Nicht im Handel

Sonderdruck aus

Handbuch der Pflanzenernährung und Düngung

Begründet von K. SCHARRER und H. LINSER

Herausgegeben von Prof. Dr. H. LINSER, Gießen

Band II: Boden und Düngemittel Hälfte I

Springer-Verlag / Wien · New York / 1966

e) The Influence of Climate and Weather upon Soil Structure

By

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1. Introduction

The genesis of soil structure is very complex. Soil structure, defined as the spatial arrangement of elementary soil particles, is the result of the co-operation of several factors, the activities of which vary with time generally. Among these factors weather is an important one. It acts in different ways. On one hand the mean weather conditions (climate) have a long-term influence upon soil structure, on the other the present weather and its fluctuations affect soil structure more in the short run. In the latter effects weather can act either more directly by means of rainfall (surface clogging and crusting, water erosion, alternate wetting and drying), temperature (alternate freezing and thawing) and wind (wind erosion) or indirectly via the soil moisture conditions under which cultivations are carried out and via plant growth and microbial activities in the soil.

2. Long-term Effects of Climate

BAVER (1934) studied the relation between aggregation and climate on a large number of aggregate analyses of various soils. He found aggregation related to clay content and organic matter percentage of the main soil groups, which in turn are correlated with the climatic factors rainfall and temperature (JENNY 1930, JENNY and LEONARD 1934).

When temperature is kept constant, aggregation, measured as well by the total percentage of aggregates as by the percentage of silt and clay joined into water-stable aggregates, appears to be small in the desert soils, but increasing with increasing rainfall it reaches a maximum at the rainfall in the regions of the chernozems, further showing a decrease until it again reaches low values at the high rainfall of the climate in which podsols are formed. BAVER (1956) explained the course of the total percentage of aggregates with increasing rainfall from the small clay content, caused by the slight weathering under arid conditions, the high clay and organic matter percentages of the chernozems and dark humid-prairie soils and the low percentage of clay in the top soil of podsols, where, in consequence of the great rainfall, clay is eluviated to a lower horizon. The small percentage of silt and clay, which is aggregated in desert soils, is, according to BAVER, due to the low organic matter content and the presence of sodium. In the region of high rainfall this percentage is small too, since the top soil has low organic matter, alumina and iron content, whereas at medium rainfall it reaches a maximum in consequence of a relatively high percentage of organic matter and the presence of divalent bases.

When rainfall was kept constant BAVER found an increasing percentage of clay and silt aggregated with increasing temperature for soils from humid regions, whereas in semi-arid regions the opposite was true. He explained the latter from the decreased organic matter content, the cause in the humid regions, however, from an increased influence of iron and alumina going from podsols to laterites.

It will be clear that, owing to the great number of factors affecting soil structure, the correlations between climate and aggregation are not highly significant, but give only tendencies. These tendencies, however, show the broad effects on soil structure of climate in its capacity as a soil developing factor.

3. Surface Clogging and Crusting

The destructive influence of rainfall on the structure of the surface-layer of the soil was recognised a long time ago. The well-known pioneer in soil-physics WOLLNY (1877) was the first who studied the effect of vegetation in protecting soil structure against deterioration by rain. He found a decrease of 34 to 53% in non-capillary pore-volume if the soil was bare and explained this from a slaking of the aggregates in the soil surface, loading the infiltrating rain-water with fine soil material, which clogs the large pores. In more recent times WOLLNY's conclusions were confirmed generally by the work of LOWDERMILK (1930), HENDRICKSON (1934), DULEY (1939) and others who were studying the problem from the point of view of water erosion. From DULEY's experiments with artificial rain it appears that the compact surface layer, which may be several mm thick, not only has a greater volume-weight, but often contains coarser particles and less organic material than the underlying soil. It seems that this compact structure is formed by fitting some of the finer particles in the pores around the larger ones and that clay particles and organic material suspended in the run-off are transported to lower parts of the soil surface. This accumulation of clay and organic material in depressions and the appearance of a more sandy surface on the ridges is a common picture of bare sandy, sandy loam and sandy clay soils after a heavy rain. It was shown by DULEY that the influence on the infiltration-rate of the shallow compact surface-layer was much greater than that of soil type, slope, moisture percentage or profile. Therefore avoidance of the formation of a dense surface-layer, for instance by means of a crop or a mulch, is very important in soil and water conservation.

Recently DULEY's results regarding the clogging of the top layer were confirmed in a direct way by labelling the clay particles with Rb^{86} (SOR 1961, BERTRAND and SOR 1962) or P^{32} (KAZÓ and GRUBER 1962). The migration of fine particles and the clogging of the topsoil by them mainly occurred in the upper 3 cm. As a result of this displacement by the run-off a decrease of aggregate stability, clay, and organic matter percentage in the upper 2 cm of the topsoil was found.

The mechanism of slaking of the aggregates in the soil surface by rain is rather complex. There are at least four different causes: the compression of entrapped air, dispersion of the soil colloids, irregular swelling of the clay throughout the aggregates and the mechanical energy of raindrop impact. At present the first or last is considered to be most important, depending on the moisture content.

The slaking of aggregates which are immersed in water is a well-known phenomenon, utilized in wet-sieving techniques (TIULIN 1928; YODER 1936) to determine aggregate stability. YODER observed that slaking was only complete if the soil clods were almost air-dry and that it did not occur if they were previously saturated carefully by capillarity or if they were immersed in a non-polar fluid.

