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REPORT OF A VISIT TO THE 'INSTITUT NATIONAL DE LA RECHERCHE AGRONOMIQUE' (INRA) IN AVIGNON AND VERSAILLES

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1. INTRODUCTION

In the period from 21 to 25 april 1986, a visit was paid to the INRA soil science centres in Avignon en Versailles. The purpose of this visit was to examine and discuss research on soil compaction and regeneration and research on cracking clay soils carried out by INRA-France and ICW-The Netherlands, and to investigate the possibilities for cooperation.
The following programm was proposed by dr. P. Stengel of INRA-Avignon:

- *Monday :*
  - *a.m. : General presentation of the laboratory and discussion about choice of subjects to be developed.*
  - *p.m. : Presentation of works about :*
    -Soil compaction : J. GUERIF
    -Shrinkage and Swelling, Cracking : V. HALLAIRE, J.C. FIES, P. STENGEL

- *Tuesday :*
  - *a.m. : Water and solute movements in cracking soils :*
    A.M. de COCKBORNE, F. LAFOLIE, R. GUENNELON
    Root-growth mechanics : A. FAURE, N. SOUTY
  - *p.m. : Detailed presentation of laboratory techniques according to our visitor's interest.*

- *Wednesday :*
  - *a.m. : Presentation of field studies and measurements techniques*
  - *p.m. : Discussions and conclusions of the visit. Eventual further collaborations.*

- *Thursday :*
  Travel to Paris.

- *Friday :*
  Visit to Versailles Laboratory, Mr D. TESSIER.

This report gives a summary of the discussed topics. Every chapter is divided into two parts: 1) Cracking clay soils and 2) Soil compaction because the visit was concentrated on these two topics.
The complete visit was very well organized by our French hosts. We very much enjoyed the nummerous discussions we had at the visited institutes. Our special thanks goes to mr. J. Guerif (INRA-Avignon) who spent three days with us in Avignon, mr. P. Stengel (INRA-Avignon) who did most of the preparations of this visit , mr. V. Hallaire (INRA-Avignon) with whom we had stimulating discussions on cracking and subsidence of clay soils and mr. D. Tessier who was our host in Versailles.
This visit was partially sponsored by the Commission of the European Communities, Directorate-General for Agriculture.
In our opinion this short visit, followed maybe by some longer exchange of researchers, was a useful contribution to the solution of mutual problems in soil science and water-management of two EC-countries.

2. GENERAL INFORMATION ON INRA

INRA stands for 'Institut National de la Recherche Agronomique', in English 'National Institute for Agricultural Research'.
They are doing research on:
- Agriculture
- Agricultural and Food Industries
- Environment

INRA has been divided in 22 departments with their own discipline or groupes of disciplines. Speciality Commissions are coordinating the research on specific subjects. There are 22 centres of research with in total approximatily 300 stations, laboratorys and experimental farms.(See fig.1) Each centre is dependant of one of the 22 departments. In total there are 8000 people working on INRA.

