IV. Die Wirkung von Düngemitteln auf Bodenstruktur und Bodenlebewelt

A. The Effects of Organic and Inorganic Dressings upon Soil Structure

By

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Soil structure is defined usually as the spatial arrangement of elementary soil particles. This arrangement may be lighter or denser. A strong increase in soil porosity is obtained chiefly by tillage operations such as ploughing, rotary cultivating and so on. The result regarding soil structure depends on the workability of the soil. An improvement in porosity of a densified soil e.g. by tillage operations will be far more difficult on clay soils than on silt soils, especially when the compaction is brought about by farm implements. The increase in porosity obtained in this way however is diminishing more or less rapidly, depending on the resistance that the soil structure offers against the densifying action of climate (see chapter I.B.e.) and of passage of men, cattle or agricultural implements on the soil surface. The first destructive influence is of importance for silt soils, the second one for clay soils. So soil structure at a certain moment (actual structure) is to a great extent dependent on the workability of the soil when becoming tilled and on the resistance against destructive influences, usually called structure stability. Organic dressings with stable dung, compost or green manure and inorganic ones with lime and fertilizers, as well as dressings with soil conditioners (organic or inorganic) generally influence the structural stability and workability and hence the actual structure.

a) Organic Dressings

We will restrict ourselves in this section to the normal organic materials such as farmyard manure, compost, frozen black peat, green manure and sods (cf. section d for synthetic agents). They affect soil structure mainly because they are organic, but on the other hand they act as a compound fertilizer and can influence in this way soil structure indirectly via their effects upon plant growth (see chapter I.B.f.).

The present state of our knowledge about the way in which organic material in the soil influences soil structure is pointed out very briefly in chapter I.B.f., section 5. Here we will go somewhat more into details.

Several authors mention a relation between the organic matter percentage of the soil and soil structure, obtained from statistical studies. Baver (1935) has shown that there was a significant correlation (0.56) between the percentage of

water stable aggregates > 0.05 mm and the carbon content of a large number of different soils. A stronger correlation (0.69) however was found for aggregates > 0.1 mm, which indicates that soil organic matter promotes the formation of relatively big stable aggregates. In this respect organic colloids surpass the clay colloids, which generally appeared to be equally significant in causing aggregation. It will be clear that in light soils organic matter is the most important cementing agent. Heinonen (1955) has investigated by means of a multiple regression analysis the effect of the humus content upon water stable aggregation. On clay soils he found a positive correlation between humus content and aggregation up to an organic matter percentage of 6%. One of the authors (Boekel 1963, 1965; v. d. Boon, Boekel and v. Dijk) studied the effects of organic matter content and organic dressings (farmyard manure, compost, green manure, sods, frozen black peat) on the physical properties of clayey soils. An increase in the organic matter percentage resulted in a decrease of the sensitivity for slaking on silt soils and in an increase of the workability and the resistance against compaction by mechanical forces on heavy clay soils. Furthermore an average improvement of the visually evaluated actual soil structure (Peerlkamp 1958) with $\frac{1}{4}-\frac{1}{3}$ point was obtained per percent increase of the organic matter content. This improvement was corresponding with an increase of the air content of the soil of about $2-3\%$ of volume. However, the effect was dependent on the kind of organic material used. The influence of farmyard manure was smaller than that of compost and frozen black peat, and green manure appeared to be more favour-
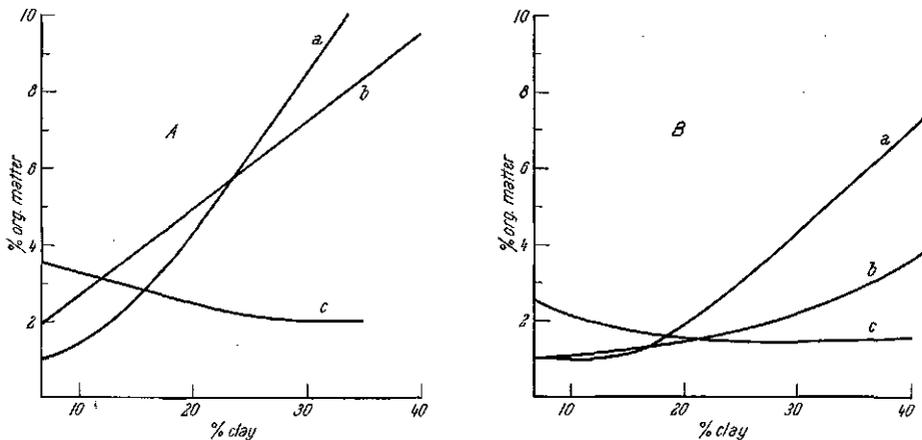

