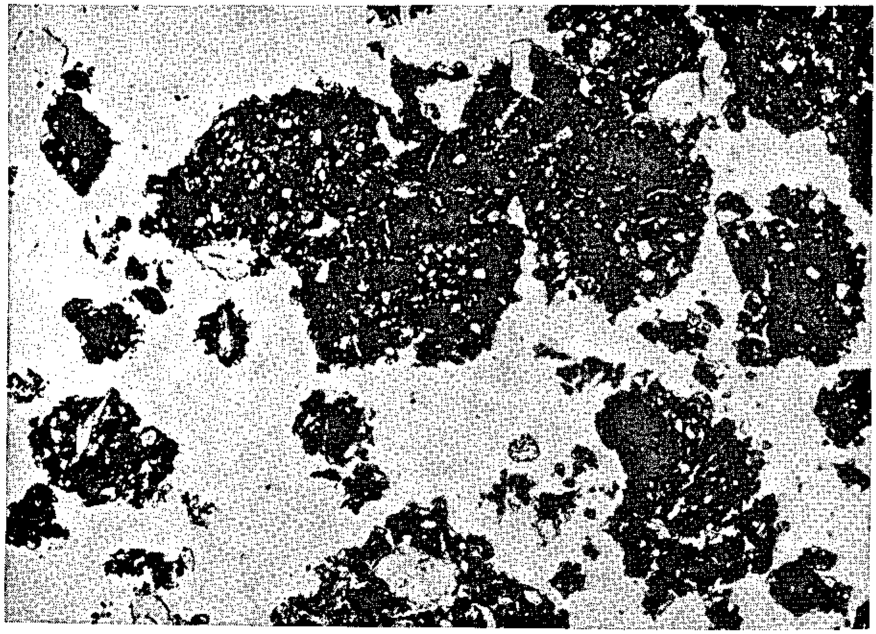
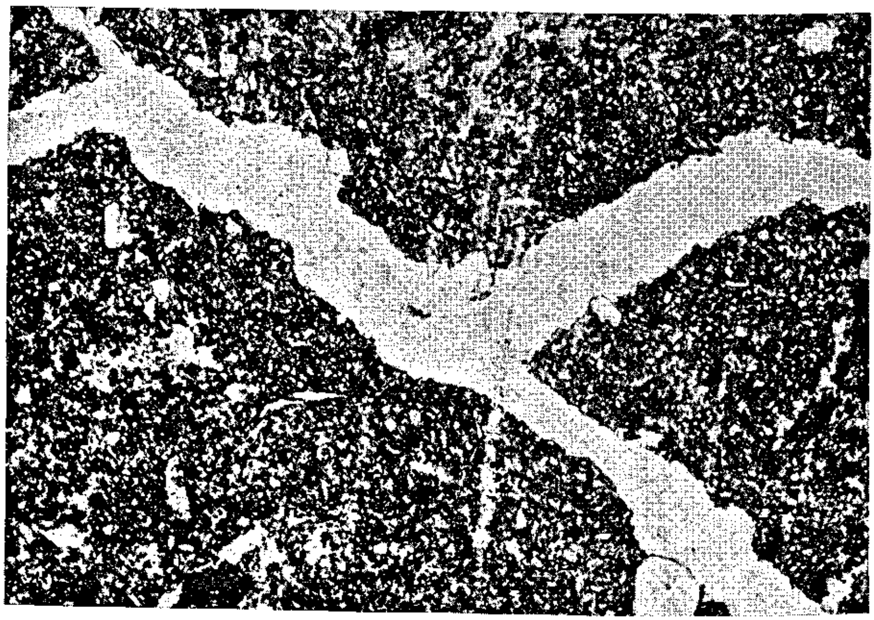


Photo 9 (left). Soil Barendrecht P1 under horticulture. The surface soil consists of granular, subangular blocky and cloddy elements. The subsurface soil consists of subangular blocky elements

Photo 10. Soil Barendrecht P2 under arable land. The surface soil consists of angular blocky elements which rest on a compacted plough sole. The subsurface soil consists of prismatic elements which are subdivided into porous subangular blocky elements

The soil textural trend and the soil drainage revealed that these two soils originally had the same properties. The large differences in the present properties are attributed to the difference in soil management. Depth: 0–50 cm. Photographs of vertical soil peels. Magn. 1/4× (cf. chapter 3)





Details of soil structure in soils Barendrecht P1 and P2

Photo 11 (top). Rounded (biogenic) structural elements (black with white patches) leaving much pore space (white) between them

Photo 12. Angular blocky (physicogenic) structural elements. Pore space included in fissures only.

Depth: about 25 cm. Micro-photos of thin sections. Plain light. Magn. 30× (cf. chapter 3)

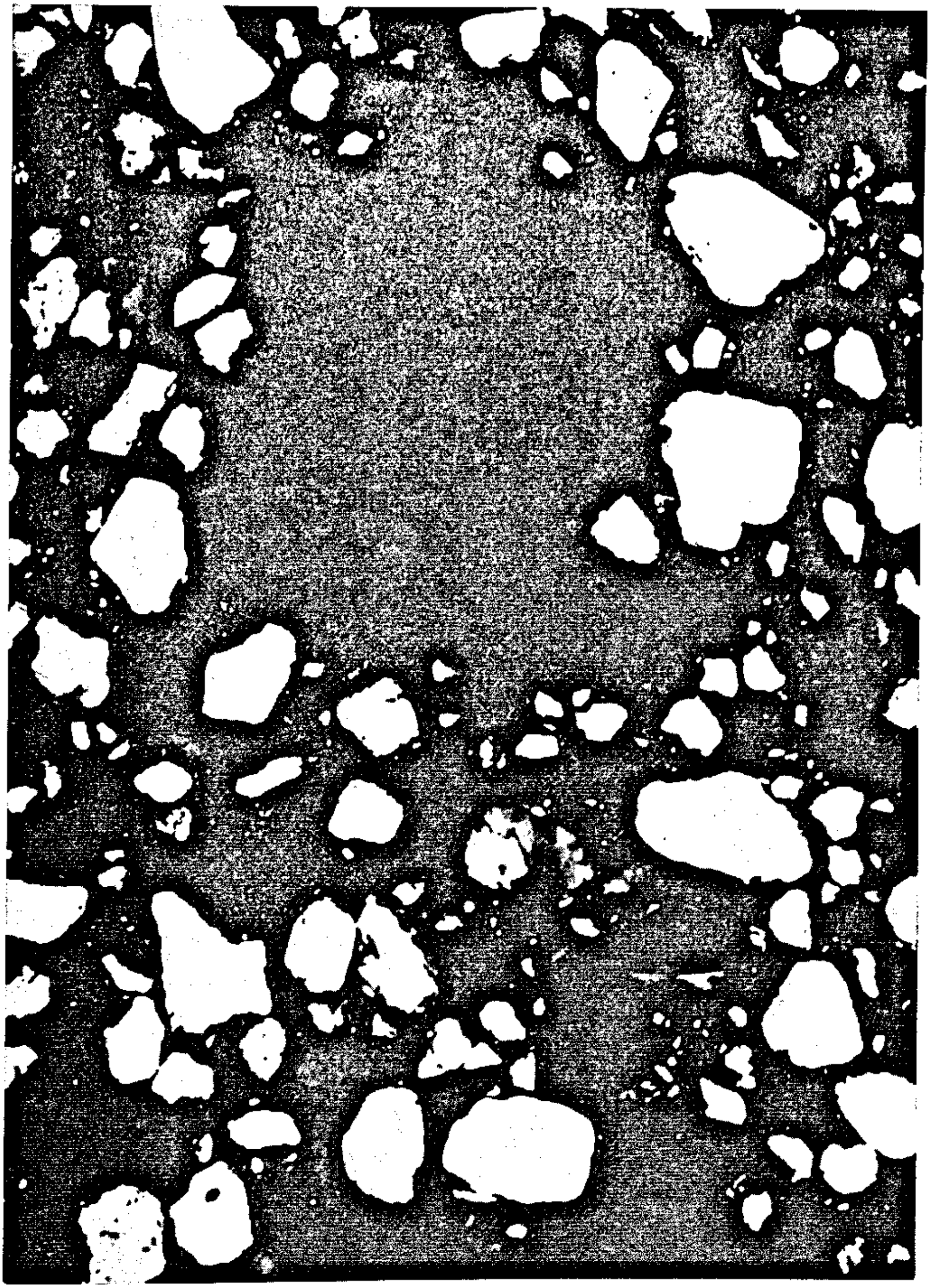
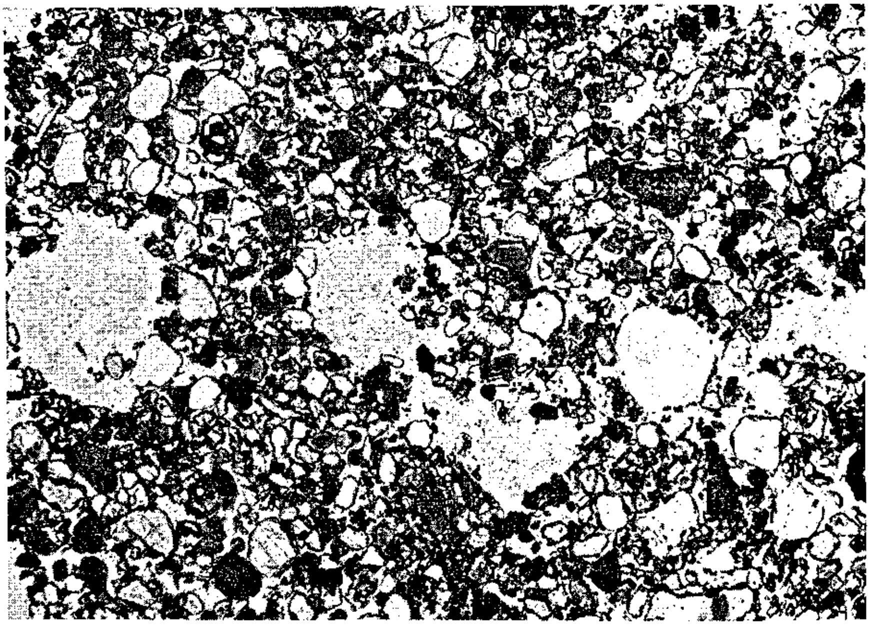
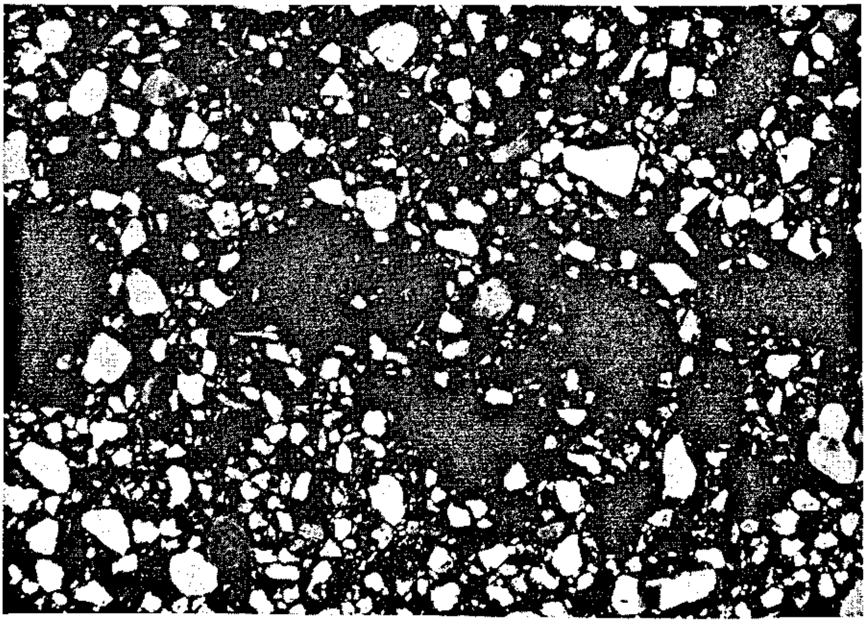