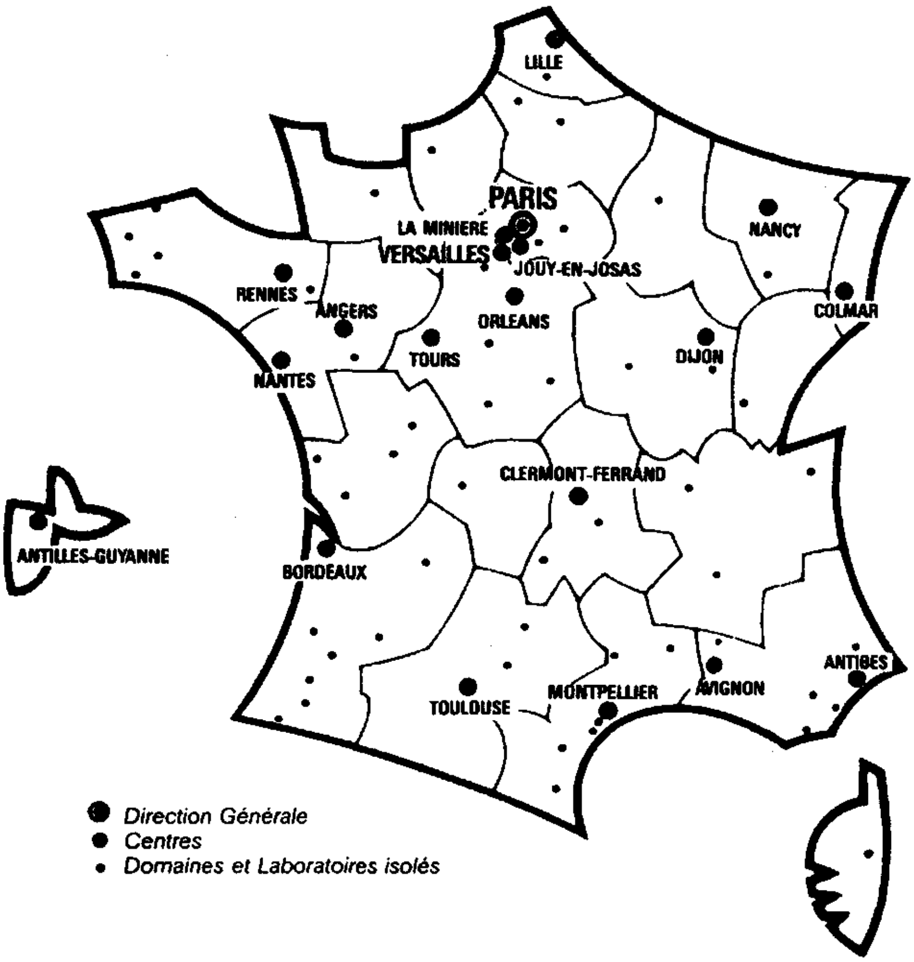


Figure 1. Stations, laboratories and experimental farms of INRA.

3. INRA-AVIGNON

3.1 Cracking clay soils

The work of the soils-department of INRA in Avignon on cracking clay soils consists of both laboratory and field studies.
In the laboratory the basic properties of clay soils are studied (e.g. texture, structure, shrinkage characteristics etc.) as well

as the transportprocesses of solutes in these soils. Both in the field an the laboratory, the mechanisms of cracking and subsidence are subject of research. In the following pages, a few subjects will be treated in more detail.

-Methods of analysis
INRA has developed a quick method to determine shrinkage characteristics of clay soils (including corresponding moisture tension values). Small aggregates (2-3mm) are saturated and placed at different moisture tension. After equilibrium is reached an amount of aggregates is saturated with kerosene after which both weight and miscible displacement is determined. After drying of the aggregates, one can easily calculate moisture content and volume of aggregates at each given tension. In this way the shrinkage characteristics of a lot of French soils have been determined. The general form of the shrinkage characteristics of a heavy and a loamy clay soil is pictured in fig.2.
In heavy clay soils shrinkage is normal till much lower suctions (more negative) then in the case of loamy clay soils.