Fig. 377. Organic matter content required for favourable physical properties of clayey soils containing different percentages of clay and with a low and a high lime state (Boekel 1965);

a   to have a good workability,
b   to obtain a good actual structure, and
c   to prevent serious slaking.
A   low lime state (pH-KCl 5),
B   high lime state (pH-KCl > 7 and $2.5-3.0$ m.e. Ca-ions per 100 grams of soil in the soil solution)

able for soil structure, probably due to secondary effects as covering the soil during a longer period, leaving the (clay) soil somewhat dryer in a wet period and binding the soil particles by means of roots and roothairs. Boekel (1965) obtained also data concerning the organic matter percentage of the soil, which is required to prevent serious slaking, to have a good workability and to obtain an actual soil structure suitable for a favourable crop growth (Fig. 377).

It appeared that this organic matter percentage was the lowest for soils with

a high lime state and with a clay content (particles $<2\mu$) between 14 and 20%, depending on the tolerance in respect to slaking.

On sandy soils an increase of the organic matter content increases the soil moisture percentage at pF 2 (field capacity) more than total pore space and moisture content at pF 4.2 (wilting point). This causes a decrease of the percentage of soil air at pF 2 and an increase of the available moisture content with increasing organic matter percentage (BOEKEL 1962b).

PEERLKAMP (1950a, b) however did not find a narrow correlation between water stable aggregation and organic matter percentage on large numbers of sandy soils, reclaimed peat soils and clay soils. It appeared that at each humus percentage a range of aggregations as measured by a wet sieving technique was possible. The upper limit of this range was more or less constant ("ideal structure"), the lower limit however showed a positive correlation with the percentage of soil organic matter. Therefore this percentage seems to determine the poorest structure which can be found normally in a soil with a certain humus content much more than the structure that is actually observed. From all these results it appears that the quantity of organic matter in the soil influences soil structure generally, but that it is not the only factor in determining the structure of a soil with a certain mechanical and mineralogical composition and perhaps it will not even be the most important one.

Therefore the question arises as well to the mechanism of cementation effects by soil organic matter as to the part the chemical composition of this organic material plays in these effects.

Soil organic matter is not an exactly defined chemical compound, but a mixture of substances derived from fresh organic material by a series of microbial and chemical processes and from the autolysis of the microbial population. In a given soil generally all kinds of intermediate products of the decomposition of plant residues and of macro and micro soil-fauna and -flora, from fresh to fully decayed, as well as several newly synthesized products are present. The most characteristic and important fraction however is the black colloidal material, often named humus. According to FLAIG (1958) it is a mixture of low and high molecular compounds. The low molecular compounds do not have any significance as cementing agents. They can affect soil structure, however, to a certain extent by their oxidizing or reducing properties and by their protective influence on the soil colloids.

The high molecular organic compounds form the most important group with regard to soil structure. They may be divided into spherical and linear colloids.

The humic acids and the albuminoids belong to the spherical compounds. Since the latter are decomposed comparatively easily, the humic acids are the most important spherical colloids in the soil. They consist of spherical particles, which are not solid but have a spongy structure giving rise to a high moisture retention. Humic acids are supposed to be formed by condensation of lignin decomposition products or phenolic or quinonic substances from microbial metabolism, accompanied by fixation of nitrogen compounds such as ammonia, aminoacids and peptides.