Photo 13. Picture of a biopore (black circle) in a sandy soil. Soil Rolde 3 at a depth of 85 cm. Photo of thin section, crossed nicols. Magn. 80× (cf. chapter 6)

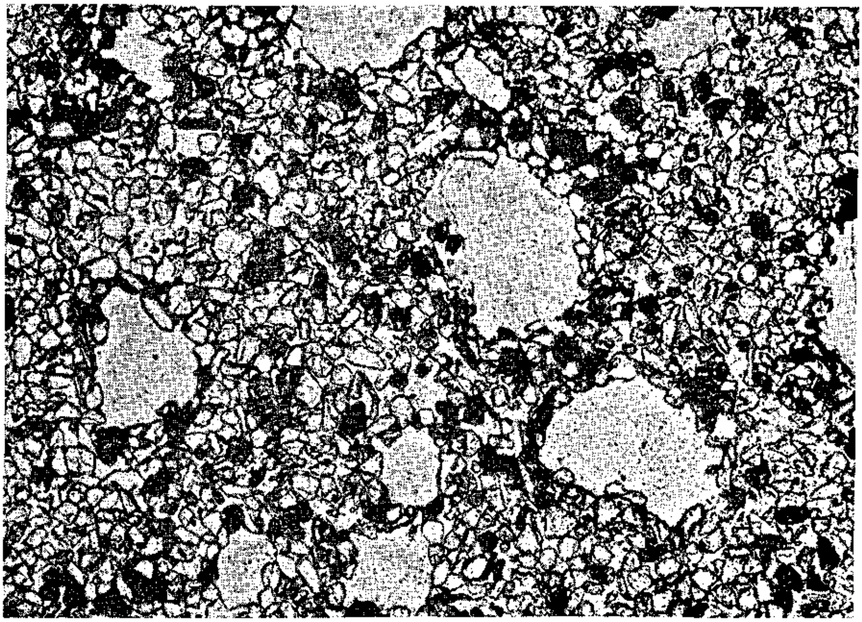




Pictures of biopores in sandy soils

In photo 14 (top) biopores as white circles, in photo 15 as black circles

Soil Rolde 3 at a depth of 80 cm (cf. chapter 6). Both photos of thin sections; 14 with plain light; 15 with crossed nicols. Magn. 22×



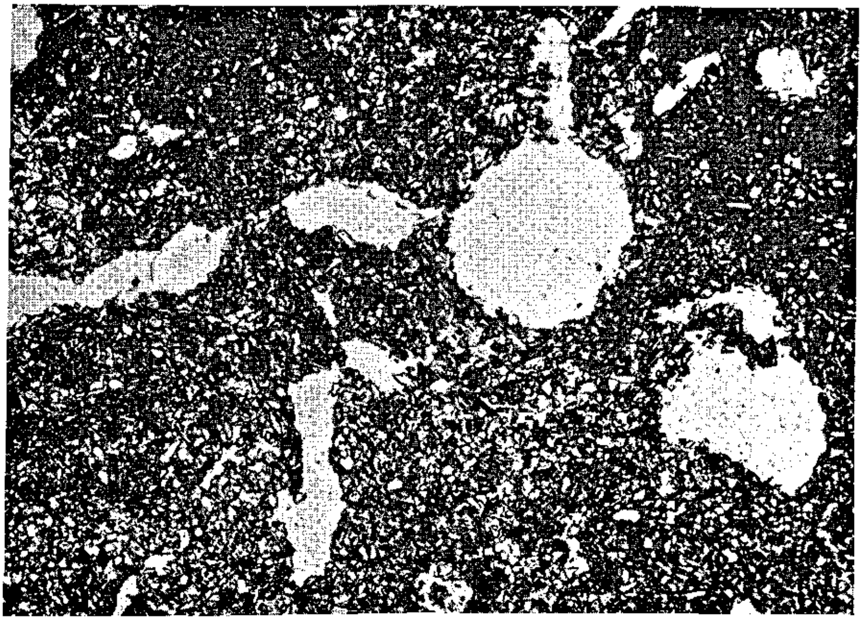
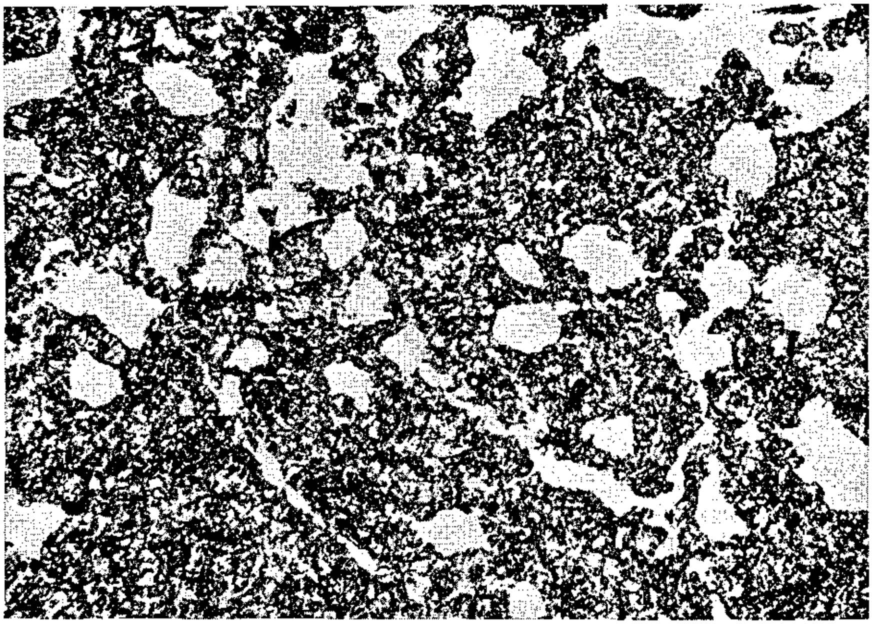


Photo 16 and 17. Pictures of biopores in spongy subsoils of light-textured creek-ridge soil (16, top) and heavier-textured river levee soil (17). Micro-photos of thin sections with plain light. Magn. 22 × (cf. 2.6)



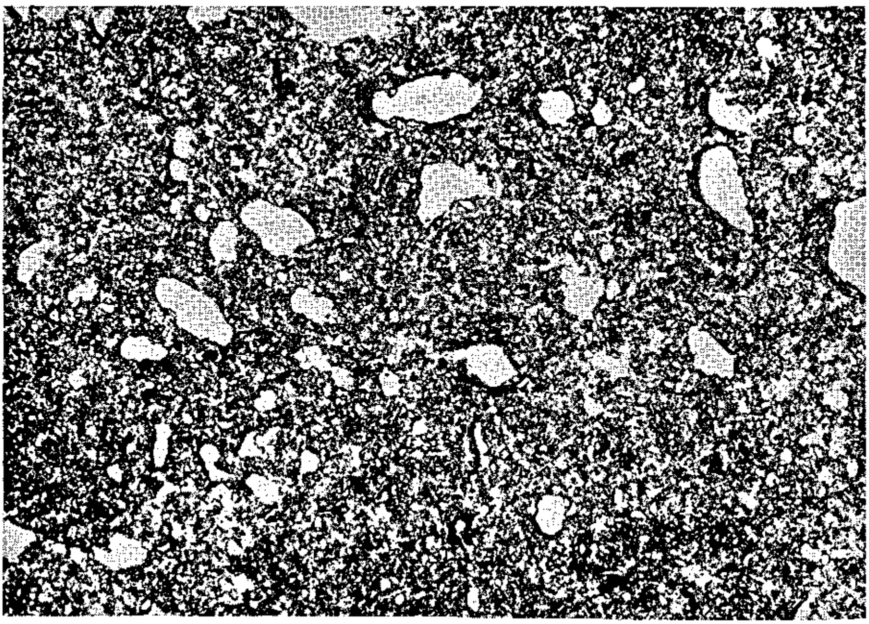


Photo 18 (top). Picture of biopores in spongy subsoil of light-textured tidal deposit soil (Barendrecht profile description P1, cf. chapter 3)

Photo 19. B2t-horizon of Typic Normudalf (7TH APPROX., 1964) *developed in loess. The black rims in photo 19 around biopores were found to exist of birefringent very fine material (illuviation cutans,* BREWER, 1960)