He concluded from this that the slaking effect was caused by water entering the clod from the entire surface by capillary tension, entrapping and compressing soil air until its pressure was exceeding the cohesion of the soil and the clod was broken down with a series of miniature explosions. HÉNIN (1938) has given a theoretical treatment of aggregate destruction by entrapped air, based on the cohesion and the wettability of the soil. The latter is evaluated by ROBINSON and PAGE (1950) who were determining the wetting angle of water on clay surfaces and found that organic matter, which is absorbed by the clay-fraction gives a considerable decrease of the wettability. Hence the capillary forces, which compress the entrapped air are smaller and the stability of the aggregates appears to be greater. This increase in stability, however, seems to be caused not only by a decrease in capillary suction but also by an increase in cohesion since a smaller wettability probably means a more difficult hydration of the cementing bonds between the soil particles too. GIUDICI (1954) recognised the importance of the rate with which water enters an aggregate. The greater this rate is, the smaller are the possibilities for the entrapped air to expand and the sooner exceeds its pressure that of the cohesion of the soil. Then a kind of micro-explosion occurs, the soil particles in a shallow outer layer of the aggregate are loosened and the process is repeated within a second layer. GIUDICI has derived formulas for the thickness of these layers and for the slaking velocity. The latter appeared to be about 32 mm per hour for a clay soil, which was slaking step by step in layers of about 1.25 mm.

Deterioration of soil structure under influence of an excess of water by a dispersion of the colloids, which cement the greater soil particles, is a common experimental fact. HÉNIN (1938, 1955) examined it. Dispersion under natural conditions occurs especially in soils in which clay colloids are the most important cementing agents. For a certain soil the rate of dispersion depends on the initial moisture percentage and on the period during which the soil has been immersed (PURI and KEEN 1925), since the rehydration of the clay, so that every particle is again surrounded by a waterfilm, is a rather slow process.

YODER (1936), HÉNIN (1938), ROBINSON and PAGE (1950) and others considered the swelling of the clay colloids as a cause of the destruction of the soil aggregates. If aggregates in the soil surface are wetted by rain this wetting does not occur homogeniously throughout the entire aggregate generally, but takes place very locally at the beginning. This causes unequal swelling of the clay colloids and tensions within the aggregate, which result in a fragmentation along cleavage boundaries formed during a foregoing dry period. ROBINSON and PAGE demonstrated this slaking effect by experiments with aggregates of different clay minerals, which were moistened in a vacuum before testing. Kaolinite-aggregates appeared to be water stable, montmorillonite-aggregates, however, slaked slowly. Illite-aggregates showed some cracks. Organic matter, absorbed by the clay, decreases its swelling properties as was shown by GIESEKING and others (1939, 1941). Therefore this seems to be one way by which organic matter increases aggregate stability.

A very important mechanism of soil structure deterioration by rainfall is the raindrop impact, which produces the so-called splash-erosion (ELLISON 1944). The kinetic energy of a falling raindrop is $^1/_2\,mv^2$ (m = mass, depending on drop size; v = velocity). The velocity is nearly constant in stagnant air, but somewhat varying under natural conditions, due to wind and turbulence.

The first raindrop measurements were made by German scientists around 1900 (see BENNETT and others 1951). More recently LAWS and his associates (1941, 1943) have studied drop-sizes and fall-velocities of raindrops. They found that there is a maximum diameter of about 7 mm. Larger drops break up into smaller ones. The fall-velocity depends on drop-size and wind, but for drops of about 6 mm it equals about 9 m/sec. (GUNN and KINCER 1949). This means that a shower of 10 mm strikes the soil surface with a total kinetic energy of about 4.10^{13} erg/ha, that is to say an energy necessary to raise a cultivated soil layer with a surface of a hectare and a depth of 15 cm up to a height of 20 cm. The energy, however, with which a single drop supplies the soil surface per unit area of impact is more important for the deteriorating effect on soil structure than the total energy per hectare of the entire shower, since the kinetic energy of one drop is passed on the small area of contact with the soil in a very short time. This energy per unit area of impact can be estimated easily by assuming the raindrop spherical and the area of impact equals the maximal cross-section of the drop. For drops of 6 mm diameter and a fall-velocity (see above) of 9 m/sec this energy appears to be about 16.10^4 erg/cm². Comparing this with the mean energy a 10 mm-shower applies to unit soil area (4.10^{13} erg/ha or 40.10^4 erg/cm²) we see the difference to be rather small. Consequently the energy which is concentrated by a raindrop impact on a small part of the soil surface is relatively high and therefore an important source of structure deterioration. A falling raindrop, however, has not a constant spherical shape but an oscillating spheroidal one, a well-known effect in fluid physics (see e.g. GRIMSEHL 1929). Hence EKERN (1951) found in his experiments with artificial rain on sand of which the surface had a certain slope that there were alternating zones with greater and smaller sand transport, coinciding respectively with areas of impact of high thin drops and of broad flattened ones.