From electron micrographs it appears that the humic acid particles, if flocculated by means of Ca-ions, can form chain-like arrangements, which in turn form a net-like coagulate similar to fibrin in clotted blood (FLAIG and BEUTELSPACHER 1951). It seems possible that this coagulate holds together clay-flocks and grains of sand to a certain extent. The aggregates produced in this way are believed to be, however, not very stable. A greater stability is obtained when the organo-mineral colloids of the so-called clay-humus-complexes (MEYER 1935)

act as cementing substances. According to BEUTELSPACHER (1955) the formation of these complexes is only possible when iron- or aluminium-ions or -oxides are present on the surface of the clay particles. A clay-humus-complex in which the humic acids are rich in nitrogen seems to be very stable (LAATSCH 1957). It is possible that this explains the great stability of the structure of the black-earths.

The linear colloids in the soil organic matter have attracted much attention during the last twenty years. GEOGHEGAN (1948), RENNIE et al. (1954) and others have shown that several linear colloids obtained from soil organic matter or synthesized in vitro by soil microbes improve aggregate stability. Polysaccharides and polyuronides are important representatives of these linear polymers. In these organic compounds condensation did not occur spatially but in one direction. More or less branched types are known as an intermediate form. Depending on the dissociation rate of the acid or basic groups and on the type of the monomers the linear polymers are more or less coiled or stretched. Polyuronides, for example, are coiled less than polyacrylic acids. Salts from polymer acids, which are better ionized in an aqueous solution than the free acids, are more stretched owing to the mutual repulsion of the anion functions of the polymer particle. This is mostly the case with salts of monovalent bases. Exchanging the monovalent cations by divalent ones causes a decrease of stretching because these salts are less ionized. These effects are important in view of the interaction of the linear colloids with the clay particles in the presence of the soil solution. According to RUEHRWEIN and WARD (1952) the linear polymers form a kind of bridge between several clay particles. MICHAELS (1954) found that this action is increasing with the rate of stretching. The linear organic colloids in the soil are not so resistant to microbial attack as the humic acids are. However, there are differences. The dextrans and levans for example, show a relatively high resistance. From many experiments on the effects of dressings with easily decomposed organic materials on well-aerated soils (see e.g. PEERLKAMP 1950a) it follows however that the aggregating effects diminish rather fast. This indicates that the microbial synthesized linear colloids are broken down generally after a few months and that this way of aggregation requires a periodical supply of fresh organic material.

According to GREENLAND et al. (1962) aggregate stability in cropped soils and in soils having been under grass for four years or less is predominately due to polysaccharides and polyuronides, but in old pasture soils it is mainly caused by other materials.

It will be clear that both kinds of aggregate formation, on the one hand the binding of the soil particles by means of coagulated humic acids or clay-humus-complexes and on the other by means of linear polymers, synthesized chiefly by microbes, play a part in the building of soil structure. A third way in which organic dressings, especially such as frozen black peat and town refuse compost, may influence structure is a macroscopical and mechanical one, which on clay soils separates the aggregates due to organic material between them. This prevents the aggregates from sticking together and the soil from an increased density. However, the relative significance of each of these mechanisms is still unknown and it remains to be seen, if there will be still more.

It is recognized generally that on arable land a small increase in the humus percentage requires a relatively long time and heavy organic dressings. KORT-LEVEN (1959, 1963) has given the following formula for the relation between the annual organic matter supply and the humus percentage of the soil after a number of years:

