f) Effects of Crop and Rotation on Soil Structure

By

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1. Introduction

The interrelation between crop and soil structure is very complex. Soil structure affects plant growth, but conversely, the crop and the sequence of crops (rotation) have again an influence on soil structure. The effects in both directions depend on many factors, among which those related to soil and climate are very important. Most of these factors vary with time more or less rapidly.

The influences that crop and rotation exert upon soil structure are to be divided roughly into direct and indirect ones. The ways in which a crop affects soil structure directly are: a) the plant cover protects the soil surface from raindrop splash and wind erosion and b) the penetrating and branching roots affect soil structure mechanically. Indirect influences of crop growth and rotation upon soil structure are: c) their effects on moisture content and temperature of the soil, which in turn affect soil structure in several ways, d) the influence which soil organic matter, due to roots and plant residues, has upon soil structure, and e) the effects of tillage operations which are necessary in agriculture.

2. Protection against Raindrop Splash and Wind Erosion

The phenomenon of soil structure deterioration by means of the kinetic energy of falling raindrops, briefly named "raindrop splash", has been discussed in detail in the preceding chapter. A plant cover can absorb this energy more or less, depending on the density of the vegetation. This has been shown already by WOLLNY (1877), who found that, the denser the plant cover, the smaller was the decrease of soil porosity during the vegetation period. From his results it appears that especially the bigger pores are preserved by a vegetative canopy (Table 7)

Table 7. *Effect of a plant cover on the porosity of a humiferous, calcareous sandy soil* (after WOLLNY 1877)

crop	total porosity (% of vol.)		non capillary porosity (in % of total porosity)	
	cover	no cover	cover	no cover
rye	62.2	58.3	54	38
peas	63.6	59.2	51	35
vetch	69.2	65.5	56	44

and that only 45 to 88% of the total rainfall reaches the soil surface directly, depending on the type of crop and on the number of plants per unit area. Important factors determined by the type of the crop are the total surface of the leaves per plant and the shape and position of the leaves. According to KÖRNICKE and WERNER (1885) lucerne has a very large surface of leaves per unit area of soil surface (Table 8), corn and beets have small leave-surfaces and clover and cereals have an intermediate position. With the exception of corn this sequence agrees roughly with that which WOLLNY, HAYNES and SMITH *et al.* (cf. BAVER 1956) obtained for the interception of rainfall by various crops. It will be obvious that the figures given in Table 8 depend not only on the type of crop but on the number of plants per unit area too. Differences in this number seem to be the cause of the different results for corn, which is illustrated by the findings of Wollny (see Baver 1956) that the percentage of total rainfall penetrating a corn crop with

Table 8. *Total surface of leaves* (m^2) *per* m^2 *soil surface* (after Körnicke and Werner 1885)

crop	leave-surface	crop	leave-surface
lucerne	85.6	barley	14.6
clover	24.5	summer-wheat	13.7
oats	21.1	corn	2.7
winter-wheat	17.5	mangolds	1.6
winter-rye	15.6		

9 or with 36 plants per m^2 is 63 and 44 respectively. It is self-evident that not only the density of the vegetative canopy at a certain moment is important for soil structure but also its changes in the course of time, especially in relation to the fluctuations in rainfall. Sowing or planting date, vegetation period, type of crop and all factors affecting its development (physical and chemical soil fertility, soil and crop treatment, plant diseases a.s.o.) play an important part with regard to the sheltering effect that a crop has upon the soil and therefore they can influence soil structure.

To protect a soil from wind erosion a crop needs to be not so dense as to prevent the surface from raindrop splash. Strips of crops perpendicular to the predominant wind direction are generally sufficient. Several scientists have studied the sheltering effect of wind-breaks (see e. g.: van der Linde and Woudenberg 1951 and Kreutz 1952). It appears that this effect can be shown up to a distance of 10 to 30 times the height of the windscreen on its lee-side and as far as about 10 times this height on the windward side. For practical purposes the shelterbelts are planted generally at distances of 20 to 30 times their height.