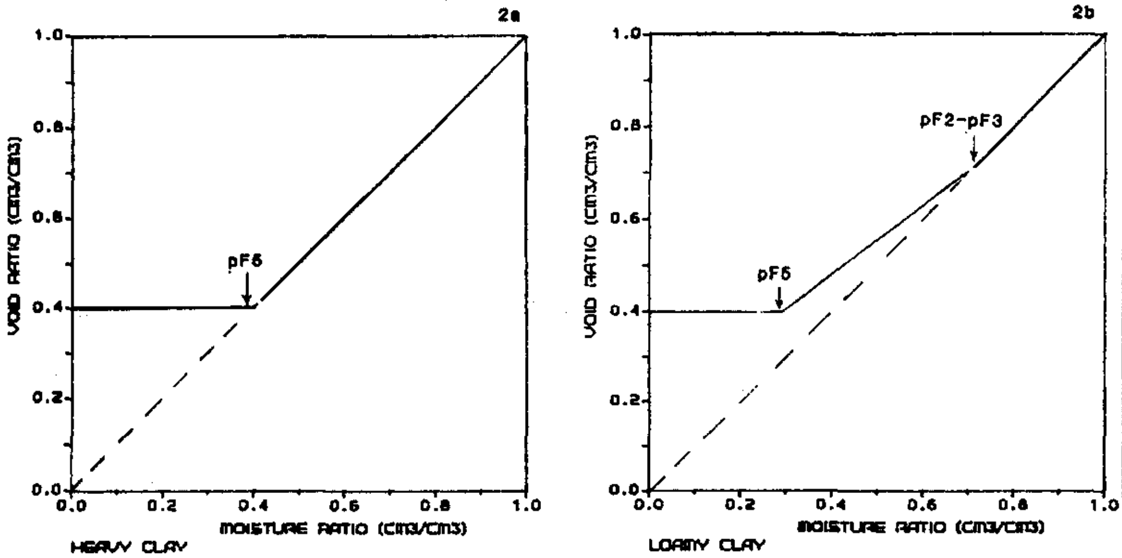


Figure 2. Shrinkage characteristics of heavy clay and loamy clay soil

-Mechanism of cracking and subsidence in clay soils
Both in the laboratory and in the field a lot of research has been done and is still in progress on the mechanisms of cracking and subsidence of clay soils. The shrinkage characteristics of a soil gives the relation between changes in moisture content and volume change of the soil. However, the influence of cracks on soil-properties differs completely from the influence of subsidence. Therefore, it is important to know what part of total soil-volume change results in cracks and what part results in subsidence. Mr. Hallaire did a lot of field work on this subject. He concluded that total volume change in a cracking clay-soil is not isotropic. During the first part of the drying of a field soil, cracking dominates while upon further drying subsidence becomes more important. Another important conclusion of this study was that the cracking pattern changed during drying. At first a fine cracknetwork developes wich, upon further drying, changes into a coarse cracknetwork. In this combined drying-cracking proces some cracks become larger while others close. This phenomena was registrated in laboratory and field. In

the field a gravimetric moisture content of 23% marked the change of the fine crack network into the coarse crack network.
During wetting of a clay, the large crack network turns back into a fine crack network. This implies that there are cracks (the little ones) that close upon drying and open upon wetting. (see figure 3)

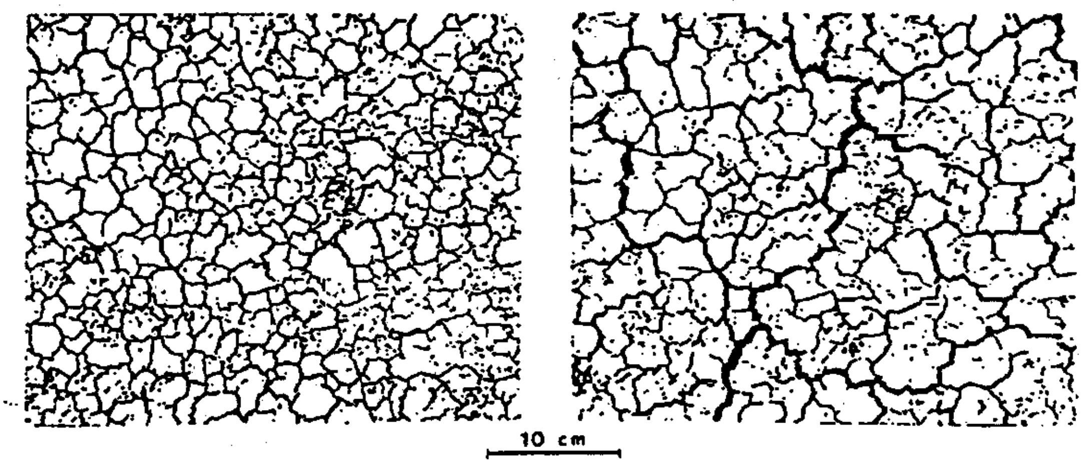
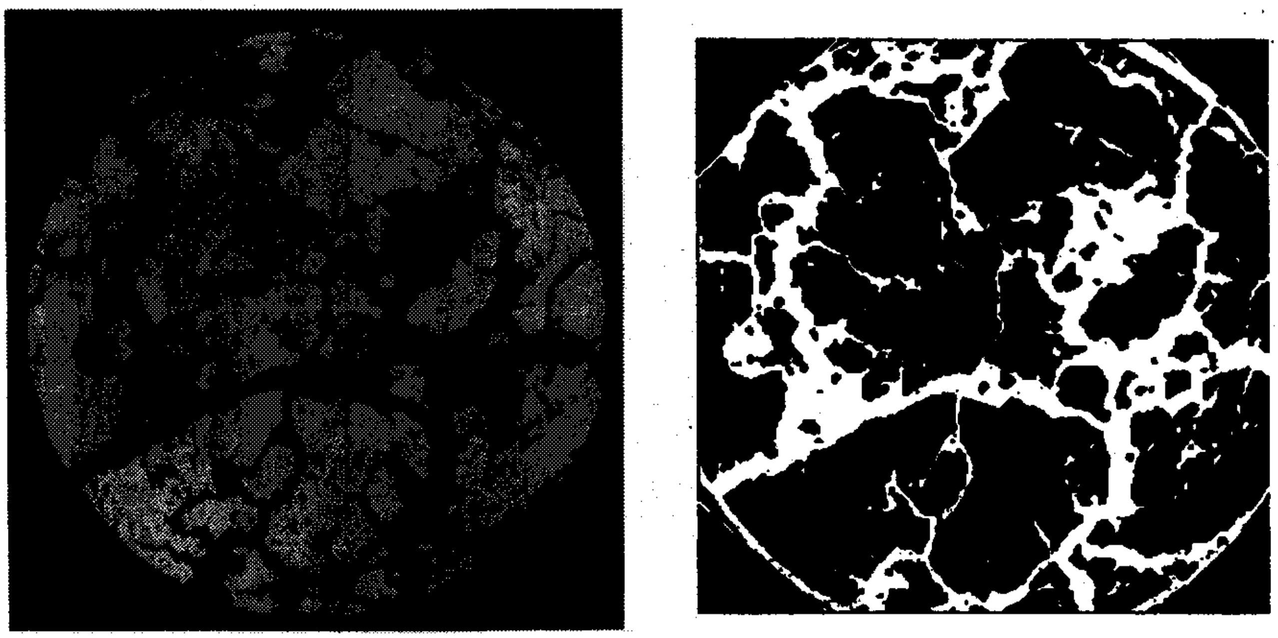