$$y_t = \frac{k_1 x (e^{k_2 t} - 1) + k_2 y_0}{k_2 e^{k_2 t}}$$

with y_0 and y_t the initial humus percentage and that after t years respectively, x the annual supply of dry organic matter, k_1 the humification coefficient, k_2 the decomposition coefficient and $e = 2.7183$. For the climatological and soil conditions of the Netherlands the coefficients k_1 and k_2 appeared to be 0.4 and 0.02 respectively. If the topsoil of one hectare (say 2,000,000 kg) with a humus content of 3% recieves an annual dressing of 20,000 kg farmyard manure[1] over a period of ten years and if the annual "natural organic dressing" (roots, stubbles and other plant residues) is supposed to be 2,000 kg (dry), then the formula gives an increase in the humus percentage to 0.36. This means, however, that as much as 25% of the quantity of organic material which has been brought into the soil with the farmyard manure is retained as humus. It must be emphasized that this 25% is found only when the initial humus content is much lower than that in the state of equilibrium between organic matter supply and decomposition. Near this state—the humus content in the example just mentioned would approximate a value of 5% in this case—the increase of the humus percentage is very small, but it takes a very long time (150 years) to get a humus percentage of 4.9 before this occurs by a constant annual supply. Now the question arises as to how great the annual organic dressing must be to obtain an improvement of the visually evaluated soil structure (PEERLKAMP 1958) by one point in say a 10 year period. According to the findings of BOEKEL (1965) such an improvement of soil structure requires an increase in humus content of about 3%. Supposing the initial humus percentage to be 4, KORTLEVEN's formula gives for an increase to 7% an annual supply of 20,540 kg dry organic material on one hectare (about 2.10^6 kg) topsoil. If roots and other plant residues give 2,000 kg, an annual dressing of about 18.5 tons/ha dry organic matter or about 125 tons/ha farmyard manure during a period of 10 years is necessary to increase the visual structure evaluation by one point. Many arable clay soils have a visual structure evaluation of 4—5 but for a good structured soil (e.g. for horticultural purposes) this figure must be 7 or 8. It will be clear from this that under the climatological conditions of Northwestern Europe structure improvement of arable land by means of organic dressings requires considerable quantities of organic material and a long period. During a few months after an organic dressing has been applied there will probably be an additional but temporary structure improvement due to the microbial synthesized linear organic colloids. This action of the organic dressings, however, disappears as soon as they have stopped. Then only the effect of the increased organic matter content is left.

In grassland the conditions for the formation of humic acids seem to be more favourable than in arable land. On one hand this will be due to the lack of soil cultivation (HARMSEN 1951), on the other small animals (worms, grubs and so on) according to LAATSCH (1949) and others have a favourable influence on humus formation. In their intestinal canal carbohydrates from their food are decomposed, lignins are liberated and organic and inorganic materials are thoroughly mixed, thus advancing the formation of clay-humus-complexes. Together with the large quantity of fresh organic material which is brought into the soil when ploughing up grassland, this may be the cause of the good results with respect to soil structure which several authors have obtained with ley farming (see e.g. Low 1955).

It will be clear, however, that the effects upon soil structure of ley farming and organic dressings depend largely on the external circumstances and on the moment at which structure has been observed. In this connection it may

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[1] 15% dry organic matter.

be mentioned that one of the authors (Boekel) did not find an effect of ley farming on the structure of a sandy soil. On a loamy sand however he obtained an increase of total pore space and air content. Ferwerda (1951) could not find any influence on soil structure of dressings with farmyard manure on sandy soils one year after application. Baver and Farnsworth (1940) however report a great effect upon total and non-capillary porosity if farmyard manure has been ploughed into the soil during the preceding autumn. Apparently a dressing with farmyard manure has, in the short run, only a very temporary effect caused by the linear colloids formed during the microbial decomposition of more or less fresh organic material, but decomposed in turn by actynomicetes and so on. It must be emphasized that if the organic dressing is applied in spring this temporary structure improvement is obtained in summer, during a period in which in Northwestern Europe structure deterioration is very small due to the low precipitation and to the sheltering effect of the crop.