The reaction of a bare soil surface to raindrop impact has been studied by ELLISON *et al.* (1944, 1945, 1950), EKERN (1951), ROSE (1960) and BISAL (1960). ELLISON (1944) was the first who measured raindrop splash. He found that raindrops with a diameter of about 5 mm and a fall velocity of $5^1/_2$ m/sec produced splashes up to a distance of 152 cm. Aggregates and particles of 2 mm diameter were thrown as far as 40 cm. The splashing parts of the raindrop were found to be loaded with clay, silt and sand after impact with the surface of a silt loam. The sand clogged the surface as the turbid splash water infiltrated into the soil during the first minutes, taking the clay and silt with it. After 2 or 3 minutes the surface appeared to be sealed and a maximal splash occurs due to a water-film which has been formed on the soil surface. If there is a certain slope this water moves downhill and its eroding effect is increased greatly by turbulences caused by raindrops falling in the shallow water layer (STALLINGS 1957). ELLISON (1944) found the percentage of smaller aggregates (<0.105 mm) in the splash and in the run-off as well as in the $1^1/_2$ cm top layer after rainfall to be greater than in the original top soil. Apparently the bigger aggregates had been broken up by the splash process. ELLISON and SLATER (1945) studied the infiltration rate in relation to the quantity of splashed soil. They found the infiltration to be nearly inversely proportional to the logarithm of the quantity of soil transported per time unit by splash. This quantity (S) in turn is dependent on the impact velocity of the raindrops (V), the drop diameter (d) and the rainfall intensity (I). Up to now, however, it doesn't seem to be sure what on one hand the relation is between S and V, d and I on the other. According to ELLISON (1944) S should be proportional to $V^{4.33}$, $d^{1.07}$, $I^{0.65}$. ROSE (1960), however, for a constant d, states a dependence of S on $V \cdot I$, more than on $V^2 \cdot I$, and according to BISAL (1960) S should be proportional to $V^{1.4} \cdot d$. Nevertheless can be concluded that at the moment of impact the fall velocity of raindrops is an important factor determining soil splash and surface clogging, which is confirmed by the experiments of EKERN (1951). SCHUFFELEN and VAN SCHUYLENBORGH (1950) tested the mechanical influence of raindrop impact in a more direct way by comparing the effects of a raindrop with those of a little metallic ball. They found in both cases curves of the same shape for the relation between aggregate stability and fall height and concluded from this that the mechanical effect of raindrop impact is the most important one. It seems, however, that the parts which raindrop impact and air-compression play in structure deterioration depends on the moisture percentage of the soil (KOEPF 1958). At moisture percentages below about 20%, the influence of compressed air decreases with increasing moisture content. Above 25 % moisture the kinetic energy of the raindrop is the principal factor.

If a soil which has been exposed to rainfall is desiccated, the sealed surface forms a crust. This is a common experience, even for a sandy soil poor in clay, silt and organic matter, where such a crust may give some protection against wind erosion. The hardest rainfall induced crusts are found on sandy loams, especially if the clay:silt:sand ratio is so that the smaller particles can be fitted in the pores between the greater ones (DULEY 1939). CARNES (1934) introduced a modulus of rupture *(R)*, which is related with rainfall by $R=a\,e^{bx}$, wherein x=the precipitation and a and b are constants. In relation to the great importance of fall velocity of raindrops in splash effects as mentioned above it seems probable, however, that not only the total quantity of precipitation determines the hardness of the soil crust, but that drop velocity should be an important factor too. Surface crusts hinder the water and gas exchange between soil and atmosphere and may prevent the emergence of seedlings (LUTZ 1952, RICHARDS 1953). The rate of clogging and crusting of a bare soil surface depends on rainfall and soil properties. The influence of the latter on marsh silt soils in the northern Netherlands was recently studied by PELGRUM (1963). Clogging and crusting was only small if the percentage of clay ($<2\,\mu$) was more than 20 but became severe if this percentage decreased below 15. To prevent the soil surface from this structure deterioration apparently pH—KCl should be somewhat above 7, the quantity of Ca^{++}-ions in the soil solution higher than 2 maeq/100 g dry soil, and the organic matter percentage 2 or more. The length of the period during which the soil surface was exposed to the influence of weather also appeared to be an important factor. The later in autumn the soil was ploughed the less clogging and crusting could be observed in the next spring.

4. Water Erosion

Water erosion is the transport of soil downwards on the surface of sloping land under influence of rainfall or melting snow. It occurs generally when the intensity of precipitation is greater than the infiltration rate of the soil and if the surface is bare or only partly covered by a crop (f.i. a row-crop). The problem of water erosion is a very broad one and has drawn much attention from agricultural engineers and soil scientists during the last 25 years. References to the following manuals (e.g. STALLINGS 1957) and summarizing papers (e.g. KURON 1954, BLAKELY *et al.* 1957) can be made for a general survey of their work. We have here to restrict ourselves to the influence of weather upon soil structure in the erosion process. Erosion requires a loosening and a transport of soil particles, that means a structure deterioration. The principal mechanisms for soil loosening in water erosion are raindrop splash (splash erosion) and a scouring action of flowing water (scour erosion). The first is discussed in the foregoing section. Experiments (EKERN 1951) have shown that the percentage of the splashed soil which is moving downhill equals 50+S, if S means the slope expressed as a percentage. Raindrop splash decreases the infiltration rate of the soil surface very rapidly, inducing in this way a surface flow of water downhill (run-off), which gives scour erosion. This scouring effect is increased greatly by soil particles suspended in the run-off due to the turbulent action of the waterfilm on the soil surface when raindrops fall on to it. The erosiveness is maximal if the loosening and transporting power of the surface stream are balanced, that is to say when this stream contains abrasive material just enough to loosen as much soil as the stream can carry together with this abrasive material (STALLINGS 1957).