Both micro-photos of thin sections with plain light. Magn. 22×

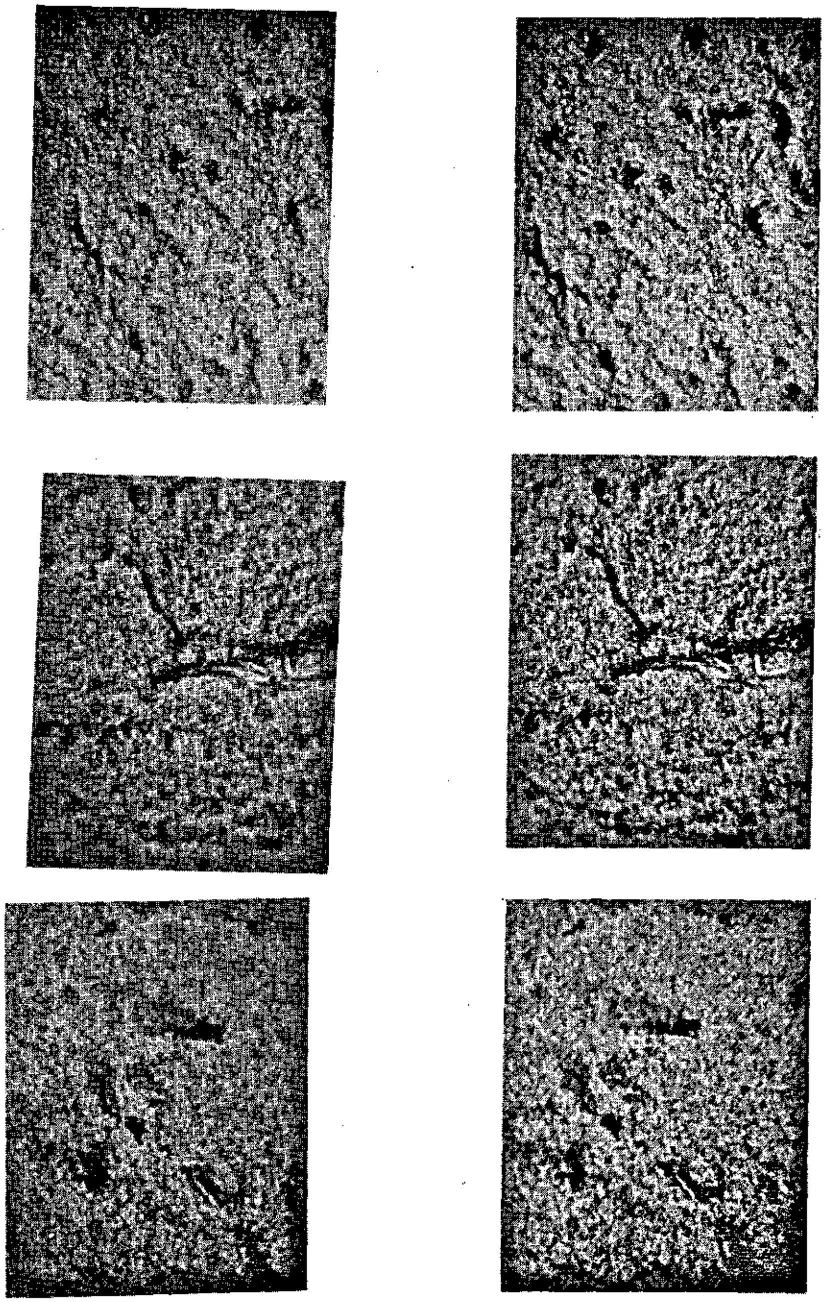
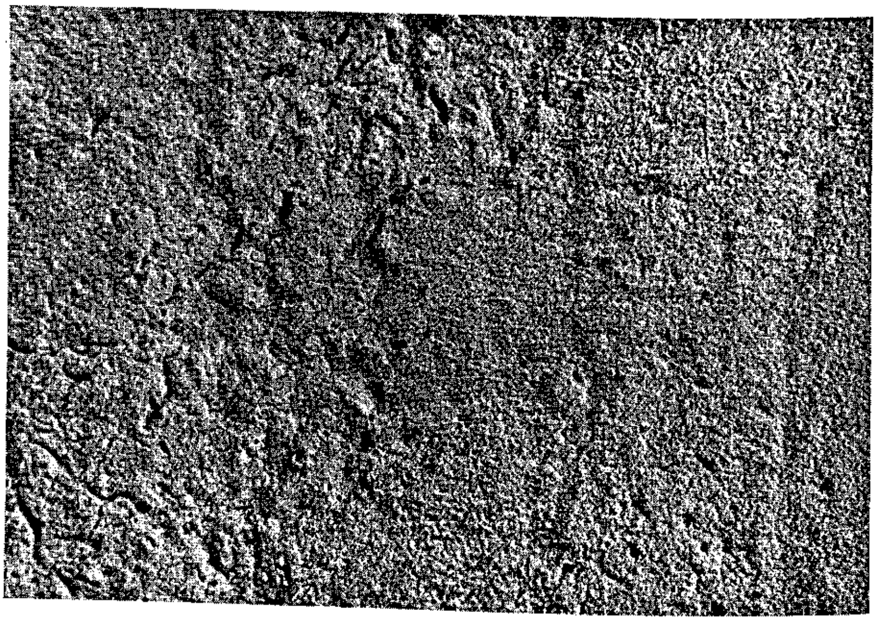


Photo 20 (top), 21 and 22. Stereo pairs showing biopores as they occur in soil peels of sandy soils Soil Rolde 3 (cf. chapter 6). These micro-photos were taken with a camera attached to a stereomicroscope.
Pictures show biopores cut normal to their length axe (top), according to their length axe (middle) and oblique (bottom). Magn. about 6× (cf. VAN DER PLAS and SLAGER, 1964)



Pictures of biopores in a sandy soil (Rolde 3, cf. chapter 6)

Photo 23 (top). Abundant biopores, depth 60 cm

Photo 24. Less biopores and only occurring in the part of soil where the stratification was disturbed, depth 90 cm.

Photos of soil peels. Magn. 1× (cf. 2.5)

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Appendix I. Some notes on methods and terms used in this publication

A. Methods

1. *The soil profile descriptions* were prepared according to the SOIL SURVEY MANUAL (1962). When describing soil structure the nomenclature was used of the Soil Survey Manual if it provided appropriate terms. If not, descriptive terms were used, which were adopted from the soil structure classification of JONGERIUS (1957). The detailed description of soil structure, which was presented for each soil, was also adopted from the classification of JONGERIUS (1957). For the readers' comfort part of this classification is reproduced below. Minor changes were introduced.

The description of soil structure includes in this scheme: type, porosity, size and grade.

TYPE

A3a: granular
A4a: subangular blocky
A5a: angular blocky
B3a: compound rough prismatic
B3b: compound smooth prismatic
B5a: (single) rough prismatic
B5c: (single) smooth prismatic
C2: compound plate
G1b: sponge
H1: stratified sedimentation structure
H2: partly disturbed stratified sedimentation structure

POROSITY (unlike JONGERIUS, 1957)

Two types of small biopores were recognized, viz., very fine (smaller than 1 mm) and fine (1–2 mm) biopores. The following combinations were used:

1. very fine and fine biopores
2. mainly very fine biopores
3. mainly fine biopores
4. no biopores

Further the following subdivision was made according to the abundance of biopores: few (—), common ( ) and many (+). The (—) and (+) were added to the porosity number, e.g. 1+ or 3—.

SIZE (in millimetres)

	I	II	III	IV	V
Spherical	<1	1–2	2–5	5–10	10–20
Prismlike	<10	10–20	20–50	50–100	–
Platelike	–	–	–	–	>10

GRADE

The numbers ½ and 1 approximately correspond to the concept of 'weak' of the SOIL SURVEY MANUAL (1962), 1½ and 2 to 'moderate' and 2½ and 3 to 'strong'.

The sequence of notation is: type, porosity, size and grade. In case of compound structures the notation of the compound element is given first followed by the notation of the composing element. If two non-compound structural types occur at the same depth, the notations are connected by a (+) sign. If an intergrade type of structure occurs a (—) sign is used. If a change in soil structure is noticed with increasing depth which is gradual, a (→) sign is used.

2. *Counting the numbers of biopores* larger than 2 mm. was done in two classes viz., 2–4 mm and larger than 4 mm. During the profile description horizontal sections of 25 × 20 cm. were cleaned at regular intervals in the profile wall (cf. section 2.5 and HOEKSEMA and OP 'T HOF, 1960).

3. *Soil porosity and pF.* During fielddescriptions undisturbed samples were taken by means of cylindrical sample cores of 100 cm³. For pore space determination (determination of soil porosity in the total soil mass) (PS%) the samples were dried in the laboratory at 105°C. The volume of the solid soil material was calculated from the dry weight, divided by a specific weight of 2.65 g/cm³ of the solid soil material. For each % of organic matter which the sample contained, the specific weight was reduced with 0.02 g/cm³. The volume of the solid soil material was subtracted from 100 cm³ and the result was reported as the pore space in % (PS%). For pF determinations the filled sample cores were placed on a sandbed for pF values of 0.4 and 2.0 resp. After each determination the sample was weighed. Afterwards the sample was dried and the volumes of solid soil material, water and air at the various pF values were calculated. The determination at pF 4.2 was performed on separate samples using a pressure membrane apparatus. All volumes were calculated on basis of the total soil volume at pF 2.0.

The reported values for the pore space and pF determinations result from duplicate, sometimes even from triplicate determinations.

4. *Water permeability.* During fielddescriptions undisturbed samples were taken by means of cylindrical sample cores of 100 cm³ which were about 5 cm high. In the la-

boratory the samples were placed during one hour in a water permeability apparatus under a constant over-pressure of 1 inch of water. The waterflow passed the samples from bottom to top, to avoid air inclusions. The amount of water, which passed the sample in 1 hour, was measured. The reported K-value in cm/h was calculated according to HÉNIN (1961) from the height of the sample core, the volume of water which passed the sample in 1 hour, the height of the column of water over-pressure, and the cross section of the sample core. The reported values result from duplicate determinations.

5. *Calcium carbonate.* Disturbed samples were taken during field descriptions. In the laboratory a weighed amount of soil (fine earth fraction) was exposed to 25% HCl for 2 hours and the amount of carbondioxide, which developed, was determined volumetrically. The reported values result from duplicate determinations.

6. *Organic matter.* Oxidation by means of a mixture containing sodium bichromate and hydrochloric acid. Titration with potassium permanganate. The reported values result from duplicate determinations.

7. *Particle size analysis.* Effectuated for fine earth fraction only. Fractions over 50 micron with sieve analysis, using Rotap sieves. Fractions finer than 50 micron with pipet analysis, using the Robinson pipet device. Removal of organic matter with 10% H_2O_2; removal of calcium carbonate with 0.2 N HCl. Dispersion with sodium pyrophosphate 0.12 N. The reported values result from duplicate determinations.

8. *Phosphate determinations.* Extraction with 1% citric acid. Colorimetric determination using molybdene blue. The reported values result from duplicate determinations.

9. *pH (water and $CaCl_2$).* 1 : 1 ratio of soil and water or soil and 0.01 M $CaCl_2$. The reported values result from duplicate determinations.

B. Terms

Trend. The term trend was used in this publication to denote the vertical succession of layers with regard to any soil property. Two soils, for instance, were said to have the same soil textural trend, if at every depth the soils had the same soil texture. The term trend was used in this publication with regard to the following soil characteristics: texture, structure, biopores, calcium carbonate content, organic matter content, water permeability, soil-water-air-ratio at various pF values and pore space.

Biological activity. This term (cf. HOEKSEMA, 1953) was used to designate the activity of the soil flora and soil fauna; in general, however, it was used in this publication for the soil animal activity only.

Biological homogenization. Biological homogenization is the mixing of soil constituents by means of soil fauna and soil flora, resulting ultimately in at least a constancy of the clay content (within narrow limits) over that part of the soil which is called homogenized (cf. 2.5). This definition was changed from the original one, presented by HOEKSEMA (1953).

Perforation. The formation of biopores.

Disturbance. Disturbance of stratified structures by soil animals.

Biopores. Soil pores which result from biological activity and which may be recognized as such.

Bioporosity. The fraction of the pore space which is included in biopores.

Permanent heterogeneous pore-size distribution. This term was used to designate a pore-size distribution which contains both small and large pores for the whole year (cf. HOEKSEMA, 1953).

Soil structure (cf. JONGERIUS, 1957). The spatial arrangement of the elementary constituents and any aggregates thereof, and of the cavities occurring in the soil.

Biogenic structures (cf. DE HAAN, 1965). Structures resulting from biological activity.

Physicogenic structures (cf. DE HAAN, 1965). Structures resulting from soil physical processes, such as swelling and shrinking.

Geogenic structures (cf. JONGERIUS, 1961). Structures which show the characteristics of their geological mode of formation, such as undisturbed stratified sedimentation structures.