The question arises how organic material must be brought into the soil to obtain the best structure: fresh or partly decomposed. Generally it can be said that fresh material gives a relatively great but very temporary improvement of soil structure. The better the circumstances for microbial decomposition the greater and the shorter is the effect upon soil structure and probably the smaller the contribution to the formation of humus will be. To get effects of a longer duration it seems recommendable to advance the formation of humic acids and clay-humus-complexes in the farmyard manure or compost heaps. Nevertheless, a more permanent improvement of soil structure by means of organic dressings will take many years.

b) Liming of Clay Soils

It is well-known that a sodium clay, such as e.g. a clay soil that has been flooded with sea water so long ago that rain could leach the excess of salt, has a structure which is much poorer than that of a calcium clay. Generally farmers recognise that in this case soil structure can be improved by giving dressings of gypsum. Practical agriculture however is not so familiar with the fact that gypsum gives— usually only for a short period—an improvement of the structure of a "normal" calcium clay soil too (Boekel 1958a, b). The onion growers in a marine clay district of the Netherlands put this method into practice in preparing their seed beds. Moreover sugar factory lime sludge is in great demand by practical agriculture in several countries as an agent for improving the structure of clay soils.

In view of these practical applications it is somewhat surprising that in the scientific literature results as well as explanations differ. Baver (1928) could find neither a difference in aggregation between a hydrogen clay and a calcium clay, nor a correlation between the amount of exchangeable calcium and aggregation. Therefore he was in doubt whether lime had a favourable effect upon soil structure or not. Bradfield (1936) concluded the same from a lack of better aggregations on clay soils rich in lime. Browning and Milam (1944) did not find any effect of lime only on the aggregation of sandy clay soils. Combined with organic material however a varying effect was obtained, depending on the type of soil and the kind of organic matter. Czeratzki (1957) however observed a considerable improvement of the aggregate stability of a grey brown podsolic in consequence of liming. Schachtschabel and Hartge (1958) measured the effect of lime on the structural stability of several soils by means of a wet sieving technique. They found that an improvement was obtained only when the initial structure state was rather bad due to other factors than those related

with lime. The minimum stability, generally occurring in spring, was increased. BOEKEL (1958a) showed a considerable improvement of the structure of a heavy clay soil by liming. The soil became more porously and crumbly. On a sandy clay soil, however, in summer the effect of liming on the actual soil structure was very small (BOEKEL 1962a), but in winter and spring slaking was affected in a very favourable way (PELGRUM 1963). MÉRIAUX (1961) reports that liming at 5 tons/ha CaO on acid loams progressively increased soil permeability and slightly improved the proportions of stable aggregates, the effects of ground $CaCO_3$ being greater than that of CaO.

How one should interpret this confusion with respect to the influence of liming on the structure of a clay soil? It seems there are several causes. SCHACHTSCHABEL and HARTGE (1958) suppose the diversity of results to be due to the application of different methods in characterizing soil structure. Furthermore the effect of liming will be the smaller the higher the structure level of the untreated soil is and according to BOEKEL (1958a) it depends on the type of soil too.

The concept of soil structure is very complex and it is not possible to evaluate the structure of a soil completely by means of one method of measuring. Generally several aspects have to be determined to get a sufficient characterisation of soil structure. In practice however it is not always possible to do so and one is compelled to restrict oneself to very few aspects, say one or two. Then a well-considered choice is necessary and the aspect which has to be measured must be chosen so that it is the most important one for the creation of soil structure under the given circumstances. Most arable soils can be brought into a rather good actual structure by means of soil cultivations under favourable conditions of moisture state and weather. How actual structure will be at a later time depends chiefly on the resistance that the structure offers against destructive forces exerted by climate and men. Therefore it is very important to recognize for each special case the main mechanism of structural deterioration. It must be emphasized that this mechanism is not the same for all clay soils. For light sandy clay and loamy soils a dispersing action of water will be most important and a suitable wet sieving technique can be used as a model for this action. According to BOEKEL and PEERLKAMP (1956) however the structure deteriorating mechanism for medium textured and heavy clay soils is much more a plastic deformation of the wet soil under influence of mechanical forces as exerted by implements and gravity. Then consistency of the wet soil will be a better index than the results of a wet sieving analysis.

Much attention has been given to the effect of the adsorbed cations on the physical properties of a clay soil (HISSINK 1925, KELLEY and BROWN 1925, BAVER 1928 and others). Most of these experiments are made however with soil suspensions and it is not certain whether results obtained in this way are allowed to be generalized into terms of soil structure as observed in the field. Thus it will be clear that the effect of liming a clay soil as determined by a laboratory-method can be different, depending on the method which has been used. Probably a great part of the differences in results can be explained in this way.

