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# EVALUATION OF THE STRUCTURE OF CLAY SOILS BY MEANS OF SOIL CONSISTENCY

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## 1. Introduction

Soil structure is usually defined as the arrangement of the soil particles. This arrangement is the result of the action of several forces. Some of these forces act in a favourable way, for instance such cultivation operations as plowing and harrowing of the soil, the activity of the soil population, etc....

Other forces have an unfavourable influence. The most important of these are the effect of the rain (mechanical and dispersive), the effect of walking and riding on the soil (mechanical) and the effect of gravity (mechanical) under wet conditions.

There are periods when the forces which work in a favourable way are numerous and strong, and other periods when the unfavourable forces play an important part. This means that the soil structure occurring at a certain moment, mostly called the actual structure, isn't constant, but varies greatly in a period of time.

Therefore it is difficult to characterize soil structure by measuring the actual structure as e.g. by determining total pore size, pore size distribution or mean aggregate diameter. Additional figures about the stability of the soil structure against destructive forces are necessary. To obtain those figures, it is necessary to know something about the nature of the destructive forces.

We found that for sandy clay soils the dispersing action of water is the most important cause of the decrease in soil structure, while on heavy clay soils, in general, the mechanical forces are the principal cause of the deterioration. This is clearly shown in figure 1.

These results are obtained from an experiment in Mitscherlich pots. The pots were filled with different soils : 2 sandy clay soils, 2 heavy clay soils and a moderate heavy clay soil. During the first four weeks, the soils were irrigated by sprinkling and under the influence of the mainly dispersive force of this artificial rain the structure of the sandy clay soils decreased. The heavy clay soils however remained in the same condition. The structure of the latter soils decreased after 4 weeks, when the soil was compressed with a force of 0,1 kg/cm$^2$ but there was no further change in the sandy clay soils.

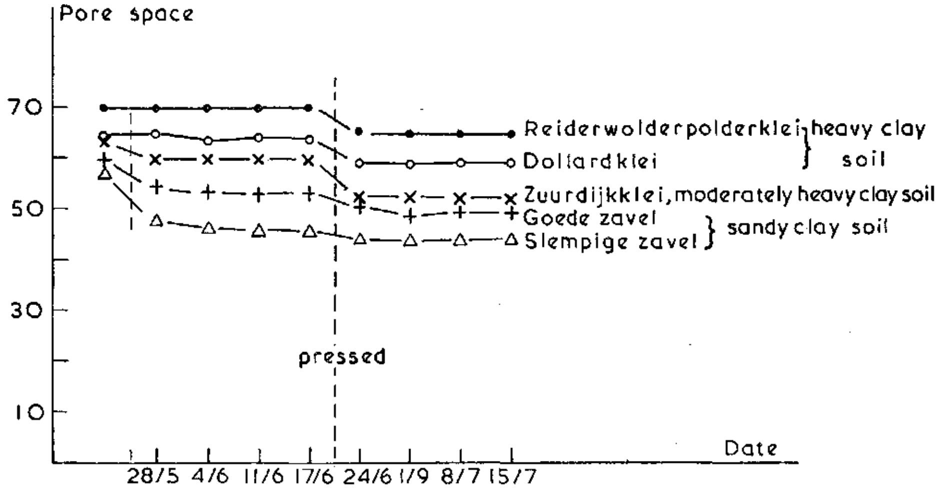


Fig. 1

Deterioration of soil structure of some clay soils

This result was in agreement with our experience obtained in an experiment on small plots with several clay soils. By avoiding mechanical forces, such as walking and riding, soil structure on the heavy clay soils was much better than under normal treatment. On sandy clay soils however the difference was small.

These and other observations suggested the importance of the mechanical deformation of soil aggregates. It will be clear that this deformation depends strongly on the *resistance* of the clay aggregates against the mechanical forces, and that this resistance depends on the moisture conditions of the soil.

Therefore it would be very usefull to measure the mechanical resistance of clay soils. Many scientists have tried to do it directly, but this seems to be rather difficult, especially for routine measurements.

## 2. Method

We introduced another way, building on the findings of Terzaghi (2) and the methods of Atterberg (1). Terzaghi found a relation between moisture content and compression (fig. 2).