Figure 3. Evolution of cracking pattern during drying.

-Image analysis



a   b

Figure 4. Computer tomography picture of an undisturbed clay core. (diameter core = 16 cm)
4a. Original picture.
4b. Picture after image-analysis.

In a large part of the INRA-research on structure of soils, use is made of an image analyser. Fotographs of soil surfaces or of carefully prepared planes in the subsoil were analysed, in which way the results mentioned above were reached. During the visit we had a discussion about a picture of a cracked clay soil that was made by using Computer Tomography (C.T.). C.T. is a medical technique which uses rontgen-radiation to make a two dimensional picture of a plane of a human body. In the academic medical centre in Amsterdam, such a non-destructive C.T.-picture was made of a undisturbed colum of cracked clay-soil with very good result. This picture was analysed with the image analyser at INRA-Avignon. In fig. 4 the original C.T.picture is given together with the resulting image. In picture 4.b. some 30 % of the area can be considered as cracks. Total moisture loss from saturation was equal to 50 %. The combination of C.T.-scanning and image analysing seems to be a very simple and non-destructive method for studying soil-structure.

-Infiltration in tubular pores
To get more information on infiltration into heterogeneous soils laboratory studies were carried out on packed and undisturbed soil cores with macropores. Nitrate and phosfate were used as solutes. The results indicate that only 10-20% of total structural porosity takes part in flow processes and that the existence of only a few small pores transports solutes to great depths.

- Modelling of processes in soils
An important part of research at INRA-Avignon consists of the modelling of soil-physical,-chemical and -biological processes. For instance models have been developed or are in progress for flow of solutes in structured soils, for germination of seeds, for root growth etc.

3.2 Soil compaction

In Avignon research on soil compaction is mainly done on aggregated soils in the toplayer. The clods in such a soil consists of aggregates and they can be crushed easily. When this soil has been compacted, especially in a wet condition, the aggregates will stick together. After tillage the clods are massive and impenatrable for roots. Some properties of soil which are changed by compaction are bulk-density,strength,permeability and gas diffusivity. Mean topics we talked about were bulkdensity and soil strength.In case of a aggregated soil pore space can be divided into a "textural" (intra-aggregates) and a "structural" (inter-aggregates) part.This can be expressed in the void ratio e.

$$e = \frac{\text{volume of the pores}}{\text{volume of the solid part}}$$

$$e^{T} = e^{\tau} + e^{S}$$

e^{T} = total void ratio
e^{τ} = textural void ratio
e^{S} = structural void ratio

When we are talking about the soil strength of a aggregated soil we have to look at the structural strength and at the textural strength. The structural strength depends on the cohesion c^{S} and the angle of internal friction φ^S between the aggregates. The textural strength is the strength of the aggregates and depends on the cohesion c^τ and the angle of internal friction φ^τ in the aggregates. In the laboratory the basic propperties of a aggregated soil has been studied. Changing of bulkdensity because of compaction has been studied in the field.