Appendix II

Profile descriptions and analytical data
Profiles P 1—P 15

Profile P1: Barendrecht

Location:	topographical map of the Netherlands, scale 1 : 50.000 (1958), sheet: 37 East, coordinates: N 429.675-E 098.090. (former Island of IJsselmonde)
Described:	by S. SLAGER, 27.3.1963
Climate:	formerly: temperate humid. Since 1948: heating throughout the year and sprinkling, resulting in an annual precipitation of some 2000 mm
Landuse:	formerly horticultural crops without glass cover. Since 1948: horticultural crops in glass house. Crops: lettuce, tomatoes, cucumbers. Manuring: 60 tons farmyard manure per hectare per year and artificial manure. Heating, sprinkling and artificial drainage. Soil desinfectation by means of steaming. Soil tilth by means of a spade
Parent material:	light tidal deposit
Physiography:	levee of tidal creek
Hydrology:	1. permeability: moderate 2. groundwater: deeper than 2 m 3. drainage class: moderately well drained 4. artificial drainage: tile drainage every 12 m on a depth of 80 cm
Root distribution:	depth of penetration about 50 cm
Classification:	*Anthraquept* (cf. chapter 7)

PROFILE DESCRIPTION

Ap1,	0– 19 cm	very dark grayish brown (10YR 3/2), moist; silt loam; side by side strong fine crumb, strong fine subangular blocky and strong coarse clods; friable; diffuse and wavy on:
Ap2,	19– 35 cm	very dark (grayish) brown (10YR 2.5/2), moist; silt loam; strong fine crumb; very friable; diffuse and wavy on:
A13,	35– 48 cm	dark gray to dark grayish brown (10YR 4/1.5), moist; silt loam; strong very fine subangular blocky; friable; few, fine, faint, strong brown mottles; diffuse and wavy on:
B2,	48– 66 cm	dark gray to dark grayish brown (10YR 4/1.5), moist; loam; compound weak medium prismatic and strong very fine subangular blocky; friable; few, fine, faint, strong brown mottles; diffuse and wavy on:
B31,	66– 93 cm	dark gray to dark grayish brown (10YR 4/1.5), moist; sandy loam; side by side weak very fine subangular blocky and porous sponge; very friable; common, medium, faint, strong brown mottles; diffuse and wavy on:
B32g,	93–104 cm	dark gray to grayish brown (2.5Y 4.5/1), moist; sandy loam; side by side weak very fine subangular blocky and porous sponge; very friable; common, medium, distinct, strong brown mottles

DETAILED DESCRIPTION OF SOIL STRUCTURE

Ap1,	0–19 cm	30% A3a 1+ II 3 30% A4a 1 IV 2½ 40% dense clods of some centimetres diameter
Ap2,	19– 35 cm	90% A3a 1+ II 3
A13,	35– 48 cm	90% A4a 1 III 2½
B2,	48– 66 cm	B3a III 1/A4a 1 III 2½
B31,	66– 93 cm	A4a 1 III 1 + G1b
B32g,	93–104 cm	A4a 1 III ½ + G1b

SOIL POROSITY

horizon	depth in cm	PS%
Ap1	12	61.4
Ap2	24	66.8
A13	39	50.0
B2	63	44.6

ANALYTICAL DATA

horizon	*depth in cm*	*organic matter %*	$CaCO_3$ *%*	*pH*		*particle size distribution in μ*					
				H_2O	0.01*M* $CaCl_2$	>*210*	*105–210*	*50–105*	*16–50*	*2–16*	<*2*
Ap1	0–10	12.9	7.6	7.2	7.1	2.7	2.6	23.8	41.7	10.7	18.5
Ap1	10–20	11.6	7.7	7.3	7.0	2.6	2.1	24.7	40.9	11.1	18.6
Ap2	20–30	11.3	7.8	7.3	6.9	2.1	1.7	26.2	43.2	10.4	16.4
Ap2, A13	30–40	5.8	9.6	7.5	7.2	1.4	1.4	19.7	44.0	15.1	18.4
A13	40–50	4.0	11.4	7.7	7.3	0.9	1.1	23.3	48.5	10.0	16.2
B2, B31, B32g	50–100	1.0	16.2	7.8	7.5	1.0	2.0	26.0	50.0	11.0	10.0

PHOSPHATE CONTENT

horizon	*depth in cm*	*ppm* P_2O_5
Ap1	0–10	1550
Ap1	10–20	1500
Ap2	20–30	1370
Ap2, A13	30–40	680
A13	40–50	290

Profile P2: Barendrecht

Location:	topographical map of the Netherlands, scale 1 : 50.000 (1958), sheet: 37 East, coordinates: N. 429.950–E 098.030. (former Island of IJsselmonde)
Described:	by S. SLAGER, 22.4.1963
Climate:	temperate humid
Landuse:	arable land. Crops: potatoes, wheat, barley, celeriac, sprouts, beets
Parent material:	light tidal deposit
Physiography:	levee of tidal creek
Hydrology:	1. permeability: moderately slow 2. groundwater: 130 cm 3. drainage class: moderately well drained 4. artificial drainage: tile drainage every 15 m on a depth of 80 cm
Root distribution:	depth of penetration: about 90 cm
Classification:	*Typic Normaquept* (7TH APPROXIMATION, 1964)

PROFILE DESCRIPTION

Ap1,	0– 17 cm	dark grayish brown (10YR 4/2), moist; silt loam; strong very fine angular blocky; firm; abrupt and wavy on:
Ap2,	17– 30 cm	dark grayish brown (10YR 4/2), moist; silt loam; strong very fine to fine angular blocky; very firm; abrupt and wavy on:
B1,	30– 47 cm	dark (grayish) brown (10YR 4.5/2), moist; silt loam; compound weak medium prismatic and weak very fine subangular blocky; slightly sticky, slightly plastic; few, fine, faint, strong brown mottles; gradual and smooth on:
B21,	47– 63 cm	(dark) grayish brown (2.5Y 4.5/2) moist; silt loam; structure as in B1-horizon; slightly sticky, slightly plastic; few, fine, prominent, strong brown mottles; diffuse and smooth on:
B22,	63– 93 cm	grayish brown (2.5Y 5/2) moist; silt loam; porous sponge changing into disturbed sedimentation pattern; slightly sticky, non plastic; common, fine, prominent, strong brown mottles; diffuse and smooth on:
B3g,	93–100 cm	olive gray (5Y 5/2) moist; silt loam; disturbed sedimentation pattern changing into undisturbed sedimentation pattern; slightly sticky, non plastic; many, fine, distinct, strong brown mottles

DETAILED DESCRIPTION OF SOIL STRUCTURE

Ap1,	0– 8 cm	A5a 1— II 3
Ap1,	8–17 cm	A5a (1— -3) III–IV 3
Ap2,	17–30 cm	A5a (3— -4) IV 3; roots grow along the partly shell-shaped pedfaces
B1,	30–47 cm	B3a III 1/A4a 1 III $\frac{1}{2}$
B21,	47–63 cm	B3a III 1/A4a 1 III $\frac{1}{2}$ → G1b
B22,	63–93 cm	G1b → H2
B3g,	93–100 cm	H2 → H1

SOIL POROSITY

horizon	*depth in cm*	*PS %*
Ap1	5	53.8
Ap2	28	46.2
B1	41	49.8
B21	59	48.6
B22	74	45.9

ANALYTICAL DATA

horizon	*depth in cm*	*organic matter %*	*$CaCO_3$ %*	*pH*		*particle size distribution in μ*					
				H_2O	*0.01 M $CaCl_2$*	*>210*	*105–210*	*50–105*	*16–50*	*2–16*	*<2*
Ap1	0–17	4.9	9.5	7.8	7.3	0.9	0.8	9.4	51.6	13.6	23.6
Ap2	17–30	4.4	10.9	7.8	7.3	0.7	0.8	9.2	50.1	15.9	23.1
B1	30–47	0.6	14.7	7.9	7.5	0.4	0.7	8.6	52.7	16.5	21.1
B21	47–63	0.6	16.9	8.0	7.5	0.7	1.4	12.9	56.4	13.5	15.1
B22	63–93	nd	16.6	8.1	7.5	0.7	1.3	20.0	56.8	11.2	10.0
B3g	93–100	nd	15.9	8.1	7.5	1.0	2.2	26.1	50.5	10.5	9.7

Profile P3: Barendrecht

Location:	topographical map of the Netherlands (1958), scale 1 : 50.000, sheet: 37 East, coordinates: N 429.770 — E 098.160. (former Island of IJsselmonde)
Described:	by S. SLAGER, 22.4.1963
Climate:	temperate humid
Landuse:	pasture
Parent material:	light tidal deposit
Physiography:	levee of the tidal creek
Hydrology:	1. permeability: moderate 2. groundwater: 100 cm 3. drainage class: somewhat imperfectly drained 4. artificial drainage: tile drainage every 15 m on a depth of 85 cm
Root distribution:	depth of penetration: about 80 cm
Classification:	*Humic Normaquept* (7TH APPROXIMATION, 1964)

PROFILE DESCRIPTION

A11,	0– 16 cm	black to very dark brown (10YR 2/1.5) moist; silt loam; compound weak very thick platy and strong very fine subangular blocky changing into moderate very fine subangular blocky; firm; clear and smooth on:
A12,	16– 26 cm	dark grayish brown (10YR 4/2) moist; silt loam; compound weak medium prismatic and moderate very fine subangular blocky; friable to firm; few, fine, faint, strong brown mottles; clear and smooth on:
B1,	26– 51 cm	grayish brown to gray (2.5Y 5/1) moist; silt loam; compound weak medium prismatic and weak very fine subangular blocky changing into porous sponge; slightly sticky, slightly plastic; common, fine, distinct, strong brown mottles; diffuse and smooth on:
B2,	51– 66 cm	grayish brown (2.5Y 5/2) moist; silt loam; porous sponge; slightly sticky, slightly plastic; common, medium, prominent, strong brown mottles; diffuse and smooth on:
B3g,	66–100 cm	gray to grayish brown (2.5Y 5/1) wet; silt loam; porous sponge changing into disturbed sedimentation pattern; slightly sticky, slightly plastic; common, medium, prominent, strong brown mottles

DETAILED DESCRIPTION OF SOIL STRUCTURE

A11,	0– 7 cm	C2 V ½/A4a 1 II 3
A11,	7– 16 cm	A4a 1 III 1½
A12,	16– 26 cm	B3a III 1/A4a 1 II–III 1½
B1,	26– 51 cm	(B3a III 1/A4a 1 II–III ½) → G1b
B2,	51– 66 cm	G1b
B3g,	66– 80 cm	G1b → H2
B3g,	80–100 cm	H2

SOIL POROSITY

horizon	*depth in cm*	*PS %*
A11	8	56.2
A12	25	53.5
B1	40	52.8
B2	58	52.2
B3g	74	47.7