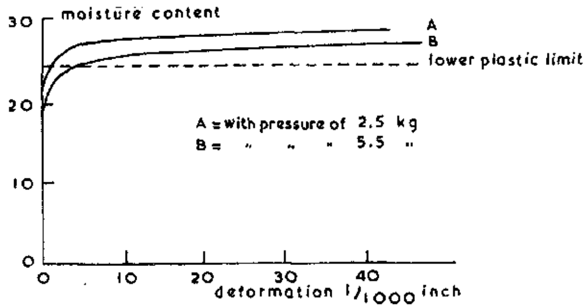


Fig. 2

Deformation of clay soils in relation with the moisture content

At a low moisture content the compaction is rather small, at a higher moisture percentage it increases greatly. Further it was evident that the moisture content at the change in slope of the graph practically agreed with the lower plastic limit. Therefore the location of the moisture content of the soil in respect of the *lower plastic limit* is important for the soil structure of *heavy clay soils.*

For *sandy clay* soils however, the location of moisture content in respect of the *upper plastic limit* seems to be important in determining soil structure. Under rather wet conditions, these soils disperse easily, because moisture content under those conditions is nearly as high as or sometimes higher than the *upper plastic limit.* Hence we use the *Atterberg consistency limits,* especially the lower plastic limit and the upper plastic limit, to get an idea about soil structure capacity.

It will be clear however that these consistency limits alone cannot give information on soil structure, but they must be completed with data about moisture percentages under field conditions. We are using the moisture content at pF 2,0 (called „field capacity''), determined by means of the suction method.

From this data an index for soil structure can be computed; for heavy clay soils the ratio lower plastic limit : moisture percentage at pF 2,0 and, for sandy clay soils, the ratio upper plastic limit : moisture percentage at pF 2.0.

Experience has taught us that if the first quotient is much smaller than 1,0, consistency and structure capacity will be poor. If this quotient is 1,0 or greater then we have a favourable condition.

For sandy soils the condition is quite good if the quotient upper plastic limit : field capacity is much greater than 1,0, say near 1,4 or 1,5. If this quotient is however 1,0 or less, the soil will disperse easily.

We have obtained several hopeful results by this method by studying the influence of several materials on soil structure.

## 3. Results

As a first example, in table 1 the effect of organic manuring on a sticky clay soil in the neighbourhood of the town of Groningen is shown. We have determined the soil structure on old arable land with a very poor structure and on plowed grassland with a rather good structure. The differences are not only shown clearly by visual evaluation, but also by the measurement of consistency.

**TABLE 1**

**Influence of organic matter on soil consistency**

| | lower plastic limit (L. P.) | upper plastic limit (U. P.) | Field cap. (F. C.) | L. P. / F. C. | U. P. / F. C. | Vis. str. |
|---|---|---|---|---|---|---|
| **Zuidwolde** | | | | | | |
| Arable land ........ | 30,5 | 53,4 | 41,2 | 0,74 | 1,30 | 2 |
| Ploughed grassland .. | 46,0 | 65,8 | 47,1 | 0,97 | 1,40 | 6 |
| **Serooskerke** | | | | | | |
| Without org. mat. ... | 19,8 | — | 32,4 | 0,61 | — | 5 |
| With org. mat. ...... | 19,7 | — | 28,4 | 0,69 | — | 6 |
| **Dinteloord** | | | | | | |
| Without org. mat. ... | 23,1 | — | 32,1 | 0,72 | — | 4 |
| With org. mat. ...... | 23,8 | — | 30,5 | 0,78 | — | 6 |

Table 1 shows also the difference in soil structure between a parcel repeatedly treated with some organic matter and another parcel, never treated with organic matter. Although the difference

**TABLE 2**

**Influence of some soil conditioners and gypsum on soil consistency**

| | lower plastic limit (L. P.) | upper plastic limit (U. P.) | Field cap. (F. C.) | L. P. / F. C. | U. P. / F. C. | Vis. str. |
|---|---|---|---|---|---|---|
| **Sandy clay soil** | | | | | | |
| 0 | 20,6 | 23,8 | 28,8 | 0,72 | 0,83 | 6+ |
| Krilium ........... | 21,8 | 27,6 | 25,0 | 0,87 | 1,11 | 8 |
| Aerotil ............ | 23,0 | 26,1 | 23,9 | 0,96 | 1,09 | 8 |
| Inundated with salt water: o ....... | 18,7 | 21,8 | 31,9 | 0,59 | 0,68 | 2+ |
| Inundated with salt water: gypsum . | 19,9 | 24,7 | 27,7 | 0,72 | 0,89 | 6½ |
| **Heavy clay soil** | | | | | | |
| 0 ....... | 26,9 | 40,0 | 36,4 | 0,74 | 1,10 | 6— |
| Krilium ........... | 27,8 | 41,6 | 33,4 | 0 83 | 1,25 | 8— |
| Aerotil ............ | 27,8 | 39,1 | 33,4 | 0,83 | 1,17 | 8— |
| Inundated with salt water: 0 ....... | 24,8 | 39,5 | 46,7 | 0,53 | 0,84 | 1+ |
| Inundated with salt water: gypsum . | 26,8 | 42,6 | 37,6 | 0,71 | 1,13 | 6 |

is not very great, it is clear that the effect of organic matter could be shown by the visual method as well as by the consistency measurement.