Erodibility of soils for water decreases according to the following sequence: loess loam, sandy loam, clayey loam and clay soils (HEMPEL 1954). Clay soils are eroded only by very high rainfall intensities. When the eroded soil in the run-off, which may be aggregated partly (WEAKLY 1962), settles in depressions the soils thus formed generally have poor structures (KURON 1958).

It will be clear that structure deterioration by precipitation, directly by raindrop impact or more indirectly by a surface flow of rain or melting water, is a fundamental process in water erosion. Therefore maintenance or improvement of soil structure and especially of structure stability (QUENTIN and COMBEAU 1962) is one of the principal measures in soil and water conservation, beside surface covering and provisions for an orderly disposal of run-off water. According to RAM *et al.* (1960) the effectiveness of a cover crop in preventing splash erosion depends on the spatial volume of the crop (=mean height × density).

5. Alternate Wetting and Drying

It is a common experience that a clod of a clay soil or a dried mass of a clayey soil after thoroughly puddling, shows a fragmentation into small pieces if exposed to a few cycles of alternate wetting and drying. Several research workers used this phenomenon in making artificial aggregates for stability measurements (f.i. PETERSON 1943, McHENRY 1945).

The mechanisms by which disruption of clods and aggregates can occur when they are wetted are discussed in section 3. We will rule out of court here the raindrop impact, being a typical surface phenomenon. Considering the topsoil, unequal swelling and compression of entrapped air are the most important causes for a certain fragmentation of the larger structure elements if rewetted at a rather low moisture percentage. KOEPF (1958) has shown that aggregate stability depends on the moisture content and has a maximum at 20—25% of weight moisture for the three different clay soils he was investigating. Apparently the air content at this moisture percentage is so low that disruption of the aggregates by air compression becomes negligible, while on the other hand moisture content is not high enough for mechanical forces to produce a plastic deformation easily. Consequently soil structure has the lowest stability if rewetted in a dry or in a wet state. In the last case however fragmentation into smaller aggregates does not generally occur, but the moisture state of the soil will come into the neighbourhood of the upper plastic limit and soil will collapse into a non-aggregated state due to gravity and other mechanical forces (BOEKEL and PEERLKAMP 1956).

If a very wet clay soil is desiccating, it will shrink. This shrinkage equals the loss of water as long as the soil remains saturated (HAINES 1923). When air enters the soil, however, shrinkage decreases and air content increases strongly. HAINES has shown that this air remains partly occluded in the soil during a subsequent rewetting and causes an increase of the total soil volume.

It will be clear that these changes in volume give rise to unequal strains throughout the soil mass, since wetting as well as drying begins at the exterior, thus bringing about an unequal moisture distribution, which is advanced by the entrapped air. These unequal strains and stresses due to alternate wetting and drying, together with the disruptive action of air compressed in the pores on wetting, produce the fragmentation which has been generally perceived.

Koepf (1960) studied the shrinkage patterns of different puddled soils when drying. He found a positive correlation between shrinkage and clay and organic matter percentages and a negative one between shrinkage and volume of solid material in undisturbed samples. In general the top soil was showing a stronger shrinkage as compared with a subsoil of the same clay content. These two lastly mentioned effects in connection with the more often occurring variations in moisture percentage of the top soil will be important for the development of the top layer's structure.

6. Alternate Freezing and Thawing

Practical farmers are all familiar with the idea that freezing and thawing cycles during winter may be very helpful in obtaining a good structure of clay soils in the next spring. Therefore it will be clear that the effect of alternate freezing and thawing has drawn the attention of soil scientists during the last century. Schumacher (1864) and Wollny (1897) and later Jung (1931), gave important contributions to our knowledge about this problem. The older work has been summarized in a paper by Czeratzki (1956).

When a wet soil freezes soil water crystallises first in the greater pores due to the positive correlation between moisture tension and freezing-point depression. The difference in vapour tension above the solid and the liquid state of soil water causes a growth of the ice crystals at the cost of the moisture content of the soil between these crystals, which is removed, and further, what is most important generally, by moisture transport from lower lying zones or from the ground water as is shown by Czeratzki (1956). Moisture supply from above (atmosphere, precipitation, melting snow) is sometimes possible too. The growing ice mass, which can appear either as layers or lenses of ice or be distributed more homogeneously throughout the soil, depending on the circumstances, exerts pressure on the adjacent soil. Thus these parts of the soil become denser and more stable (Van Schuylenborgh 1947). Apparently desiccation also contributes to this stabilization, owing to certain physicochemical effects. In this way, freezing of a moist soil brings about a frost structure, which can be homogeneous or heterogeneous (stratified), depending on texture, moisture percentage, water-supply and freezing velocity. Fine textured moist sandy soils (grain size $<50—70\ \mu$, Taber 1930) with a wet subsoil give strongly stratified frost structures when frozen slowly. If capillary water transport is low, as in coarse textures or in very dense soils, if the subsoil is rather dry or if the freezing temperature is low, ice lenses become very thin and small and under suitable conditions there arises a homogeneous distribution of the ice mass throughout the soil. The large numbers of small crystals which are formed then, cause a breaking up of the aggregates and a dispersion of the soil.