ANALYTICAL DATA

horizon	*depth in cm*	*organic matter %*	*$CaCO_3$ %*	*pH*		*particle size distribution in μ*					
				H_2O	*0.01 M $CaCl_2$*	*>210*	*105–210*	*50–105*	*16–50*	*2–16*	*<2*
A11	0–16	15.7	6.8	7.3	6.9	1.6	2.7	8.4	50.3	14.8	22.2
A12	16–26	11.6	8.7	7.5	7.2	0.9	2.1	18.7	45.8	10.6	21.9
B1	26–51	5.6	12.9	7.6	7.3	0.6	1.3	17.1	43.1	13.3	24.6
B2	51–66	nd	17.2	8.0	7.5	0.8	1.5	20.4	41.7	14.4	21.2
B3g	66–100	nd	17.6	8.1	7.6	0.4	1.6	31.7	44.1	10.6	11.6

Profile P4: Zwijndrecht

Location:	topographical map of the Netherlands (1959), scale 1 : 50.000, sheet: 38 West, coordinates: N 425.800 — E 101.800. (former Island of IJsselmonde)
Described:	by S. SLAGER, 25.4.1963
Climate:	temperate humid
Landuse:	during some 30 years used for growing cucumbers under glass; since 1961 glass-house with lettuce, cauliflower and tomatoes. Manuring during some 30 years with 80 tons farmyard manure per hectare per year. Now: heating, sprinkling and artificial drainage. Soil disinfection by means of steaming. Soil tilth by means of a spade
Parent material:	heavy tidal deposit
Physiography:	basin of tidal landscape
Hydrology:	1. permeability: moderately slow 2. groundwater: 75 cm 3. drainage class: imperfectly drained 4. artificial drainage: tile drainage every 15 m on a depth of 100 cm
Root distribution:	depth of penetration: about 75 cm
Classification:	*Anthraquept* (cf. chapter 7)

PROFILE DESCRIPTION

Ap1,	0– 23 cm	black to very dark brown (10YR 2/1.5) moist; clay loam; side by side strong very fine to fine crumb and weak very fine subangular blocky; friable; gradual and wavy on:
Ap2,	23– 47 cm	very dark gray to very dark grayish brown (10YR 3/1.5) moist; silty clay loam; compound weak fine to medium prismatic and side by side medium very fine subangular blocky, strong very fine to fine crumb and weak very fine angular blocky; friable; gradual and wavy on:
B2,	47– 75 cm	dark grayish brown to gray (10YR 4.5/1.5) moist; silty clay; compound weak fine to medium prismatic and strong very fine to fine angular blocky; sticky and plastic; few, fine, faint strong brown mottles; gradual and smooth on:
Cg,	75–100 cm	Gray (5Y 5/1) wet; silty clay; strongly reduced

DETAILED DESCRIPTION OF SOIL STRUCTURE

Ap1,	0– 23 cm	60% A3a 1+ I–II 3 40% A4a 1+ I–II 1
Ap2,	23– 47 cm	B3a II–III 1 divided into: 50% A4a 1+ II–III 1½ 40% A3a 1+ I–II 2½ 10% A5a 1 II–III ½
B2,	47– 75 cm	B3a II–III 1/A5a 1 III–IV 2½

SOIL POROSITY

horizon	*depth in cm*	*PS %*
Ap1	13	69.8
Ap2	39	65.1
B2	58	55.6

ANALYTICAL DATA

horizon	*depth in cm*	*organic matter %*	*$CaCO_3$ %*	*pH*		*particle size distribution in μ*					
				H_2O	*0.01 M $CaCl_2$*	*>210*	*105–210*	*50–105*	*16–50*	*2–16*	*<2*
Ap1	0–23	12.3	0.3	6.7	6.3	19.4	5.1	4.9	30.6	11.2	28.8
Ap2	23–47	10.1	0.3	6.7	6.4	7.9	3.5	5.5	26.9	23.6	32.6
B2	47–75	3.0	0.1	6.9	6.6	0.4	0.9	3.3	29.8	24.6	41.0
Cg	75–100	nd	0.0	7.1	6.6	0.0	0.0	1.6	21.3	29.6	47.5

PHOSPHATE CONTENT

horizon	*depth in cm*	*ppm P_2O_5*
Ap1	0–23	3220
Ap2	23–47	2790
B2	47–75	1360
Cg	75–100	740

Profile P5: Zwijndrecht

Location:	topographical map of the Netherlands (1959), scale 1 : 50.000, sheet: 38 West, coordinates: N 425.770 — E 101.900. (former Island of IJsselmonde)
Described:	by S. SLAGER, 25.4.1963
Climate:	temperate humid
Landuse:	arable land with a crop rotation including many times wheat and sugar beets
Parent material:	heavy tidal deposit
Physiography:	basin of tidal landscape
Hydrology:	1. permeability: moderately slow 2. groundwater: 120 cm 3. drainage class: imperfectly drained
Root distribution:	depth of penetration about 80 cm
Classification:	*Typic Normaquept* (7TH APPROXIMATION, 1964)

PROFILE DESCRIPTION

Ap1,	0– 10 cm	dark grayish brown (10YR 4/2) moist; silty clay loam; strong very fine angular blocky; firm; gradual and smooth on:
Ap2 ,	10– 28 cm	dark grayish brown to gray (10YR 4.5/1.5) moist; silty clay loam; weak to strong fine subangular blocky; very firm; gradual and smooth on:
B1,	28– 43 cm	dark gray to gray (10YR 4.5/1) moist; silty clay; compound weak fine prismatic and strong very fine to fine angular blocky; very firm; gradual and smooth on:
B21g,	43– 75 cm	grayish brown to gray (2.5Y 5/1) moist; silty clay; side by side strong very fine prismatic and moderate very fine angular blocky; firm; common, fine, faint, yellowish brown mottles; gradual and smooth on:
B22g,	75– 90 cm	dark gray (10YR 4/1) moist; silty clay with peat remnants; weak fine subangular to angular blocky; firm, common, fine, faint, yellowish brown mottles; clear and wavy on:
B3g,	90–100 cm	very dark grayish brown to very dark gray (2.5Y 3/1) moist; silty clay with some peat remnants; medium very fine subangular to angular blocky; firm

DETAILED DESCRIPTION OF SOIL STRUCTURE

Ap1,	0– 10 cm	A5a 1—II 3
Ap2,	10– 18 cm	A5a 3 IV ½
Ap2,	18– 28 cm	A5a 3 IV 2½
B1,	28– 43 cm	B3a 1 II½/A5a 1 III–IV3
B21g,	43– 75 cm	B5c 1 — I–II 3 + A5a 1 — II 1½
B22g,	75– 90 cm	(A4a — A5a)1— IV ½
B3g,	90–100 cm	(A4a — A5a)1 II–III 1½

SOIL POROSITY

horizon	*depth in cm*	*PS %*
Ap1	8	48.4
Ap2	25	45.5
B1	41	48.0

ANALYTICAL DATA

horizon	*depth in cm*	*organic matter %*	*CaCO₃ %*	*pH*		*particle size distribution in μ*					
				H_2O	*0.01 M $CaCl_2$*	*>210*	*105–210*	*50–105*	*16–50*	*2–16*	*<2*
Ap1	0–10	2.3	1.4	7.4	7.1	1.5	2.2	4.3	30.9	25.5	35.6
Ap2	10–28	3.2	1.6	7.6	7.1	1.6	2.3	4.4	34.9	24.0	32.8
B1	28–43	2.1	2.3	7.7	7.3	1.2	2.8	2.1	24.0	27.4	42.5
B21g	43–75	1.8	0.0	7.6	7.2	0.0	0.0	1.6	23.9	28.3	46.2
B22g	75–90	nd	0.0	7.1	6.8	0.0	0.0	0.6	22.0	26.2	51.2
B3g	90–100	nd	0.0	6.3	6.0	0.0	0.0	0.2	22.6	29.6	47.6

Profile P6: Zwijndrecht

Location:	topographical map of the Netherlands (1959), scale 1 : 50.000, sheet: 38 West, coordinates: N 425.840 — E 101.630. (former Island of IJsselmonde)
Described:	by S. Slager and V. J. G. Houba, 10.5.1963
Climate:	temperate humid
Landuse:	pasture
Parent material:	heavy tidal deposit
Physiography:	basin of the tidal landscape
Hydrology:	1. permeability: slow 2. groundwater: 64 cm 3. drainage class: poorly to imperfectly drained 4. artificial drainage: ditches every 8 m, 50 cm deep
Root distribution:	depth of penetration: about 50 cm
Classification:	*Thapto Histic Normaquept* (7th Approximation, 1964)

PROFILE DESCRIPTION

A11,	0–10 cm	very dark brown to very dark grayish brown (10YR 2.5/2) moist; silty clay; strong very fine subangular blocky changing into compound moderate medium to coarse prismatic and strong very fine subangular blocky; firm; gradual and smooth on:
A12,	10–22 cm	olive brown (2.5Y 4/4) moist; silty clay; compound moderate medium to coarse prismatic and strong very fine subangular blocky changing into compound moderate coarse prismatic and strong fine angular blocky; firm; few, fine, faint, yellowish brown mottles; diffuse and smooth on:
B2g,	22–45 cm	dark gray (2.5Y 4/1) moist; silty clay; compound medium coarse prismatic and strong fine angular blocky; firm, common, fine, distinct, yellowish brown mottles; clear and wavy on:
IICg,	45–65 cm	very dark brown to very dark grayish brown (10 YR 2.5/2) wet; peaty silty clay; massive; sticky and plastic; intense reduction

DETAILED DESCRIPTION OF SOIL STRUCTURE

Ap1,	0– 4 cm	A4a 1 II–III 2½
Ap1, Ap2,	4–15 cm	B3a III–IV 1½/A4a 1 II–III 2½
Ap2, B2g,	15–45 cm	B3a IV 1½ /A5a 1— → 3 IV 3

SOIL POROSITY

horizon	*depth in cm*	*PS %*
Ap1	6	61.5
Ap2	17	61.6
B2g	37	56.1

ANALYTICAL DATA

horizon	*depth in cm*	*organic matter %*	$CaCO_3$ %	*pH*		*particle size distribution in μ*					
				H_2O	0.01 M $CaCl_2$	>210	105–210	50–105	16–50	2–16	<2
Ap1	0–10	11.9	0.0	5.7	5.3	1.8	1.2	2.6	20.8	27.5	46.1
Ap2	10–22	6.8	0.0	6.0	5.5	2.0	1.8	4.2	21.4	26.1	44.5
B2g	22–45	3.7	0.0	6.2	5.7	0.4	0.6	2.2	20.2	28.6	48.0
IICg	45–65	9.0	0.0	6.2	5.7	0.0	0.0	0.5	15.7	29.8	54.0

Profile P7: Beuningen

Location:	topographical map of the Netherlands, scale 1 : 25.000, (1954), sheet: 40C, coordinates: N 430.925 — E 182.565 (Land van Maas en Waal)
Described:	by S. SLAGER, 1.4.1964
Climate:	temperate humid
Landuse:	till 1952 grass-orchard with cattle-grazing. Since 1952 grass-mulch experimental field. Mulched plot
Parent material:	light on heavier river deposit
Hydrology:	1. permeability: moderately rapid 2. groundwater: deeper than 1.50 m 3. drainage class: well drained 4. artificial drainage: none
Root distribution:	depth of penetration more than 100 cm
Classification:	*Typic Eutrochrept* (7TH APPROXIMATION, 1964)