Further we were using the consistency method to measure the differences in soil structure on small plots, treated with several soil sonditioners and other materials. The results are summarized in table 2.

By comparing them with the results of the visual evaluation it appears that the consistency method is suitable for soil structure measurements of clay soils.

## LITERATURE

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## SAMENVATTING

**Beoordeling van de bodemstructuur van kleigronden door consistentiemetingen**

Structuurverval in kleigronden wordt voor een groot gedeelte veroorzaakt door mechanische krachten, teweeggebracht door het betreden en het gebruik van landbouwmachines. Dit vooral is afhankelijk van de weerstand van de bodem tegen deze mechanische krachten. We hebben getracht deze weerstand te meten, waarbij we vaststelden dat geen enkele rechtstreekse methode hiervoor voldoening schonk. Daarom werd de oplossing langs een andere weg gezocht en wel door voort te bouwen op de bevindingen van Terzaghi, die aantoonde dat de vervorming van kleigronden onder invloed van druk sterk toeneemt, wanneer het vochtgehalte dit van de onderste plasticiteitsgrens overtreft.

Onze methode steunt op het bepalen, samen met de veldcapaciteit (vochtgehalte bij pF 2,0), van de bovenste en onderste plasticiteitsgrenzen.

De ligging van de veldcapaciteit tussen de hogervermelde plasticiteitsgrenzen kan gebruikt worden als maatstaf voor de consistentie van een kleigrond.

De methode werd in verschillende gevallen aangewend, waardoor het mogelijk was de invloed van verschillende producten (grondverbeteraars, kalk, organisch materiaal) na te gaan op de wezenlijke bodemstructuur.

## RESUME

### L'évaluation de la structure des sols argileux par des mesures de consistance

La détérioration de la structure des sols argileux est en grande partie causée par des forces mécaniques, notamment par le piétinement et les machines agricoles. Cette détérioration est déterminée par la résistance des sols aux forces mentionnées. Par conséquent nous avons tenté de mesurer cette résistance; cependant des mesures directes ne donnèrent pas satisfaction dans la pratique. C'est pour cela que nous nous sommes inspiré de l'expérience de Terzaghi, qui a démontré que la déformation des sols argileux sous pression augmente fortement si le taux d'humidité dépasse la limite de plasticité inférieure.

Notre méthode consiste donc en la détermination des limites de plasticité inférieure et supérieure, combinée à la détermination de la capacité en eau au champ (taux d'humidité à pF 2,0).

La localisation de cette dernière mesure, par rapport aux valeurs de consistance mentionnées, peut être considérée comme la détermination de la consistance d'un sol argileux.

La méthode a été appliquée dans différents cas et il fut ainsi possible de mesurer l'influence de différents produits (conditionneurs de sol, chaulage, matière organique) sur la structure intrisèque du sol.

## ZUSAMMENFASSUNG

### Beurteilung der Struktur toniger Böden durch Festigkeitsmessungen

Der Zerfall der Struktur auf Tonböden wird grösstenteils durch die mechanischen Kräfte verursacht, welche beim Gehen und Fahren auf der Bodenobenfläche entwickelt werden. Dieser Zerfall kann durch den Widerstand, den der Boden gegen diese Kräfte entwickelt, gemessen werden. Deshalb haben wir Widerstandsmessungen als Methode angewandt, doch sind solche direkten Messungen für Serienarbeiten schwer ausführbar. Es wurde dann eine andere Methode versucht, abgeleitet aus den Erfahrungen Terzaghi's, der gezeigt hat, dass die Formänderung eines Tonbodens durch Druck schnell zunimmt, wenn der Feuchtigkeitsgehalt über die untere Plastizitätsgrenze hinausgeht.

Unsere Methode besteht in einer Bestimmung der oberen und unteren Plastizitätsgrenze zusammen mit der Bestimmung des Wassergehaltes bei Feldkapazität (pF 2,0).

Die Lage dieses letzten Wertes in Beziehung zu den genannten Festigkeitsbestimmungen darf als eine Messung der Festigkeit eines Tonbodens angesehen werden.

Diese Methode ist für verschiedene Böden angewandt worden, und es war möglich, in dieser Weise den Einfluss verschiedener Produkte (Bodenverbesserungsmittel, Kalk, organisches Material) auf die Bodenstruktur zu messen.