In a clay soil with a heterogeneous frost structure and a level surface the ice lenses are nearly horizontal. Together with vertical cracks due to shrinkage in the desiccated zone below frost depth, cracks in which, by continuing frost, ice is formed too, the ice lenses divide the soil into polyhedric clods. In ploughed land with a rough surface frost can penetrate into the soil clods from different directions. This generally gives a more irregular pattern of ice layers, dividing big clods into small ones, which are more dense and stable. This means: freezing improves macro-structure, but not micro-structure (VAN SCHUYLENBORGH 1947). If this granulating action of frost is to be of any importance for soil structure in spring however, it is necessary that the obtained frost structure withstands thawing. Since freezing can increase moisture content considerably (POST and DREIBELBIS 1942 report moisture percentages up to 213%), it is possible that the soil becomes very wet during thawing. Depending on the rate of thawing, water discharge, evaporation and rainfall during the thawing period and also depending on soil characteristics; the soil will remain relatively dry and preserve its frost induced granulation or it will be soaked with water and structure will collapse. The latter occurs f.i. in silty soils and in sodium clay soils. Several authors (WOLLNY 1897, GÜNTHER 1931, GARDNER 1945, GRIM 1954) emphasise the importance of calcium in stabilizing frost structures. Organic matter is considered to be an important stabilizing agent too (BAVER 1956). SCHUFFELEN and VAN SCHUYLENBORGH (1950) have studied the influence of the size and moisture content of aggregates of clay soils on the increase of their stability due to one or more freezing-thawing cycles. They found that this stability-increase increased with increasing moisture percentage for 2—4 mm aggregates, but was constant or decreasing for sizes of 1—2 mm. This can be explained by the co-operation of the stabilizing effect owing to mechanical compression of the aggregates by growing ice crystals (JUNG 1931) and the lowering of stability caused by the drying and wetting that accompanies freezing and thawing. According to JUNG (1931) freezing has an aggregating effect, which is greater for slow than for quick freezing and is maximal for a slow frozen soil with a moisture percentage of about 50 per cent saturation.

The effect of freezing-thawing cycles on the size of soil aggregates depends on size and moisture content of the aggregates before the treatment and on the number of cycles. LOGSDAIL and WEBBER (1959) observed an increase of the fragmentation of aggregates by 3 freezing-thawing cycles with an increasing moisture percentage. If aggregates with a diameter of about 2.5 mm and different moisture percentages are subjected to freezing-thawing cycles the mean weight diameter is decreasing and this effect was found the stronger the greater the number of cycles was. Very small aggregates (<0.25 mm) are showing an increase of the mean weight diameter, increasing with the number of cycles (SILLANPÄÄ 1961, SILLANPÄÄ and WEBBER 1961). Generally, the dispersion of soil rapidly increases with an increasing number of cycles, especially within about the first 10 cycles.

Summarizing, it can be said that the effect of freezing and thawing on soil structure is rather complex due to the great number of factors and their interactions influencing it. Most important is the breaking up of big clods of clay soils into rather small aggregates of an increased stability. It must be kept in mind however that generally these aggregates are not crumbs, but a kind of dense micro-clods, which under very wet conditions can easily be compacted again into bigger units, especially if the lime and organic matter content of the soil is low.

7. Wind Erosion

Wind erosion is the displacement of soil particles on the surface by wind. Fundamental research on soil drifting has been made by BAGNOLD (1941), MALINA (1941), CHEPIL (f.i. 1945/1946) and ZINGG (f.i. 1950).

Wind erosion begins according to MALINA (1941) with an initiation of soil movement, followed by a transport of the soil either in the air or along the surface, and ends with the deposition of the material in a new location. In each of these three steps the structure of the surface soil can be disturbed.

Wind erosion starts generally with the movement of a few loose grains due to wind pressure or to a slight mechanical disturbance of the soil surface by foot steps or a landing bird. These grains often roll on the surface, thus obtaining a rotational momentum, which helps to give the particle an uplift due to the pressure difference between the upper and lower side of a body rotating in an air stream (*Magnus*-effect). In consequence of the great wind velocity gradient near the soil surface the particle obtains an increased kinetic energy, since it is exposed to greater wind velocities at some distance from the surface. The grain will move downwards after a few moments, due to gravity. When it collides with the soil surface its energy is distributed among two or more grains, that begin to leap in turn. In this way a cumulative bouncing movement arises, which is introduced by FREE (1911) as "saltation" to distinguish it from the movement whereby soil particles are carried by wind at greater distances more or less parallel to the soil surface ("suspension movement"). A third type of movement is the rolling or sliding of grains along the surface, named "surface creep" (BAGNOLD 1941). According to CHEPIL (1941, 1945, 1946) type of movement and erodibility depend on the size of the particles (loose grains and aggregates) in the soil surface. The grain fraction 100 — 500 μ or the aggregate fraction 180 — 1200 μ moves in saltation, smaller particles move in suspension. Surface creep occurs with the grain fraction 500-1000 μ and the aggregate fraction 1200 — 2500 μ. Greater particles are not blown by wind generally. The grain fraction 100-150 μ shows maximal erodibility. The greater part of a wind blown soil usually moves in saltation (about 55-75%).