PROFILE DESCRIPTION

A11,	0– 18 cm	very dark grayish brown (10YR 3/2), moist; sandy loam; moderate, very fine subangular blocky; very friable; gradual and smooth on:
A12,	18– 32 cm	dark yellowish brown (10YR 4/4), moist; sandy loam; moderate to weak, very fine to fine subangular blocky; friable; diffuse and smooth on:
A13,	32– 47 cm	dark yellowish brown (10YR 4/4), moist; sandy loam; weak, fine subangular blocky; friable; diffuse and smooth on:
B1,	47– 62 cm	(dark) yellowish brown (10YR 4.5/4), moist; loam; strong to moderate, very fine subangular blocky; friable; diffuse and smooth on:
B2,	62– 88 cm	yellowish brown (10YR 5/4), moist; (silty) clay loam; moderate to weak, very fine subangular blocky; slightly sticky, non plastic; diffuse and smooth on:
B3,	88–120 cm	yellowish brown (10YR 5/4), moist; silt loam; porous sponge; friable; few, fine, faint, strong brown mottles

DETAILED DESCRIPTION OF SOIL STRUCTURE

A11,	0– 8 cm	A4a 1 II–III 1½
A11, A12,	8– 32 cm	A4a 1 III–IV 1½ → ½
A13,	32– 47 cm	A4a 1 IV ½
B1, B2,	47– 88 cm	A4a 1 II (–III) 2½ → ½
B3,	+ 88 cm	G1b

NUMBER OF BIOPORES PER M^2: cf. figure 1

SOIL POROSITY: cf. figure 2

ANALYTICAL DATA

horizon	*depth in cm*	*organic matter %*	$CaCO_3$ %	*pH* H_2O	*pH* 0.01 M $CaCl_2$	*particle size distribution in μ* >420	210–420	105–210	50–105	16–50	2–16	<2
A11	0–10	3.2	1.6	7.4	7.0	3.6	18.5	20.0	12.4	18.5	10.7	16.3
A11, A12	10–20	1.9	2.4	7.6	7.1	4.0	17.8	20.7	12.7	19.6	9.9	15.3
A12	20–30	1.2	2.7	7.6	7.0	3.6	17.4	21.3	12.7	19.8	10.7	14.5
A12, A13	30–40	0.9	3.7	7.8	7.3	3.3	18.9	21.8	12.2	18.4	10.8	14.6
A13, B1	40–50	0.6	3.9	7.7	7.2	2.3	19.9	22.5	11.8	17.8	11.1	14.6
B1	50–60	nd	4.6	7.8	7.3	1.0	9.5	15.4	13.8	26.4	14.5	19.4
B1, B2	60–70	nd	8.0	7.8	7.3	0.6	4.3	8.6	10.4	30.3	18.2	27.6
B2	70–80	nd	12.3	7.9	7.4	0.2	1.4	2.6	5.1	33.8	23.9	33.0
B2, B3	80–90	nd	13.0	7.9	7.2	0.4	1.6	5.2	15.4	34.6	19.5	23.3
B3	90–100	nd	14.9	8.0	7.5	0.2	0.8	4.0	22.8	37.5	15.3	19.4

Profile P8: Beuningen

Location:	topographical map of the Netherlands, scale 1 : 25.000, (1954), sheet: 40C, coordinates: N 430.925 — E 182.575 (Land van Maas en Waal)
Described:	by S. SLAGER, 2.4.1964
Climate:	temperate humid
Landuse:	till 1952 grass-orchard with cattle-grazing. Since 1952 grass mulch experimental field. Clean-cultivated plot
Parent material:	light on heavier river deposit
Physiography:	river levee
Hydrology:	1. permeability: moderately rapid 2. groundwater: deeper than 1.50 m 3. drainage class: well drained 4. artificial drainage: none
Root distribution:	depth of penetration more than 100 cm
Classification:	*Typic Eutrochrept* (7TH APPROXIMATION, 1964)

PROFILE DESCRIPTION

A11,	0–14 cm	very dark grayish brown (10YR 3/2), moist; sandy loam; moderate, very fine to fine subangular blocky; friable; clear and smooth on:
A12,	14–29 cm	very dark grayish brown to dark brown (10YR 3.5/2.5), moist; sandy loam; moderate to weak, very fine to fine subangular blocky; friable; gradual and slightly wavy on:
B1,	29–43 cm	dark brown to brown (10YR 4/3), moist; loam; weak very fine to fine subangular blocky; friable; diffuse and smooth on:
B2,	43–80 cm	brown to dark yellowish brown (10YR 4/3.5) moist; loam to silty clay loam; strong to moderate very fine subangular blocky; slightly sticky, non plastic; diffuse and smooth on:
B2, B3,	+80 cm	(dark) yellowish brown (10YR 4.5/4), moist; silty clay loam; moderate to weak, very fine subangular blocky; friable; few, fine, faint, strong brown mottles

DETAILED DESCRIPTION OF SOIL STRUCTURE

A11,A12,	0– 20 cm	A4a 1 III–IV 1½
A12,B1,	20– 43 cm	A4a 1 III–IV ½
B1, B2,	43–100 cm	A4a 1 III 2½ → ½
B3,	+ 100 cm	G1b

NUMBER OF BIOPORES PER M^2: cf. figure 1

SOIL POROSITY: cf. figure 2

ANALYTICAL DATA

horizon	*depth in cm*	*organic matter %*	*$CaCO_3$ %*	*pH*		*particle size distribution in μ*						
				H_2O	*0.01M $CaCl_2$*	*>420*	*210–420*	*105–210*	*50–105*	*16–50*	*2–16*	*<2*
A11	0–10	2.4	1.1	7.3	6.9	3.8	20.7	19.1	11.1	19.9	10.1	15.3
A12	10–20	1.5	2.5	7.7	7.1	5.2	22.2	19.1	10.5	18.0	10.2	14.8
A12, B1	20–30	0.8	3.0	7.9	7.2	4.1	23.2	21.3	10.8	17.7	9.4	13.5
B1	30–40	0.7	3.8	7.9	7.3	2.1	15.2	18.7	12.4	22.6	11.3	17.7
B1, B2	40–50	0.7	4.9	7.9	7.3	1.1	7.7	14.8	14.6	25.8	16.9	19.1
B2	50–60	nd.	6.2	8.2	7.5	0.9	6.4	12.6	14.3	30.3	14.8	20.7
B2	60–70	nd.	11.1	8.2	7.4	0.3	1.8	4.7	8.5	34.7	21.4	28.6
B2	70–80	nd.	13.5	8.1	7.5	0.4	1.9	2.8	6.3	39.8	20.4	28.4
B2	80–90	nd.	13.8	8.1	7.5	0.3	1.4	2.1	6.6	40.0	20.5	29.1
B3	90–100	nd.	12.7	8.1	7.5	0.3	1.3	2.1	7.4	41.3	19.6	28.0

Profile P9: Oosterhout

Location:	topographical map of the Netherlands, scale 1 : 25.000, (1954), sheet: 40C, coordinates: N 433.340 — E 184.155 (Betuwe)
Described:	by S. SLAGER and V. J. G. HOUBA, 15.7.1963
Climate:	temperate humid
Landuse:	till 1937 pasture. From 1937 till 1948 orchard with clean cultivation. Since 1948 orchard with grass mulching
Parent material:	rather heavy textured river deposit (clay plug)
Physiography:	in former river streambed
Hydrology:	1. permeability: very slow 2. groundwater: deeper than 1.20 m 3. drainage class: imperfectly drained 4. artificial drainage: none
Root distribution:	depth of penetration about 50 cm
Classification:	*Humic Normaquept* (7TH APPROXIMATION, 1964)

PROFILE DESCRIPTION

A11,	0– 30 cm	(very) dark grayish brown (10YR 3.5/2), moist; silty clay loam; weak very thick compound platy subdivided into strong very fine subangular blocky, followed, with increasing depth, by moderate medium compound prismatic subdivided into strong very fine subangular blocky, followed with increasing depth by weak coarse compound prismatic subdivided into strong fine angular blocky; friable to firm; few, fine, faint black mottles; diffuse and smooth on:
B1g	30– 43 cm	dark grayish brown (10YR 4/2), moist; silty clay; weak coarse compound prismatic subdivided into strong fine angular blocky; friable to firm; few, fine, faint, black and strong brown mottles; diffuse and smooth on:
B2g,	43– 70 cm	grayish brown (2.5Y 5/2), moist; silty clay; strong coarse compound prismatic subdivided into side by side weak medium prismatic and moderate fine angular blocky; firm to very firm; few, fine, faint, black and strong brown mottles; diffuse and smooth on:
Cg,	70–115 cm	grayish brown (2.5Y 5/2), moist; silty clay; weak medium compound prismatic subdivided into moderate fine angular blocky; firm to friable; few, fine, faint black mottles and many, coarse, distinct, strong brown mottles

DETAILED DESCRIPTION OF SOIL STRUCTURE

C1,	0– 5 cm	C2 V 1/A4a 1— III 2½
A1,	5– 16 cm	B3a III 2/A4a 1 III 2½
A1, B1g,	16– 43 cm	B3a IV 1/A5a 1— IV 2½
A2g,	43– 70 cm	B3b IV 3/(B5c 3— III ½) + (A5a 3— IV 1½)
Bg,	70–120 cm	B3a III 1/A5a 3— III 1½

NUMBER OF BIOPORES PER M²: cf. figure 3

SOIL POROSITY

horizon	*depth in cm*	*PS %*
A1	17–22	49.0
B1g	35–40	42.3
B2g	52–57	46.6
B2g	75–80	47.4

ANALYTICAL DATA

horizon	*depth in cm*	*organic matter %*	*$CaCO_3$ %*	*pH*		*particle size distribution in μ*					
				H_2O	*0.01 M $CaCl_2$*	*>210*	*105–210*	*50–105*	*16–50*	*2–16*	*<2*
A1	0–30	3.6	0.0	6.1	5.5	2.2	7.7	6.6	17.5	29.8	36.2
B1g	30–43	1.4	0.1	6.8	6.5	0.8	4.2	4.4	16.0	33.6	41.0
B2g	43–70	nd.	0.1	7.1	6.8	0.5	2.4	2.7	8.1	32.1	54.2
Cg	70–120	nd.	0.1	7.4	6.8	0.8	2.5	3.1	7.9	34.4	51.3

Profile P10: Oosterhout

Location:	topographical map of the Netherlands, scale 1 : 25.000, (1954), sheet: 40C, coordinates: N 433.200 — E 184.350 (Betuwe)
Described:	by S. SLAGER and V. J. G. HOUBA, 22.7.1963
Climate:	temperate humid
Landuse:	till 1937 pasture. From 1937 till 1948 orchard with clean cultivation. Since 1948 orchard with grass mulching
Parent material:	medium textured river deposit, becoming lighter textured with increasing depth
Physiography:	river levee
Hydrology:	1. permeability: moderately rapid 2. groundwater: 135 cm, in winter some 70 cm 3. drainage class: somewhat imperfectly drained 4. artificial drainage: none
Root distribution:	till 70 cm many roots occur; between 70 and 120 cm roots occur, most of them being dead
Classification:	*Aeric Mollic Normaquept* (7TH APPROXIMATION, 1964)