3. Mechanical Effects of Plant Roots

It is a common experience that a soil containing a well-branched root system, such as a grass sod, generally has a good structure. How this favourable influence is exerted by the roots is a question, which still cannot be answered completely at present. Roots can affect soil structure in several ways: they can exert pressures upon the soil, the branched root system can keep loose soil particles together, dessicates the soil, thus influencing soil structure, the different types of organic matter arising from a microbial attack of the dead roots affect the structure and its stability, and perhaps root excretions play a part. In this section we will restrict ourselves to the mechanical effects, in which the roots are acting more directly. The indirect influences via moisture content and organic matter will be treated in the sections 4 and 5 respectively.

The growing roots develop a net-work of fine channels in the soil, which is left more or less complete after the roots have been decayed. The volume of this network can be estimated from determinations of root-weights (see e.g. Schuurman 1958), supposing the moisture percentage of the fresh roots is 78 and their density is 1.04 g/cm³. From the results mentioned in Table 9 it appears that in comparison with the total pore volume of the soil (of say 50%) the root volume is rather small and that in the top layer the latter volume is much greater for grass than for wheat. It must be emphasized however that this effect of increasing the porosity is to a certain extent a cumulative one, since in the next season the roots grow partly on other places and most root holes have lifetimes longer than one year. Therefore, undoubtedly the observed effect will be much greater

Table 9. *Root volumes for perennial ray grass and spring wheat on a clay soil*

crop	layer (cm below surface)	weight (kg/ha) of the air-dry roots[1]	root volume	
			m^3/ha	% of volume
perennial ray grass	0—10	6000	26.2	2.6
	10—40	3000	13.1	0.4
spring wheat	0—10	1500	6.6	0.7
	10—40	800	3.5	0.1

[1] After SCHUURMAN (1958).

than is suggested by the figures in Table 9. It must be noticed that this effect is not only confined to the topsoil, but is especially significant for the structure of the subsoil. In this respect deep rooting crops such as lucerne are important.

Roots are thought to loosen the soil by the pressure they exert on the adjacent soil, due to their transversal growth. Especially when roots penetrate into a clod along a former cleavage plane or another point of weakness they can split up the clod and can introduce or increase the granulation. Mainly this occurs in clayey soils under moderate moisture conditions. If such a soil is wet root pressure gives a plastic deformation, in the dry soil roots are usually unable to penetrate clods and are growing and branching in cracks already present. On the other hand the transversal root pressure can press the particles of a loose soil together into small aggregates and perhaps may increase the stability of such aggregates, if present, by means of a certain compression.

Roots and root hairs often literally enmesh soil granules, thus enlarging their stability. According to Low (1955) this occurs especially in sandy soils, where the relatively large pores enable the roots to penetrate into the soil comparatively easy. The aggregates formed in this way are fairly water-stable, but are generally very weak toward mechanical forces. In clay soils this aggregate building by roots seems to be of little importance because of the strong binding forces in these soils.

Much more experimental results, however, must be available to obtain a complete understanding of the mechanical root effects upon soil structure.

4. Influence of Soil Moisture and Temperature as Affected by Crop Growth

The ways in which soil moisture and soil temperature can affect the structure of the soil were described in the preceding chapter. Here we will report briefly on the influence a crop has on soil moisture content and soil temperature in relation to structure.

A crop diminishes the quantity of precipitation that reaches the soil surface (interception) and decreases the evaporation from this surface. On the other hand it increases the removal of moisture from the soil by transpiration.

The quantity of intercepted rainwater that evaporates directly from the plants varies with the kind of crop and with the kind and size of precipitation.

Although only very few data for the interception of agricultural crops are available, its annual magnitude seems to be generally between 5 and 15 percent of the annual rainfall (Ackermann *et al.* 1955).