Liming can affect a soil clay generally in two ways. On the one hand it may increase the percentage of Ca-ions in the exchange complex by means of cationic exchange, on the other it may increase the Ca-ion concentration of the soil solution. Both may have an influence on soil structure by their lowering effect on the zeta potential. The forces that two clay particles exert on each other are the attracting LONDON-VAN DER WAALS forces which are not influenced by the composition of the exchange complex and the ionic concentration of the soil solution,

and the repelling force of the negatively charged surfaces of the clay particles, the electrical fields of which are modified by the surrounding adsorbed cations as well as by those of the soil solution. According to Houwink (1937) the distance between the clay particles in a moist clay soil is determined by the resultant of these attracting and repelling forces. More Ca-ions in the adsorption complex or in the soil moisture means a decrease of the zeta potential and of the thickness of the cationic swarm. The distance between the clay particles will decrease and the effect of the London-van der Waals force will increase. Consequently the resistance against dispersion will be enlarged.

Boekel (1958a) has shown that liming has a favourable influence on consistency and structure of heavy clay soils and suggests that this can be explained by the theory of Houwink (1937) for the swelling of a clay soil consisting of non-swelling clay minerals such as e.g. kaolinite or illite. According to this theory the observed strong increase of the swelling when the entire pore volume is filled with water is due to a dissociation of the exchangeable cations into the soil water, bringing about an increase of the repelling force and of the distance between the (platy) clay particles. If enough water is present this is sucked between the particles, thus increasing the swelling of the clay and its plasticity. As is pointed out above a higher percentage of Ca-ions in the exchange complex or a higher concentration of cations in the soil solution will counteract the enlargement of the distance between the clay particles and consequently will improve the consistency.

Hartge (1959) has shown however by surface tension measurements in the centre and near the walls of the soil pores that the adsorption of organic compounds by the surface of inorganic soil particles is increased by increasing the Ca-ionic concentration of the soil moisture. In this way structure stability can be improved too.

Apart from the way in which it can be explained, it seems to be certain that an increase in the Ca-ion concentration in the soil solution can improve the structure of a heavy clay soil, even if it has a high pH and contains some $CaCO_3$. Therefore, in agreement with practical experience, dressings with sugar factory lime sludge and gypsum have a greater effect the structure of medium textured and heavy clay soils than marl and similar poorly soluble materials (see also Table 375). The solubility of gypsum however is so great that in humid regions its effect on the structure of a Ca-clay soil disappears within one year by leaching (Boekel 1958a, b).

c) The Effect of Fertilizers upon Soil Structure

The influences that dressings with fertilizers can have on soil structure may be divided into two groups: direct and indirect ones. The direct effects are related to the way in which the fertilizers influence the exchange complex and the cation concentration in the soil solution, the indirect ones to their influences on plant growth. The first group is chiefly significant for clay soils, the second one for sandy soils too.

It will be clear that continued heavy dressings of sodium or potassium salts on clay soils will increase the percentage of Na^+ or K^+ in the exchange complex, which results in an increase of the zeta potential, a greater distance of the clay particles and a poorer structure. Table 375 illustrates this for a heavy clay soil, which received during the period 1928/1952 each year a potassium dressing of 500 kg K_2O per ha. Soil structure was improved by liming (14,000 kg CaO per ha in 1928 and 5,000 kg/ha in 1949), by dressings of gypsum (during 1946/1954

yearly 3,000 kg/ha) or by both. The determination of air content and aggregates > 8 mm were made in September 1954 after dropping the potassium dressing for the third time. The unfavourable effect of the heavy dressings with potassium is clearly shown by the plots treated with lime or gypsum. On the plots which never received lime or gypsum the differences due to potassium are small and in the opposite direction. Structure is very poor on these plots and probably potassium has had some indirect favourable influence. It must be emphasized however that the effects of lime and gypsum are much greater than those of potassium. It seems that under certain conditions small quantities of sodium, potassium and magnesium can improve soil structure. LAATSCH (1941) ascribes this effect of sodium to a mobilization of a part of the humic compounds that increase the humus clay binding.