-Laboratory tests on aggregated soil.
To study the mechanism of compaction oedometer tests have been done on probes that consists of aggregates of 2-3 mm diameter.

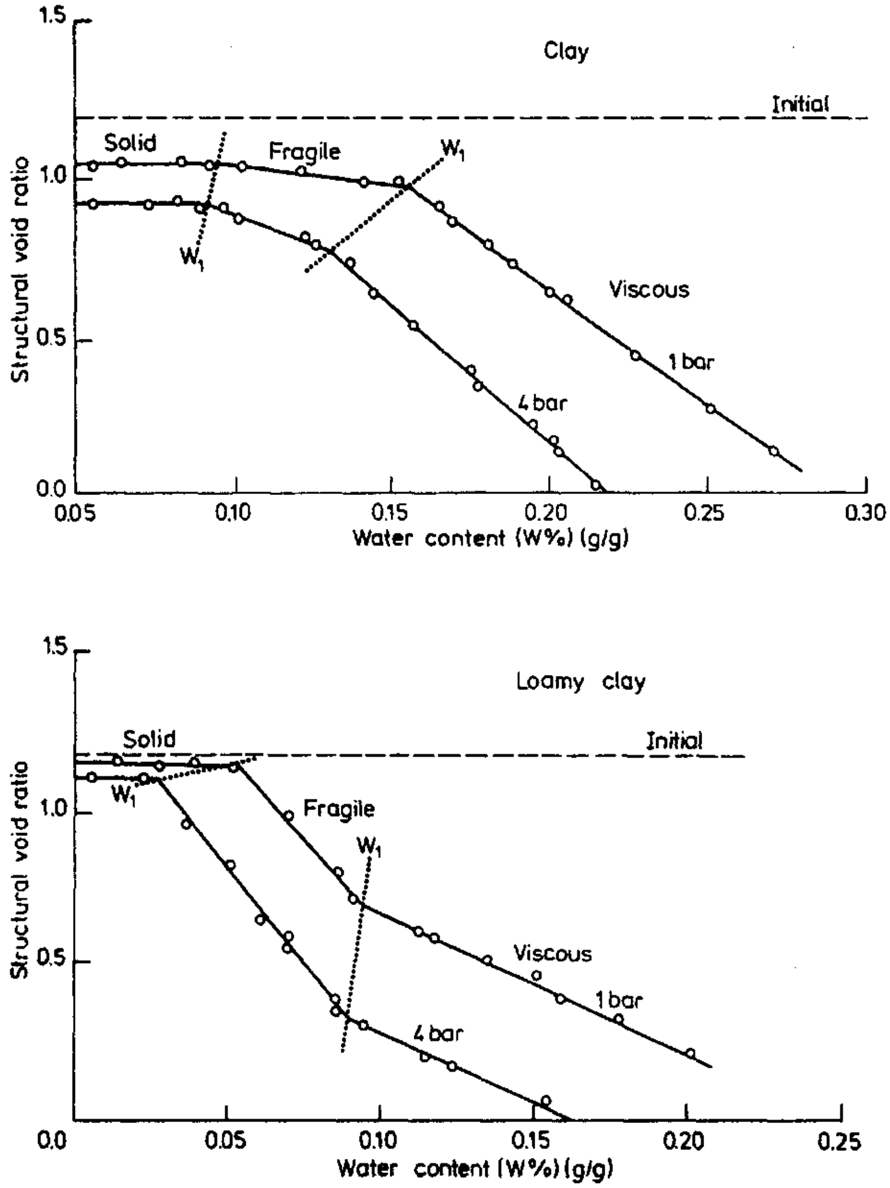


Figure 5. Compaction of aggregates bed: Effect of water content and pressure on structural void ratio.