PROFILE DESCRIPTION

A11,	0– 19 cm	dark brown to brown (10YR 4/3), moist; loam; weak very thick platy subdivided into medium very fine to fine subangular blocky, followed with increasing depth by side by side medium very fine to fine subangular blocky and medium fine granular; very friable to friable; diffuse and smooth on:
A12,	19– 37 cm	yellowish brown, (10YR 5/4), moist; loam; side by side weak coarse compound prismatic subdivided into strong very fine to fine subangular blocky and strong very fine to fine subangular blocky; friable; few, fine, faint, black mottles; diffuse and smooth on:
B1,	37– 45 cm	(light) yellowish brown (10YR 5.5/4) moist; loam; structure intermediate between the structures of A12 and B21 horizons; friable; few, fine, faint, black mottles; gradual and smooth on:
B21,	45– 71 cm	light brownish yellow (10YR 6/2), moist; sandy loam; porous sponge; friable; few, fine, faint, black mottles, common, fine, faint strong brown mottles; clear and smooth on:
B22g,	71– 93 cm	(light) grayish brown (2.5Y 5.5/2), moist; sandy loam; porous sponge; friable to slightly sticky, non plastic; many, coarse, faint, strong brown mottles; abrupt and smooth on:
B3g	93–122 cm	grayish brown (2.5Y 5/2), wet; sandy loam; disturbed sedimentation structure; slightly sticky, non plastic; many, coarse, faint, strong brown mottles; abrupt and smooth on:
Cg,	122–130 cm	grayish brown (2.5Y 5/2), wet; sand; undisturbed stratified sedimentation structure; non sticky, non plastic; many, coarse, faint, black and strong brown mottles

DETAILED DESCRIPTION OF SOIL STRUCTURE

A11,	0– 8 cm	C2 V 1/A4a 1— III–IV 1½
A11,	8–19 cm	50% A4a 1 III–IV 1½ 50% A3a 1 II 1½
A12, B21,	19–41 cm	(B3a IV 1/A4a 1 III–IV 2½) + (A4a 1 III–IV 2½)
B21, B22g,	41–93 cm	G1b
B3g,	93–122 cm	H2
Cg,	+122 cm	H1

NUMBER OF BIOPORES PER M²: cf. figure 3

SOIL POROSITY

horizon	*depth in cm*	*PS %*
A11	8–13	46.2
A12	25–30	40.5
B21	50–55	44.9
B22g	78–83	38.5
B3g	100–105	40.4

ANALYTICAL DATA

horizon	*depth in cm*	*organic matter %*	*$CaCO_3$ %*	*pH*		*particle size distribution in μ*					
				H_2O	*0.01 M $CaCl_2$*	*>210*	*105–210*	*50–105*	*16–50*	*2–16*	*<2*
A11	0–19	2.9	2.2	7.7	7.2	3.3	19.1	14.3	19.1	18.8	25.4
A12	19–37	1.3	1.9	8.1	7.5	2.2	15.4	12.7	22.2	22.2	25.3
B1	37–45	0.8	5.0	8.1	7.4	1.2	23.6	18.6	16.4	26.6	13.6
B21	45–71	0.5	15.9	7.8	7.4	0.9	31.7	27.1	17.9	10.2	12.2
B22g	71–93	nd.	17.9	8.3	7.5	0.3	25.3	33.9	21.0	8.7	10.8
B3g	93–122I	nd.	18.7	8.4	7.5	1.1	23.2	32.3	23.2	9.9	10.3
B3g	93–122II	nd.	24.6	8.1	7.5	1.4	3.6	9.8	32.9	26.4	25.9
Cg	122–130	nd.	4.8	8.4	7.4	62.6	32.8	2.9	0.5	0.5	0.7

Profile P11: Slijk-Ewijk

Location:	topographical map of the Netherlands, scale 1 : 25.000 (1954), sheet: 40 C, coordinates: N 433.8 — E 128.4 (Betuwe)
Described:	by S. Slager and W. L. Asin, 3.8.1962
Climate:	temperate humid
Landuse:	Grass mulch orchard, well dressed with natural and artificial manure
Parent material:	medium to heavy textured on light textured river deposit
Physiography:	area transitional between riverlevee and river basin
Hydrology:	1. permeability: moderately rapid on rapid 2. groundwater: 1.70 m below surface. During winter deeper than 1 m below surface 3. drainage class: moderately well drained 4. artificial drainage: no tile drainage. The profile is situated in an area where the groundwater level has been lowered substantially
Root distribution:	depth of penetration about 90 centimeters, mostly through biopores
Classification:	*Aeric Mollic Normaquept* (7th Approximation, 1964)

PROFILE DESCRIPTION

A1,	0– 24 cm	dark grayish brown (10YR 4/2) moist; clay loam; compound moderate very thick platy subdivided into strong very fine to fine subangular blocky changing with increasing depth into compound moderate coarse prismatic subdivided into moderate very fine subangular to angular blocky; slightly sticky and slightly plastic; few, fine, faint, strong brown and black mottles; gradual and smooth on:
B21,	24– 49 cm	dark brown to brown (10YR 4/3) moist; clay loam; compound moderate coarse prismatic subdivided into strong very fine angular blocky; sticky and plastic; few, fine, faint, strong brown and black mottles; gradual and wavy on:
B22,	49– 70 cm	dark grayish brown (10YR 4/2) moist; clay loam; compound moderate coarse prismatic subdivided into fine strong angular blocky; sticky and plastic; few, fine, distinct, strong brown and black mottles; gradual and smooth on:
B23,	70– 90 cm	dark grayish brown (10YR 4/2) moist; clay loam; moderate very coarse prismatic; slightly sticky, slightly plastic; common, fine, distinct, strong brown and black mottles; clear and smooth on:
II B31g,	90–102 cm	grayish brown (2.5Y 5/1) moist; sandy loam; disturbed sedimentation structure; very friable; few, fine, distinct, strong brown and black mottles; diffuse and smooth on:
II B32g,	102–115 cm	gray to light gray (10YR 6/1) moist; sandy loam; disturbed sedimentation structure; very friable to loose; many, fine, prominent strong brown mottles

DETAILED DESCRIPTION OF SOIL STRUCTURE

A11,	0– 7 cm	C 2 V 2/A4 1 III–IV 2½
A12,	7–24 cm	B3a IV 2/(A4 → A5) 1 III 1½
B21,	24–49 cm	B3a IV 2/A5 2 II–III 2½
B22,	49–70 cm	B3a IV 2/A5 1— IV 2½
B23,	70–90 cm	B5c 1 V 2
IIB31g, IIB32g,	90–115 cm	H2

NUMBER OF BIOPORES PER M^2

horizon	*depth*	*2–4 mm*	*>4 mm*
A1	5 cm	660	560
A1	15 cm	660	300
B21	30 cm	340	440
B22	60 cm	160	180

SOIL POROSITY

horizon	*depth in cm*	*PS %*
A1	5	55.4
A1	15	49.4
B21	33	42.8
B22	63	41.9
II B32g	103	41.3

ANALYTICAL DATA

horizon	*depth in cm*	*$CaCO_3$ %*	*pH*		*particle size distribution in μ*				
			H_2O	*0.01 M $CaCl_2$*	*>210*	*105–210*	*50–105*	*2–50*	*<2*
A1	10–15	0.0	6.4	5.9	5.3	10.7	8.5	44.8	30.7
B21	30–35	0.0	6.8	6.4	3.9	9.5	7.9	47.3	31.4
B22	50–60	0.0	6.9	6.4	3.1	12.3	9.8	39.0	35.8
II B31g	95–100	13.1	8.3	7.3	2.6	43.5	28.2	19.5	6.2

Profile P12: Slijk-Ewijk

Location:	topographical map of the Netherlands, scale 1 : 25.000, (1954), sheet 40 C, coordinates: N 433.7 — E 182.4 (Betuwe)
Described:	by S. SLAGER and W. L. ASIN, 21.8.1962
Climate:	temperate humid
Landuse:	Arable land
Parent material:	medium to heavy on light river deposit
Physiography:	area transitional between river levee and riverbasin
Hydrology:	1. permeability: rather slow 2. groundwater: 1.70 m below surface, in winter deeper than 1 m below surface 3. drainage class: somewhat imperfectly drained 4. artificial drainage: no tile drainage. The profile is situated in an area where the groundwaterlevel has been substantially lowered
Root distribution:	depth of penetration about 50 cm, exclusively along fissures
Classification:	*Aeric Normaquept* (7TH APPROXIMATION, 1964)

PROFILE DESCRIPTION

Ap,	0– 33 cm	dark brown to brown (10YR 4/3) moist; clay loam; strong very fine angular blocky changing with increasing depth into strong very thick platy with shell-shaped fissures and prominent rootprints subdivided into some very coarse angular blocky elements; very firm; few, fine, faint, strong brown mottles; clear and smooth on:
B21,	33– 45 cm	dark brown to brown (10YR 4/3) moist; silty clay loam; compound weak coarse prismatic, subdivided into strong fine angular blocky; firm to very firm; few, fine, faint, strong brown and black mottles; clear and smooth on:
B22,	45– 66 cm	grayish brown (10YR 5.5/2) moist; silty clay; compound coarse prismatic subdivided into strong fine angular blocky; firm; few, fine, distinct, strong brown and black mottles; gradual and smooth on:
B23g,	66– 80 cm	grayish brown (10YR 5/2) moist; loam; strong very coarse prismatic; slightly sticky, slightly plastic; many, fine, distinct, strong brown and black mottles; clear and smooth on:
II B31g,	80– 90 cm	pale brown (10YR 6/2) moist; sand; disturbed sedimentation structure; loose to very friable; many, fine, distinct strong brown mottles; abrupt and smooth on:
II B32g,	90–115 cm	grayish brown to light yellowish brown (2.5Y 5.5/2) moist; loam; disturbed sedimentation structure; friable; many, coarse, distinct, strong brown and black mottles

DETAILED DESCRIPTION OF SOIL STRUCTURE

Ap,	0– 3 cm	A5 1 III 3
Ap,	3–33 cm	compound very thick platy with shell-shaped fissures and prominent root prints, subdivided into some very coarse very dense angular blocky elements.
B21, B22,	33–66 cm	B3a IV 1/A5 1 IV 2½
B23g,	66–80 cm	B5c 1 IV 3
II B31g, II B32g,	80–115 cm	H2

NUMBER OF BIOPORES PER M^2

horizon	*depth in cm*	*2–4 mm*	*>4 mm*
Ap	15	20	20
B21	40	360	60
B22	55	220	0
B23g	75	100	0