Table 375. *Effects of dressings with potassium, lime and gypsum on the structure of the ploughing layer of a heavy clay soil*
(VAN DER PAAUW 1955)

Treatment	% air		% aggregates > 8 mm	
	0	500 K_2O	0	500 K_2O
no lime......................	5.7	6.2	93.6	91.9
lime	11.4	7.7	81.8	85.7
gypsum......................	12.7	10.6	69.3	78.5
lime and gypsum	13.9	10.9	56.9	72.5

As has been shown already that dressings with calcium salts, especially if these are rather easily dissolved, can improve the structure of clay soils.

According to VON NITZSCH (1939/1940), LAATSCH (1941), BRANDT (1952), NIESCHLAG (1953), GERICKE (1956) and VON CAPPELN (1959) polyvalent anions such as PO_4^{---} and HPO_4^{--} can act as bridges between clay particles and decrease the swelling and shrinking of the soil, thus affecting soil structure. TJULIN (1940) reports that phosphates are influencing the formation of humus. In soils poor in phosphate nearly all the organic material brought into the soil is mineralized, whereas in soils rich in phosphate relatively much humus is formed. The HCO_3^- also seems to have a favourable but much smaller effect. Cl-ions are thought to deteriorate soil structure.

Table 376. *Effect of nitrogen dressings upon aggregation and yield of sugar beet seed on a heavy marine clay soil at two different ground water levels*

ground water depth (cm)		40		150	
N-dressing (kg/ha)		80	200	80	200
mean diameter waterstable aggregates (mm)		2.98	2.43	2.48	2.22
yield (kg/ha)	grain.............	31.9	38.0	42.6	45.6
	straw	50.9	68.0	61.9	72.4

Generally dressings with fertilizers improve plant growth, thus increasing the root mass, the effect of covering the soil surface and the desiccation of the soil by transpiration. In this way they can have a favourable influence on soil structure (see chapter I.B.d.). This is illustrated by Table 376. A heavy dressing

with nitrogen has decreased the mean diameter of the stable aggregates, which is too large in this heavy clay soil. This effect is greater on the poorer structure, due to the higher ground water level, than at the plots with the lower water table and is going parallel to the yield. Schmidt (1959) also found a favourable influence of nitrogen on aggregate stability. The greatest effect was obtained on mature brown earths or on soils with a neutral reaction, the smallest one on pseudo-gley brown earths or on soils with a low pH. On sandy soils with a low level of fertility dressings with fertilizers or trace elements can affect soil structure in the same way.

d) The Effects of Soil Conditioners

As was mentioned in section a) soil structure can be improved by organic dressings in two ways: a by the formation of humic acids and clay-humus-complexes, b by microbial synthesized linear colloids, such as polysaccharides and polyuronides. The first way has the disadvantage that it takes a very long time before the humus percentage of the soil has been increased sufficiently, the second one that the effect is only temporary. It is clear that scientists have been endeavouring for a long time to develop organic compounds which do not have these disadvantages, are microbially stable and act rapidly. Two directions of development are to be distinguished according to the two ways in which organic material affects soil structure. The oldest is the attempt to make an artificial stable humus. Hudig and Siewertsz van Reesema (1940) have developed two types of stable humus, X_1 for sandy soils and X_2 for clay soils. These products were prepared from sphagnum peat by oxidation with gaseous oxygen at an elevated temperature and pressure in presence of NH_3 and aluminium or iron compounds. The effects of these products upon soil structure however appeared to be so small that they could only be shown with refined laboratory methods. Marian (1953) introduced a kind of stable humus (Actumus) derived from ligninic materials. Boekel (1959) could not find any effect of this agent on the structure of a sandy clay soil.