An indication of the tensile strength has been derived by cracking single aggregates. The force needed to do so is proportional to the tensile strength. With the oedometer tests and the cracking

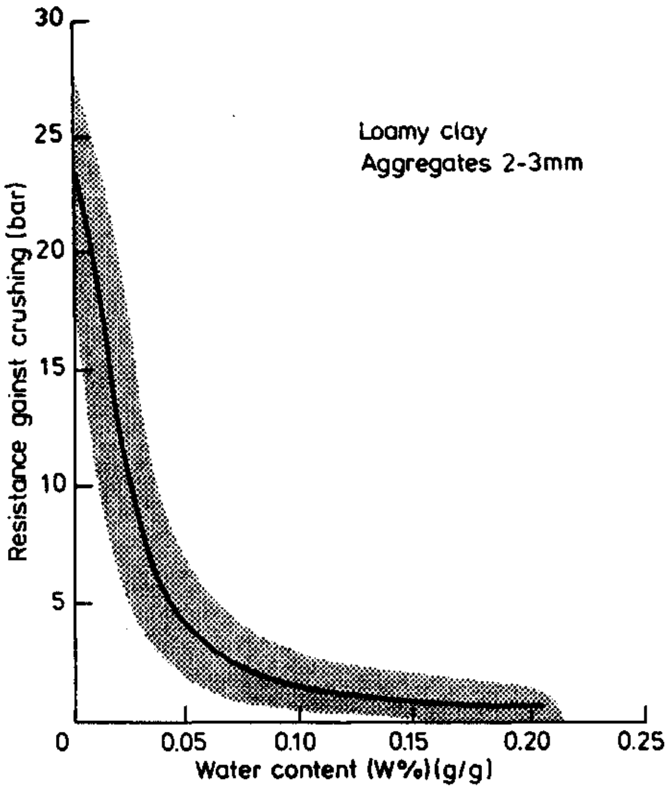


Figure 6. "Textural" tensile strength versus water content measured on aggregates (2-3 mm diameter).

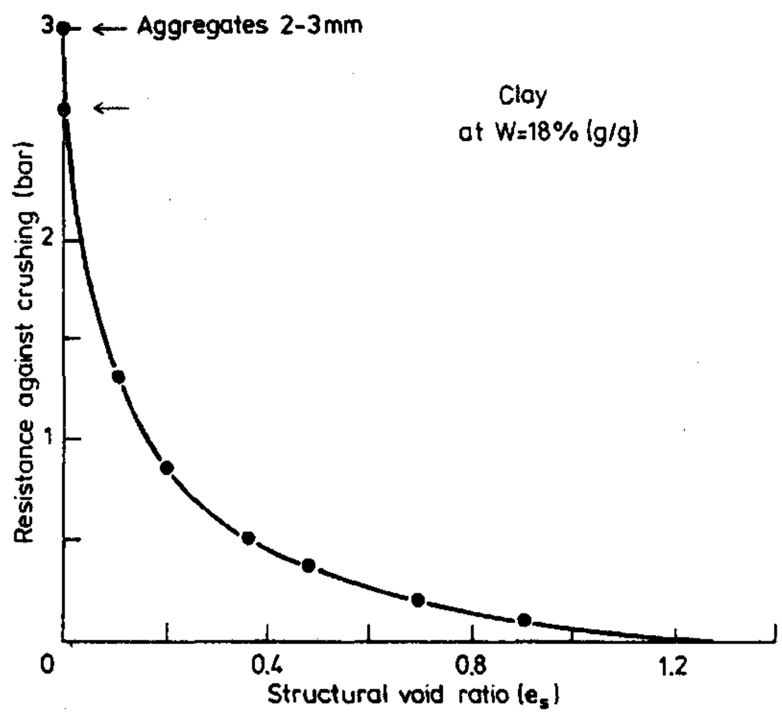


Figure 7. Resistance against crushing of a structure of aggregates at a given moisture content (ψ= 5 bar) versus structural void ratio.

tests the effect of water content of the aggregates has been studied. See figure 5.
As can been seen in figure 5 below a certain water content W1 the aggregates keep solid and act like sand grains. Between a water content W1 and W2 the aggregates are not strong enough anymore and they are crushing. Above a water content W2 the aggregates deform viscous. The properties of the single aggregate (See figures 6 and 7) determinate the properties of the aggregates bed.

-Field experiments.
To study the effect of water content and soil layers on compaction wheeling tests have been done at different tyre inflation pressures. With a sinkage plate apparatus combined with a gamma-ray probe compression curves of a multilayered soil could be obtained. It showed that a slight topsoil drying, prior to wheeling, enhances the effectivines of low pressure tyres in preventing excess compaction.