It will be clear from these results that a well structured soil with a high percentage of aggregates greater than 2.5 mm in its surface will have a considerable resistance to wind erosion. A high rate of stability of these aggregates is a self-evident condition for a more durable resistance. Therefore clayey soils are not eroded by wind generally if the clay content is higher than 15% (v. d. SPEK 1950). On the other hand wind erosion on most sandy soils is introduced by a breaking up of the aggregates due to rainfall (see section 3). When in this way a sufficient number of erodible particles is obtained, soil blowing will start, if wind velocity is high enough (generally more than about 7-8 m/sec on the reference height of 6 m). As well by the impacts of the particles moving in saltation as by the scouring action of the surface creep, destruction of soil surface structure can occur, thus increasing soil drifting. Often this destruction is irreversible as the greater part of the soil organic matter and the finest grains are blown far away in suspension. Sometimes a deposition of the particles moving in saltation and surface creep occurs on adjacent fields, which were not eroded before, due to a plant cover or a good structure. Then it is often seen that the vegetation dies or soil structure is disturbed by abrasion and the soil of these fields starts to drift too. Summarizing it can be said that, under suitable conditions, wind can set in motion particles of the soil surface, which then disturb the soil structure by impact and abrasion. Wind erosion can be combatted by measures which increase the size and stability of the soil aggregates or decrease the wind velocity near the soil surface.

8. Indirect Influences of Weather upon Soil Structure

In the sections 3—7 the more direct effects of precipitation, temperature and wind are discussed. Meteorological conditions, however, influence soil structure in an indirect way too, especially via soil cultivations and plant growth.

The influence of ploughing and other cultivations upon the structure of several soils is affected strongly by their moisture content, which in turn is determined to a great extent by weather during the foregoing period. It is e. g. a common experience that a very wet autumn often gives poor structures, especially at present, as it is possible now to drive on the land and to plough it under wet soil conditions, due to motorization. Results of Low (1955) suggest that cultivations under dry conditions of the soil give a stable tilth.

Plant growth as well as the microbial population of the soil are influenced by soil moisture content and soil temperature. Both are determined by a complex of soil and meteorological factors among which radiation, precipitation, air temperature and wind velocity play an important part. Plant growth brings organic matter into the soil periodically by means of the roots and of above-ground parts which are buried in the soil. This organic material decays by microbial activity, thus giving a temporary improvement of soil structure (PEERLKAMP 1950), which depends as well on the total mass of roots as on microbial activity. It will be clear that in this way meteorological conditions can influence soil structure indirectly.

9. Seasonal Variability of Soil Structure

The different meteorological factors are not constant and therefore their direct and indirect influences vary strongly. Several authors (ALDERFER 1946, 1950, ROWLES 1948, HÉNIN and TURC 1949, KÄMPF 1952, LOW 1955, KULLMANN, 1958, and others) have shown the great variability of soil structure and especially of aggregation, within rather short periods of e. g. a few weeks. HEINONEN and PUKKALA (1954) report great and frequent variations of total pore volume too. Due to the complexity of the entire problem of structure variability in which not only meteorological factors play a part but also measures of soil cultivation, crop rotation, fertilizing, manuring and other agircultural treatments, it has been not possible till now to explain the observed effects fully and to derive rules with a general applicability. Although some of the published variabilities of soil aggregation may be due to the analysing method (KULLMANN and KOITZSCH 1956) it seems to be sure that meteorological conditions and their variability have important effects, which are often much greater than the influences of soil treatments.

Literature

ALDERFER, R. B.: Seasonal variability in the aggregation of Hagerstown silt loam. Soil Sci. 62, 151–168 (1946). — Influence of seasonal and cultural conditions on aggregation of Hagerstown soil. Soil Sci. 69, 193–203 (1950).

BAGNOLD, R. A.: The physics of blown sand and desert dunes, 1st ed. London: Methuen. 1941 (reprinted 1954). — BAVER, L. D.: A classification of soil structure and its relation to the main soil groups. Amer. Soil Survey Ass. Bull. 15, 107–109 (1934). — Soil physics, 3rd ed., pp. 123–198. New York: Wiley. 1956. — BENNETT, H. H., F. G. BELL and B. D. ROBINSON: Raindrops and erosion. U.S.D.A. Circ. no. 895 (1951). — BERTRAND, A. R., and K. SOR: The effects of rainfall intensity on soil structure and irrigation of colloidal materials in soils. Soil Sci. Soc. Amer.

Proc. 26, 297–300 (1962). — BISAL, F.: The effect of raindrop size and impact velocity on sand-splash. Canad. J. Soil Sci. 40, 242–245 (1960). — BLAKELY, B. D., J. J. COYLE and J. G. STEELE: Soil. U.S.D.A. Yearbook of Agric. 1957, 290–307. — BOEKEL, P., and P. K. PEERLKAMP: Soil consistency as a factor determining the soil structure of clay soils. Neth. J. Agric. Sci. 4, 122–125 (1956).

CARNES, A.: Soil crusts. Methods of study, their strength and a method of overcoming their injury to cotton stand. Agric. Engng. 15, 167–169, 171 (1934). — CHEPIL, W. S., and R. A. MILNE: Wind erosion of soil in relation to roughness of surface. Soil Sci. 52, 417–433 (1941). — CHEPIL, W. S.: Dynamics of wind erosion I/VI. Soil Sci. 60, 305–320, 397–411, 475–480 (1945), 61, 167–177, 257–263, 331–340 (1946). — CZERATZKI, W.: Zur Wirkung des Frostes auf die Struktur des Bodens. Z. Pflanzenernähr., Düng., Bodenkde. 72, 15–32 (1956).

DULEY, F. L.: Surface factors affecting the rate of intake of water by soils. Soil Sci. Soc. Amer. Proc. 4, 60–64 (1939).