SOIL POROSITY

horizon	*depth in cm*	*PS %*
Ap	18	40.6
B21	38	43.6
B22	58	46.1
II B32g	93	43.4

ANALYTICAL DATA

horizon	*depth in cm*	*$CaCO_3$ %*	*pH*		*particle size distribution in μ*				
			H_2O	*0.01 M $CaCl_2$*	*>210*	*105–210*	*50–105*	*2–50*	*<2*
Ap	5–15	0.0	6.4	6.4	5.8	10.0	7.7	48.1	28.4
B21	35–40	0.0	6.9	6.5	3.2	5.7	5.9	45.6	39.6
B22	55–60	0.0	7.2	6.5	1.4	2.0	2.5	48.4	45.7
II B31g	82–87	12.4	8.2	7.4	3.7	66.7	18.4	7.0	4.2
II B32g	95–105	21.0	8.6	7.7	1.0	9.8	28.2	47.3	13.7

Profile P13: Slijk-Ewijk

Location:	topographical map of the Netherlands, scale 1 : 25.000, (1954), sheet 40 C, coordinates: N 433.7 — E 182.4 (Betuwe)
Described:	by S. SLAGER and W. L. ASIN, 2.8.1962
Climate:	temperate humid
Landuse:	Grass mulch orchard
Parent material:	medium textured on heavy textured river deposit
Physiography:	area transitional between river levee and river basin
Hydrology:	1. permeability: moderately slow 2. groundwater: 1.90 m below surface, in winter 1 m below surface 3. drainage class: somewhat imperfectly drained 4. artificial drainage: no tile drainage. The profile is situated in an area where the groundwater level has been lowered substantially
Root distribution:	depth of penetration: about 70 cm
Classification:	*Typic Normaquept* (7TH APPROXIMATION, 1964)

PROFILE DESCRIPTION

A1,	0–24 cm	very dark grayish brown changing into dark grayish brown with increasing depth (10YR 3/2 → 10YR 4/2) moist; clay loam; moderate very fine subangular blocky changing with increasing depth into compound moderate coarse prismatic subdivided into strong very fine subangular to angular blocky; friable to firm; few, fine, faint, strong brown mottles; diffuse and smooth on:
B21,	24–63 cm	dark grayish brown to olive brown (10YR 4/2) moist; silty clay loam, compound moderate very coarse prismatic subdivided into strong very fine angular blocky; very firm; few, fine, faint, strong brown and black mottles; clear and smooth on:
II B22g,	63–80 cm	grayish brown (10YR 5/2) moist; silty clay; side by side compound strong very coarse prismatic subdivided into moderate fine angular blocky and weak medium prismatic; very firm; many, fine, distinct, strong brown and black mottles

DETAILED DESCRIPTION OF SOIL STRUCTURE

A1,	0–8 cm	A4 1 III 1½
A1,.	8–24 cm	B3a IV 1½/(A4–A5) 1 III 2½
B21,	24–63 cm	B3a V 1½/A5 1 → 3 III 2½
IIB22g,	63–80 cm	(B3a V 3/A5 1 → 3 IV 2) + (B5a 3— III ½)

NUMBER OF BIOPORES PER M^2

horizon	*depth in cm*	*2–4 mm*	*>4 mm*
A1	5	520	360
A1	15	440	400
B21	35	760	360
II B22g	65	140	300

SOIL POROSITY

horizon	*depth in cm*	*PS %*
A1	8	50.1
B21	43	42.3
II B22g	68	44.9

ANALYTICAL DATA

horizon	*depth in cm*	*$CaCO_3$* %	*pH*		*particle size distribution in μ*				
			H_2O	*0.01 M $CaCl_2$*	*>210*	*105–210*	*50–105*	*2–50*	*<2*
A1	2–7	0.0	6.0	5.9	5.6	8.9	6.4	46.5	32.6
A1	15–20	0.0	6.7	6.7	5.1	8.8	6.5	47.9	31.7
B21	35–40	0.0	7.4	6.8	4.4	8.1	6.0	49.8	31.7
II B22	70–75	0.0	6.7	6.2	2.6	4.6	3.6	41.4	47.8

Profile P14: Slijk-Ewijk

Location:	topographical map of the Netherlands, scale 1 : 25.000, (1954), sheet 40 C, coordinates: N 433.7 — E 182.4 (Betuwe)
Described:	by S. SLAGER and W. L. ASIN, 21.8. 1962
Climate:	temperate humid
Landuse:	Arable land
Parent material:	medium textured on heavy textured river deposit
Physiography:	area transitional between river levee and river basin
Hydrology:	1. permeability: rather slow 2. drainage class: imperfectly drained 3. groundwater: 1.70 m below surface, in winter deeper than 1 m below surface 4. artificial drainage: no tile drainage. The profile is situated in an area where the groundwater level has been lowered substantially
Root distribution:	depth of penetration: about 40 cm, exclusively along fissures
Classification:	*Typic Normaquept* (7TH APPROXIMATION, 1964)

PROFILE DESCRIPTION

Ap,	0– 24 cm	dark brown to brown (10YR 4/3) moist; silty clay loam; strong very fine angular blocky changing with increasing depth into very thick compound platy with shell-shaped fissures and prominent rootprints, subdivided into very few very coarse dense angular blocky elements; very firm; few, fine, faint, strong brown and black mottles; gradual and smooth on:
B21,	24– 48 cm	brown (10YR 5/2) moist; silty clay loam – silty clay; compound moderate coarse prismatic subdivided into strong very fine angular blocky; firm; few, fine, distinct, strong brown and black mottles; gradual and smooth on:
II B22g,	48– 80 cm	light brownish gray (10YR 6/2) moist; silty clay; compound moderate coarse prismatic subdivided into strong very fine angular blocky; firm; many, coarse, distinct, strong brown mottles; gradual and smooth on:
II B23g,	80–110 cm	light brownish gray (10YR 6/2) moist; silty clay; compound moderate coarse prismatic subdivided into side by side weak medium prismatic and moderate very fine angular blocky; sticky and plastic; abundant, fine, distinct strong brown and black mottles

DETAILED DESCRIPTION OF SOIL STRUCTURE

Ap1,	0– 3 cm	A5 1 III 3
Ap2,	3– 24 cm	very thick compound platy with shell-shaped fissures and prominent rootprints subdivided into very few, very coarse, very dense, angular blocky elements
B21, II B22g,	24– 80 cm	B3a IV 2/A5 1 III 2½
II B23g,	80–110 cm	B3a IV 2/(B5a III 1 + A5 1 III 1½)

NUMBER OF BIOPORES PER M²

horizon	*depth in cm*	*2–4 mm*	*>4 mm*
Ap	15	0	40
B21	30	220	40
II B22g	60	100	100

SOIL POROSITY

horizon	*depth in cm*	*PS %*
Ap	5	36.2
B21	28	39.8
B21	43	41.9
II B22g	63	43.3
II B23g	93	46.6

ANALYTICAL DATA

horizon	*depth in cm*	*$CaCO_3$ %*	*pH*		*particle size distribution in μ*				
			H_2O	*0.01 M $CaCl_2$*	*>210*	*105–210*	*50–105*	*2–50*	*<2*
A1	15–23	0.0	7.1	6.2	3.8	7.6	6.7	50.8	31.1
B21	25–30	0.0	7.0	6.0	2.9	6.6	6.5	49.6	34.4
B21	35–45	0.0	6.9	6.1	1.8	4.5	4.7	44.3	44.7
II B22g	60–70	0.0	7.2	6.3	0.9	1.5	1.9	46.4	49.3
II B23g	90–100	0.0	7.0	6.5	1.1	1.3	1.6	46.5	49.5

Profile P15: Slijk-Ewijk

Location:	topographical map of the Netherlands, scale 1 : 25.000, (1954), sheet 40 C, coordinates: N 433.9 — E 182.4 (Betuwe)
Described:	by S. SLAGER and W. L. ASIN, 27.8.1962
Climate:	temperate humid
Landuse:	Pasture
Parent material:	medium textured on heavy textured river deposit
Physiography:	area transitional between river levee and river basin
Hydrology:	1. permeability: moderately slow 2. groundwater: deeper than 1.50 m below surface. In winter 1 m below surface 3. drainage class: imperfectly drained 4. artificial drainage: no tile drainage. Profile is situated in an area where the groundwater level has been lowered substantially
Root distribution:	depth of penetration: about 40 cm
Classification:	*Humic Normaquept* (7TH APPROXIMATION, 1964)

PROFILE DESCRIPTION

A1,	0–15 cm	dark brown to brown (10YR 4/3) moist; silty clay loam; compound weak very thick platy subdivided into strong very fine subangular blocky; very firm; few, fine, faint, strong brown mottles; gradual and smooth on:
B21,	15–38 cm	dark brown to brown (10YR 4/2) moist; silty clay loam; compound moderate medium prismatic subdivided into strong very fine to medium angular blocky; very firm; few, fine, faint, strong brown and black mottles; gradual and smooth on:
II B22g,	38–57 cm	(dark) grayish brown (10YR 4.5/2) moist; silty clay; compound moderate medium prismatic subdivided into strong very fine angular blocky; firm; few, fine, distinct, strong brown and black mottles; clear and smooth on:
II B23g,	57–78 cm	light brownish gray (10YR 6/2) moist; silty clay; compound weak coarse prismatic subdivided into side by side: strong very fine medium angular blocky and strong medium prismatic; firm to very firm; abundant, fine, distinct, strong brown and black mottles; clear and smooth on:
II B24g,	78–110 cm	grayish brown (10YR 5/2) moist; silty clay; side by side strong medium and coarse prismatic and strong fine to medium angular blocky; sticky and plastic; many fine distinct, strong brown and black mottles

DETAILED DESCRIPTION OF SOIL STRUCTURE

A1,	0–15 cm	C2 IV 1/A5 1 II–III 2½
B21,	15–38 cm	B3a III 2/A5 1 II–IV 2½
II B22g,	38–57 cm	B3a III 2/A5 1 II–IV 3
II B23g,	57–78 cm	B3a IV ½/(A5 1 III–V 3 + B5a 1 III 3)
II B24g,	78–110 cm	(B5a 1– III–IV 3) + (A5 1— IV–V 3)

NUMBER OF BIOPORES PER M²

horizon	*depth in cm*	*2–4 mm*	*>4 mm*
A1	10	160	160
B21	25	320	120
II B22g	50	60	60

SOIL POROSITY

horizon	*depth in cm*	*PS %*
A1	8	45.3
B21	23	43.3
II B22g	43	40.6
II B23g	63	43.1
II B24g	93	44.2

ANALYTICAL DATA

horizon	*depth in cm*	*$CaCO_3$ %*	*pH*		*particle size distribution in μ*				
			H_2O	*0.01 M $CaCl_2$*	*>210*	*105–210*	*50–105*	*2–50*	*<2*
A1	2–10	0.0	6.1	5.5	6.3	7.4	5.5	48.7	32.1
B21	20–30	0.0	6.5	5.4	2.2	4.7	4.4	50.9	37.8
II B22g	40–50	0.0	6.7	6.0	1.4	4.2	4.2	43.1	47.2
II B23g	60–70	0.0	6.8	6.2	1.2	2.6	2.6	42.9	50.7
II B24g	90–100	0.0	7.2	6.5	0.8	1.6	1.7	46.1	49.8