Under a dense vegetation the evaporation from the soil surface as compared to that of a bare soil will be small, owing to the strongly diminished air movement and the lower maximal temperatures under the vegetative canopy. The total evaporation (evapotranspiration) from a soil covered with a crop, however, is much greater than the evaporation from a bare soil. Under the circumstances in N.W. Europe the ratio of their annual magnitudes is about 17 as can be derived from the lysimeter results of Maschhaupt (1948) and others. Therefore the total effect of a crop generally will be a lessened moisture content of the soil. On clay or clayey soils this can give cracks, especially in the neighbourhood of the roots where desiccation is greatest, a certain stabilisation of tilth (Low 1955) and easier cultivations after harvest in a wet autumn, resulting in a better structure. Further, keeping a clay soil covered with a crop in autumn will lessen its field capacity during winter owing to the desiccation and the retarded remoistening (Fig. 66) and according to Boekel and Peerlkamp (1956) this will decrease structure deterioration during winter.

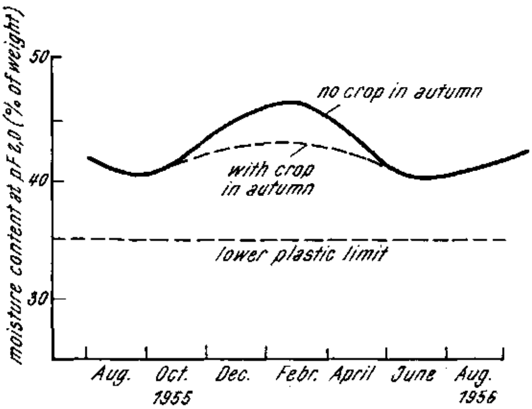

Fig. 66. Variations within a year of the moisture content at pF 2 (field capacity) of a clay soil with or without a crop in autumn (from unpublished data by Boekel)

A plant cover diminishes the diurnal as well as the annual fluctuations of soil temperature, depending on the type of crop and the climate. The smaller diurnal variations and the lower temperature of the top soil in summer, as well as its lower moisture content, may have any influence on the microbial activity in the soil and can affect in this way soil structure (cf. section 5). Covering a clay soil with a crop during winter prevents partly or entirely the beneficial effect of freezing (see the preceding chapter, section 6).

5. Effects of Organic Matter Originating from Vegetation

Generally there will be no difference of opinion about the fact that organic material brought into the soil has a favourable influence upon soil structure. Roots and stubbles of harvested crops and other plant residues contribute to a considerable extent to the organic matter supply of the soil (Table 10, Goedewaagen and Schuurman 1950). This more or less fresh organic material undergoes a series of chemical transformations in the soil owing to microbial activity and depending on weather, soil, crop and other factors that influence this activity. In the course of this transformation various intermediate products arise which can be more or less microbial resistant. It appears that some of these products play a part in respect to soil structure.

Several authors have shown that certain polysaccharides and polyuronides as well as the soil bacteria and fungi themselves affect soil structure stability (see e.g. Rennie *et al.* 1954). All these agents, however, are not microbial resistant but decay rather easily. Therefore fresh organic material must frequently be brought into the soil if it is to affect soil structure in this way. Roots and stubbles of crops give such a periodical supply (PEERLKAMP 1950).

A regular organic dressing of the soil, however, also leads to a certain percentage of organic matter in the soil when a state of equilibrium is attained. This percentage depends on climate, crop, soil and soil management. KÖNEKAMP (1957) emphasized in this respect the intensity of cultivation and the nitrogen and albumen content of the organic material. If the latters were high and the cultivation intensity low the increase of the organic matter percentage was high. According to KORTLEVEN (1959) an annual supply S (dry weight) to the soil with organic materials in the Netherlands resulted eventually in an increase of the organic matter content of the soil of 1/20 S.