EKERN, P. C.: Raindrop impact as the force initiating soil erosion. Soil Sci. Soc. Amer. Proc. 15, 7–10 (1951). — ELLISON, W. D.: Studies of raindrop erosion. Agric. Engng. 25, 131–136, 181–182 (1944). — ELLISON W. D., and C. S. SLATER: Factors that affect surface sealing and infiltration of exposed soil surfaces. Agric. Engng. 26, 156–157, 162 (1945). — Soil erosion by rainstorms. Nav. Docks P-42, 5 p.p. Dept. of the Navy, Washington, D. C., 1950.

FREE, E. E.: The movement of soil material by the wind. U.S.D.A. Bur. Soils Bull. no. 68 (1911).

GARDNER, R.: Some effects of freezing and thawing on the aggregation and permeability of dispersed soils. Soil Sci. 60, 437–443 (1945). — GIESEKING, J. E.: The mechanism of cation exchange in the montmorillonite-beidellite-nontronite type of clay minerals. Soil Sci. 47, 1–13 (1939). — ENSMINGER, L. E., and J. E. GIESEKING: The absorption of proteins by montmorillonitic clays and its effect on base exchange capacity. Soil Sci. 51, 125–132 (1941). — GIUDICI, P.: Évaluation des facteurs déterminant la désintégration hydromoléculaire des agrégats terreux. Trans. 5th Int. Congr. Soil Sci. 1945, Part II, 219–228. — GRIM, R. E.: Relation of frost action to the clay-mineral composition of soil materials. Highway Res. Board Spec. Rep. 2, 167–172 (1954). — GRIMSEHL: Lehrbuch der Physik, 7. Aufl., Bd. I, S. 288. Leipzig: Teubner. 1929. — GUNN, R., and G. D. KINCER: The terminal velocity of fall for water droplets in stagnant air. J. Meteor. 6, 243–248 (1949). — GÜNTHER, E.: Untersuchungen über die Einwirkung des Frostes auf verschiedene Ackerböden und den dadurch bedingten Einfluß auf das Wachstum von Hafer und Gerste. Landw. Jahrb. 73, 893–922 (1931).

HAINES, W. B.: The volume-changes associated with variations of water content in soil. J. Agric. Sci. 13, 296–310 (1923). — HEINONEN, R., and R. PUKKALA: Seasonal variation in soil structure. Maataloust. Aikak. 26, 116–119 (1954). — HEMPEL, L.: Beobachtungen über die Empfindlichkeit von Ackerböden gegenüber der Bodenerosion. Z. Pflanzenernähr., Düng., Bodenkde. 64, 42–54 (1954). — HENDRICKSON, B. H.: The choking of pore space in the soil and its relation to runoff and erosion. Trans. Amer. Geophys. Union 2, 500–505 (1934). — HÉNIN, S.: Étude physico-chimique de la stabilité structurale des terres. Monographie des Stat. et Lab. de Rech. Agron. Paris 1938. — HÉNIN, S., et L. TURC: Nouvelles observations sur la variation annuelle de la stabilité structurale du sol. C. R. Acad. Agric. France 36.14, 587–599 (1950). — HÉNIN, S., O. ROBICHET et A. JONGERIUS: Principes pour l'évaluation de la stabilité de la structure du sol. Ann. Agron. A 6, 537–557 (1955).

JENNY, H.: A study on the influence of climate upon the nitrogen and organic matter content of soil. Miss. Agric. Exper. Stat. Res. Bull. no. 152 (1930). — JENNY, H., and C. D. LEONARD: Functional relationships between soil properties and rainfall. Soil Sci. 38, 363–381 (1934). — JUNG, E.: Untersuchungen über die Einwirkung des Frostes auf den Erdboden. Z. Pflanzenernähr., Düng., Bodenkde. A 19, 326–333 (1931).

KÄMPF, R.: Untersuchungen über die Strukturwandlungen der Ackerkrume bei Lößlehmböden. Z. Acker- u. Pflanzenbau 95, 303–330 (1952). — KAZÓ, B., and L. GRUBER: The investigation of microsolifluction with the aid of tagged isotopes. Int. Ass. Sci. Hydrol. Publ. 59, 62–66 (1962). — KOEPF, H.: Über den Einfluß der Vorbefeuchtung auf die Stabilität von Bodenaggregaten. Proc. Int. Symp. Soil Structure Ghent 1958, 283–289 (Med. Landbouwhogeschool, Gent, 24, nr. 1, 1959). — Zur Strukturbildung verschiedener Böden durch Schrumpfung. Z. Pflanzenernähr., Düng., Bodenkde. 89, 159–170 (1960). — KULLMANN, A., and R. KOITZSCH: Zur Krümelstabilitätsmessung auf leichtem Boden. Z. Pflanzenernähr., Düng., Bodenkde. 73, 224–235 (1956). — KULLMANN, A.: Zur Problematik der Krümelstabilitätsmessungen und zur Methodik des Durchflußverfahrens. Tagungsber. Deutsch. Akad. Landw. Wiss. Berlin 13, 7–34 (1958). — KURON, H.: Ergebnisse von 15-jährigen Untersuchungen über Bodenerosion durch Wasser in Deutschland. Veröff. Int. Ass. Hydrol. 36, 8 S. (1954). — Strukturschäden durch Bodenerosion. Proc. Int. Symp. Soil Structure Ghent 1958, 24–29 (Med. Landbouwhogeschool, Gent 24, nr. 1, 1959).