-The use of the twin gamma probe.
The INRA-Avignon uses intensively the LPC-INRA twin gamma probe, which is specialy designed to measure the density of the 50 cm upper part of the soil. Much research has been done to establish the accuracy of this method. The distance between the tubes is 15,20 or 30 cm. The soil collected from access holes augered for insestion of the twin probe is used to determine gravimetric water content. The profiles of bulk density can be measured each 2.5 to 3.5 cm, starting from approximately 3 to 5 cm below the surface. To get a high accuracy after the measurement a trench is digged allong the tubes and the distance between the tubes has been measured. Samples between the tubes can be taken to determine the gravimetric moisture content. In this way accuracy of bulkdensity of $\Delta\gamma = +0.03$ g/cm3 can be derived

3.3 Possibilities for cooperation

The ICW carries out research on clay soils in order to develop simulation models that describe water transport in cracking soils. In this respect, the experience that INRA-Avignon has with field studies on the subject of cracking and subsidence could be very valuable. Especially the evolution of crack paterns and the change from cracking into subsidence during drying are of great interest of ICW. INRA could benefit from the long-term modelling experience the ICW . However, as mr. Hallaire (who did most of the research mentioned above) is leaving INRA-Avignon, it is uncertain if there is still a useful cooperation possible on this subject.

In the Netherlands there is very little knowledge of the swelling-shrinkage properties of the clay soils. Only recently ICW has started to investigate this subject. ICW could benefit from the experience of INRA-Avignon in the determination of shrinkage characteristics.

The use of computermodels in soil science and water management is an important topic both at INRA and at ICW. INRA has done a lot of work on the modelling of different processes in soils while ICW has concentrated on the developement of models that predict crop production, workability etc.(SWATRE,FLOWEX). There is a difference in scale at which the institutes work. Both partys could benefit from a exchange of experiences on modelling waterflow in soils.