More successful was the attempt of Hedrick and Mowry (1952) to stabilize a favourable structure, obtained e.g. by soil cultivation, by means of synthetic polyelectrolytes. Building on the work of Quastel and Webley (1946), who found that sodium alginate and sodium carboxymethyl cellulose improved soil structure, they have developed the soil conditioners sodium polyacrylonitrile and calcium vinyl acetate maleic acid, which have been sold as Krilium 9 and Krilium 6 respectively. These chemicals have a great resistance against microbial attack (Hedrick and Mowry 1952, Boekel 1959) in contrast to sodium alginates and carboxymethyl cellulose, which are decomposed rather rapidly. Their leaching losses are negligible. Several authors (Hedrick and Mowry 1952, Martin 1953, Peerlkamp et al. 1954, Allison 1956, Boekel and Peerlkamp 1956, Homrighausen 1957, Fiedler 1958, Kazó 1958, Boekel 1959, Weakly 1960, Modina 1962 and others) report the beneficial effects of Krilium and related polyelectrolytes that are sold under trade names such as Aerotil, Fluffium, Rohagit, Aglusol, Loxar, Solakrol etc., upon various aspects of soil structure, such as aggregate stability, infiltration rate, friability, aeration, consistency, pore volume, erosion etc. It must be emphasized however that these favourable results are chiefly restricted to soils containing clay. The rate of application varies generally from about 300 to 1,500 kg/ha active material if a top layer of 10 cm is treated.

Partially saponified polyacrylonitrile is a linear polyelectrolyte which dis-

sociates in the soil solution. The polyanions formed in this way are randomly coiled due to the presence in the soil moisture of electrolytes (sodium- and magnesium salts and so on). Such a coil behaves at some distance like an uncharged molecule with a size in the order of that of a clay particle, but it has a rarefied structure that explains the low percentage (say 0.05 or 0.1%) that is needed. It appeared that such a coiled polyanion could bind together some clay particles. RUEHRWEIN and WARD (1952) concluded from their experiments that "chemical bridges" are formed between these particles. PEERLKAMP et al. (1954) emphasized that the Krilium-anion, when drawing nearer to the electric double layer of a clay particle, forms unsoluble Krilium-salts with f.i. the calcium- and iron-ions from this layer. Owing to the rarefied structure and the size of the polyanion several points of contact are possible between the negative groups of this anion and the positive ions from the double layer. More clay particles can attach themselves in this way on one and the same polyanion. It may be possible however that the active groups ($COOH$, OH, NH_2) play a part in the binding mechanism too.

Generally it can be said that these polyelectrolytes can have a surprisingly large stabilizing effect on the structure of clayey and loamy soils. Till now however they are to expensive to play any part in practical agriculture. Therefore the production has been stopped. For scientific purposes they are of great value since they give a possibility to change soil structure without changing other soil factors (e.g. fertility).

Attempts to affect soil structure in another artificial way were made by VAN BAVEL (1950) and by GASPARINI and ALINARI (1951). VAN BAVEL has shown that a mixture of dimethyl dichlorosilane and methyl trichlorosilane increases the water stability of soil aggregates. These chemicals are volatile liquids and the gas that is formed reacts with soil moisture. The compounds obtained in this way affect aggregate stability in a favourable way. GASPARINI and ALINARI have introduced a mixture of ferriammonsulfate and organic material as a soil conditioner that is sold under the trade name Flotal. They report successful results with respect to the structure of clay soils, rich in calcium carbonate and poor in humus. HANKE (1956) has shown an irreversible coagulation of clay particles by means of Flotal. SCHREIBER (1956, 1960) found that Flotal, which usually is applied in quantities of 2,000—3,000 kg/ha, affects especially micro-structure and that aggregate formation by Flotal is increasing with increasing levels of organic matter in the soil. Excessive amounts of Flotal (e.g. 10 tons/ha) may have dispersing effects. As contrasted with Krilium etc. Flotal does not act immediately but only several months later. From experiments in vineyards it appeared that Flotal decreased water erosion. Several experiments with Flotal on various soil types in the Netherlands however showed either no affect at all upon soil structure or only a very small improvement. The cause of these various results is not yet understood.

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