Soil organic matter, consisting for the greater part of materials, which are not so easy assailable by the soil microbes as the temporary cementing agents mentioned above, affect soil structure as is shown by several authors (see e.g. PEERLKAMP 1950, BAVER 1956, BOEKEL 1959). The way, however, in which the more stable soil organic matter influences structure is still somewhat obscure at present. BEUTELSPACHER (1955) and FLAIG (1958) report that the humic acids themselves are not able to cement clay particles together, but that sesquioxides must be present too. EGAWA and SEKIYA (1956) found the fraction of very small aggregates (<0.1 mm) to have the highest percentage of colloidal clay and humic acids. Therefore these materials seem to play a part, chiefly in the formation of very small aggregates. Extraction of soil organic matter with various solvents indicates the importance of the easy soluble, so-called raw humus, accumulated in the rhizosphere, in cementing soil particles and small aggregates into big ones. According to FÖRGETEG (1957) aggregation in the top layer of 12 cm occurs especially in the period from spring till harvesting time. He concludes that root growth and microbial activity are the main causes for this aggregation, whereas soil moisture is only a secondary factor.

It is obvious that a crop not only affects soil structure by bringing fresh organic material into the soil but also more indirectly by its effects on soil moisture and temperature, which in turn influence the microbial activity. Generally speaking, however, the micro-organisms in the soil can grow within a wide range of moisture percentages and temperatures, so that the effects of the latter on microbial activities are mainly restricted to extreme circumstances.

Summarizing it can be said that a crop as well by the "natural orgânic manuring" due to its roots and stubbles, which can be transformed microbially into various structure improving agents, as by its effects on the microbial activity via moisture percentage and temperature can affect soil structure. A complete picture of this complex occurence, however, cannot be given just yet.

6. Effects of Tillage Operations as Related to Crop and Rotation

Soil cultivations and other mechanical soil treatments as e.g. the mechanical harvesting of potatoes, greatly affect soil structure. The result depends mainly on the type of soil and its moisture content. For a certain soil the latter is determined mainly by the climatological conditions. Generally, mechanical soil treatments affect principally the actual structure and not the structure stability. Therefore the result of such a treatment in the course of time mainly depends on the weather in the previous period (see the preceding chapter).

Since every crop has its specific requirements with regard to soil cultivations, etc., different crops and rotations can affect the structure of a soil in different ways, mainly owing to the different times at which the soil is treated and the frequency and intensity with which this is done. The seedbed preparation of a winter crop usually takes place earlier in autumn and therefore generally under somewhat drier conditions and also more intensively than autumn ploughing for a spring crop. At the beginning of the winter, the soil of the winter crop will be finer granulated. What happens during winter depends on the soil and weather. On a sandy clay soil the wintercrop can give a certain protection against structural deterioration, so that the structure in spring is worse on the bare soil. On a heavy clay soil, however, the crop prevents the soil, to a certain extent, from the beneficial freezing, resulting in a better structure on the bare soil in spring.

Fine seeds require fine granulated seedbeds. Low row crops make possible a more intensive treatment of the top soil by hoeing and earthing up. Harvesting potatoes and sugar-beets with lifting-machines gives an intensive soil treatment too. On heavy clay soils these intensive mechanical soil treatments can have a favourable effect upon structure if the soil is not very wet. On light soils, however, granulation becomes too fine and structure will deteriorate very easily.

Crops such as potatoes, sugar-beets and cover crops that must be harvested late in the season increase the chances that harvesting and tillage operations must be done under wet conditions and that, therefore, on clay soils structure will deteriorate.

Generally, however, these effects of mechanical soil treatments are only temporary. Usually they disappear within one year.