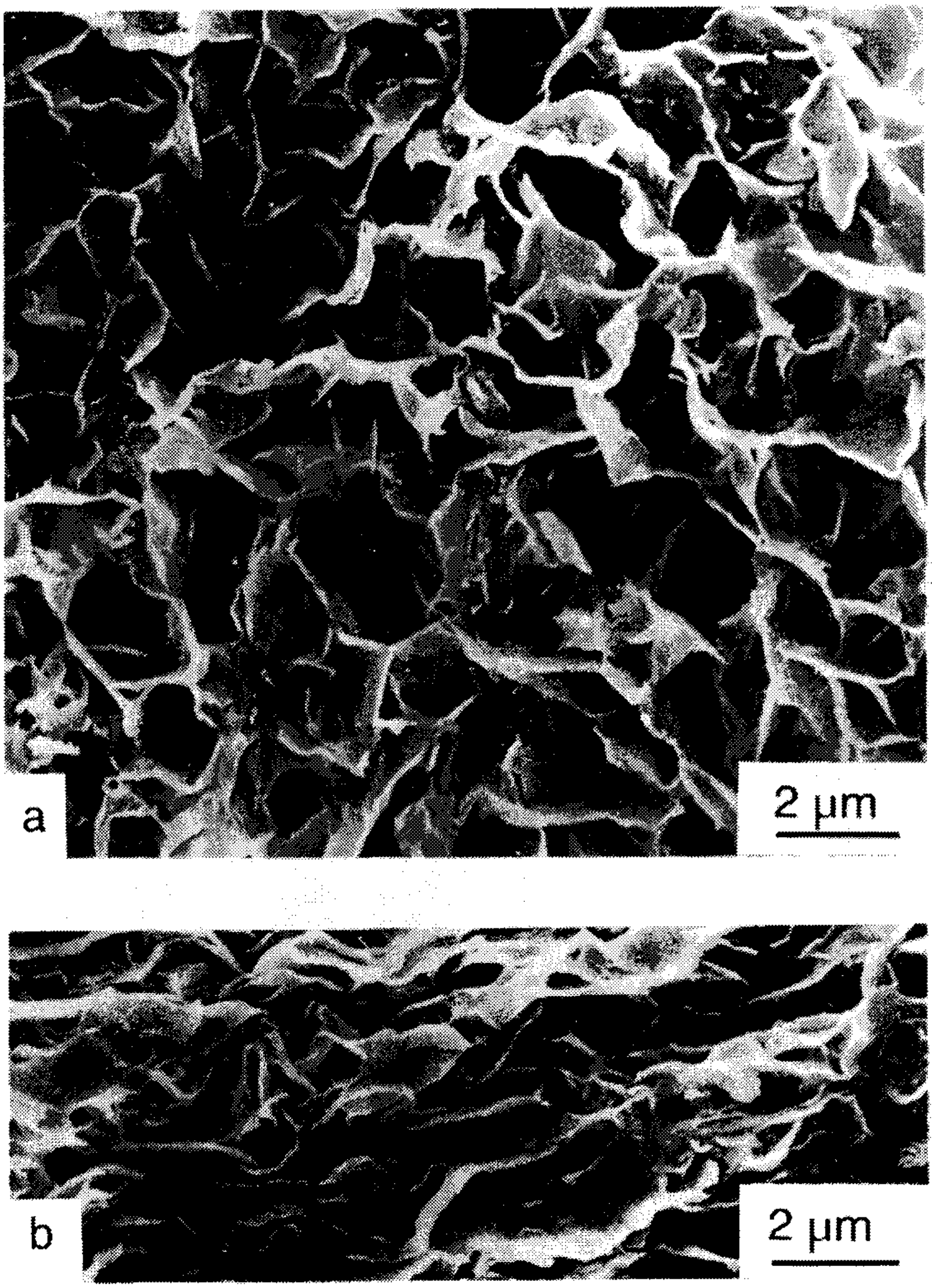


Figure 8. Natrium-smectite at volumetric watercontents of respectively 91 and 75 %.

With respect to soil compaction ICW is doing research on sandy soils to develop a model to predict compaction of the subsoil. INRA-Avignon studies aggregated soils in the toplayer. Nevertheless cooperation is useful because in future the ICW-model has to be made useful to other soils then sand. Furthermore forces on the topsoil result in pressures on the subsoil. These pressures are input for compaction model, so a good understanding of the processes in the topsoil is necessary.

4. INRA-VERSAILLES

4.1 Cracking soils.

At INRA-Avignon work on cracking clay soils is concentrated on the physico-chemical properties of clays. The microstructure of clay soils is subject of research by using electron-microscopy.
ICW determines shrinkage characteristics on undisturbed natural clods, ICW does not look into the clod to explain why a certain clod has certain properties. By using electron-microscopy it is possible to visualize the drying and volume change process of clays on a micro- scale. In figure 8 two pictures are shown of a natrium-smectite at two moisture contents. It is clearly visible that upon drying the clay-platelets approach eachother thus reducing the volume of the soil.
INRA-Versailles investigates which parameters determine the swelling and shrinkage behaviour of clay-soils, for instance the influence of type of solutes and of concentration of solutes.
Physical properties as hydraulic conductivity are also subject of research. Furthermore the valuability of Darcy's law is investigated. ICW is interested in this topic because of research into flow of water through bentonite liners for waste disposal sites.

4.2 Soil compaction.

Research on soil compaction is hardly done on INRA-Versailles. Interesting were some large scale pictures which showed the bindings between sand grains caused by organic matter. This may be one of reasons why sandy soils with organic matter are less vunerable to compaction.

4.3 Possibilities for cooperation

ICW could benefit from the experience INRA-Versailles has in determining shrinkage characteristics. Besides this the interests of INRA-Versailles and ICW lie on a completely different scale.
With respect to soil compaction onely the study of the relation between organic matter and the sand grain is of some interest for the ICW, but priority of this research is very low on INRA-Versailles.

5. CONCLUSIONS

This visit has resulted in an exchange of knowledge in the field of soil compaction and cracking clay soils. This exchange will be continued in the future.
Possibilities for cooperation are best with INRA-Avignon as the scale at which ICW and INRA-Avignon work is comparable. The two main topics for cooperation are:

1)Modelling of transportprocesses in cracking soils.
2)Soil compaction.
With respect to the first subject, a visit of one INRA-Avignon researcher (mr. de Cockborne) to ICW-Wageningen to get acquainted with ICW water-management models would be useful. A longer visit of one ICW-researcher to INRA-Avignon would be useful to get to know more of the details of INRA work on the crackingprocess.
Cooperation in the field of soil compaction can best be put into practice by a visit of mr. Guerif to Wageningen. A combined visit to ICW, STIBOKA and the Agricultural University could be organized by mr. van den Akker.