LAWS, J. O.: Measurements of the fall-velocity of waterdrops and raindrops. Trans. Amer. Geophys. Union 3, 709–721 (1941). — LAWS, J. O., and D. A. PARSONS: The relation of raindrop-size to intensity. Trans. Amer. Geophys. Union 2, 452–459 (1943). — LOGSDAIL, D. E., and L. R. WEBBER: Effect of frost action on structure of Haldimand clay. Canad. J. Soil Sci. 39, 103–106 (1959). — LOW, A. J.: Improvements in the structural state of soils under leys. J. Soil Sci. 6, 179–199 (1955). — LOWDERMILK, W. C.: Influence of forest litter on runoff, percolation and erosion. J. Forestry 28, 474–491 (1930). — LUTZ, J. F.: Mechanical impedance and plant growth. Agronomy, Vol. II, pp. 43–71. New York: Academic Press. 1952.

MALINA, F. J.: Recent developments in the dynamics of wind erosion. Trans. Amer. Geophys. Union 3, 262–284 (1941). — MCHENRY, J. R.: Mechanics in the formation of water-stable soil aggregates. Iowa St. Coll. J. Sci. 20, 25–27 (1945).

PEERLKAMP, P. K.: The influence on soil structure of the "natural organic manuring" by roots and stubbles of crops. Trans. 4th Int. Congr. Soil Sci. 1950, Vol. I, 50–54. — PELGRUM, A.: De gevoeligheid voor verslemping van lichte kleien zavelgronden. Landbouwvoorlichting 20, 637–645 (1963). — PETERSON, J. B.: Formation of water-stable structure in puddled soils. Soil Sci. 55, 289–300 (1943). — POST, F. H., and F. R. DREIBELBIS: Some influences of frost penetration and microclimate on the water relationships of woodland, pasture and cultivated soils. Soil Sci. Soc. Amer. Proc. 7, 95–105 (1942). — PURI, A. N., and B. A. KEEN: The dispersion of soil in water under various conditions. J. Agric. Sci. 15, 147–161 (1925).

QUANTIN, P., and A. COMBEAU: L'érosion et la stabilité structurale du sol. Int. Ass. Sci. Hydrol. Publ. 59, 124–130 (1962).

RAM, D. N., M. T. VITTUM and P. J. ZWERMAN: An evaluation of certain winter cover crops for the control of splash erosion. Agron. J. 52, 479–482 (1960). — RICHARDS, L. A.: Modulus of rupture as an index of crusting of soil. Soil Sci. Soc. Amer. Proc. 17, 321–323 (1953). — ROBINSON, D. O., and J. B. PAGE: Soil aggregate stability. Soil Sci. Soc. Amer. Proc. 15, 25–29 (1950). — ROSE, C. W.: Soil detachment caused by rainfall. Soil Sci. 89, 28–35 (1960). — ROWLES, W.: Physical properties related to structure of Ste. Rosalie clay and their seasonal variation. Sci. Agric. 28, 558–573 (1948).

SCHUFFELEN, A. C., and J. VAN SCHUYLENBORGH: Het gebruik van de methode Vilenski ter bestudering van de invloed van de vorst en van de micro-organismen op de structuur van de grond. Landb. Tijdschr. 62, 339–347 (1950). — SCHUMACHER, W.: Die Physik des Bodens in ihren theoretischen und praktischen Beziehungen zur Landwirtschaft, S. 275. Berlin 1864. — SCHUYLENBORGH, J. VAN: A study on soil structure. Thesis Wageningen. 1947. — SILLANPÄÄ, M.: The dynamic nature of soil aggregation as affected by cycles of freezing and thawing. Acta Agron. Scand. 11, 87–94 (1961). — SILLANPÄÄ, M., and L. R. WEBBER: The effect of freezing-thawing and wetting-drying cycles on soil aggregation. Canad. J. Soil Sci. 41, 182–187 (1961). — SOR, K. M.: Effects of rainfall energy on some physical properties of soils. Diss. Abstr. 22, 4–5 (1961). — SPEK, JAC. VAN DER: Stuivende mariene gronden (Drifting marine soils). Versl. Landb. Ond. 56.11, 28 pp. (1950). — STALLINGS, J. H.: Soil conservation. Englewood Cliffs, N.Y., 1957.

TABER, S.: Freezing and thawing of soils as factors in the destruction of road pavements. Publ. Roads 11, 113–132 (1930). — TIULIN, A. F.: Questions on soil structure. II. Aggregate analysis as a method for determining soil structure. Perm. Agric. Exper. Sta. (Div. Agric. Chem.) Rep. 2, 77–122 (1928).

WEAKLY, H. E.: Aggregation of soil carried in run-off from simulated rainfall. Soil Sci. Soc. Amer. Proc. 26, 511–512 (1962). — WOLLNY, R. E.: Der Einfluß der Pflanzendecke und Beschattung auf die physikalischen Eigenschaften und die Fruchtbarkeit des Bodens. Berlin 1877. — Untersuchungen über den Einfluß des Frostes auf die physikalischen Eigenschaften des Bodens. Forsch. a. d. Geb. d. Agrikulturphysik 20, 439–469 (1897/98).

YODER, R. E.: A direct method of aggregate analysis and a study of the physical nature of erosion losses. J. Amer. Soc. Agron. 28, 337–351 (1936).

ZINGG, A. W., and W. S. CHEPIL: Aerodynamics of wind erosion. Agric. Engng. 31, 279–282, 284 (1950).

Printed in Austria