7. The Total Effects of Different Crops upon Soil Structure

In the preceding sections the ways in which a crop can affect soil structure have been briefly discussed. What are, however, the total effects of the different crops? Although literature gives a lot of data that could help to answer this

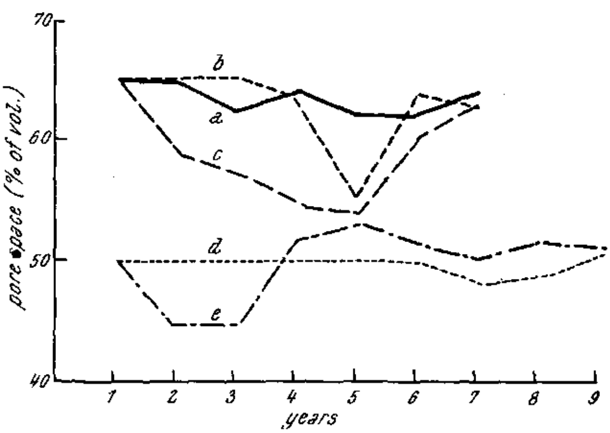

Fig. 67. Effect of ley farming on the pore space with a 2- and 4-year ley-period on a sandy soil and with a 2-year ley-period on a silty loam (according to Boekel)

a Sandy soil, continuous arable land; *b* Sandy soil, ley farming (4th and 5th year grass); *c* Sandy soil, ley farming (2nd, 3rd, 4th and 5th year grass); *d* Silty loam, continuous arable land; *e* Silty loam, ley farming (2nd and 3rd year grass)

question, most of them characterize soil structure in an insufficient way. There is a lack of data especially concerning the actual structure and its changes in the course of time. Further it is often not quite certain that the observed structural differences are entirely due to differences in crops and that no other factors play a part. Some general remarks however can be made.

It is commonly believed that grass generally has a favourable effect upon soil structure (see e.g. EBERT 1953). But it must be emphasized that this is especially true for a sod which has been ploughed up and that often the actual structure of grassland is a relatively dense one, owing to a compression of the soil by cattle. This is a common experience in ley farming, as is illustrated for two different soils in the Netherlands by Fig. 67.

On the sandy soil with a relatively large pore volume this volume is strongly reduced during the ley-period and it tends more to the level of arable land after the ley has been ploughed. On the silty loam, however, which has a much smaller pore space, the depression in the grassland years is not so great and an increased pore space level remains after ploughing the ley. WILLIAMS and COOKE (1961) report that keeping a soil three years under grass stabilizes the structure, mainly during the first year after plowing up the sod. The latter agrees with a result obtained by KOBLET and WEHRLI (1959), who furthermore found that aggregate stability was higher under grass than under legume five months after the establishment of the ley and that this stability increased with an increasing proportion of grass in grass-clover mixtures.

Several authors (EBERT 1953, PRINGLE and COUTTS 1956, WISNIEWSKI *et al.* 1958 and others) have reported on the influences of different species of grass on soil structure. Generally, however, their results are not concordant enough

Table 10. *Air dry weights of roots in the topsoil (0-20 cm), including stubbles if present, of different crops in 100 kg/ha*
(after GOEDEWAAGEN and SCHUURMAN 1950)

crop		weight of roots (incl. stubbles)
grass	old grassland	70 (23 to 110)
	ley (7 years old)	78
	ley (3 years old)	89
cereals	spring barley	14
	spring wheat	15
	winter barley	21
	winter wheat	26
	oats	28
	rye	31
root crops	potatoes	3
	sugar-beets	6
	mangolds	8
legumes and pulses	serradella	3
	peas	4
	vetch	7
	lupins	9
	trefoil	10
	horse beans	12
	white clover	14
	red clover	22
	lucerne	57

for making a sequence of the species regarding their effects on soil structure. This seems to be due to other factors such as type and fertility of the soil, moisture conditions, climate, etc. that affect grass growth and in this way soil structure too. Therefore an improvement of soil structure by growing grasses requires the use of a mixture of grass species that is adapted to the local conditions. Differences in grass species appeared to have a greater effect on the water stable aggregation of a heavy clay soil than differences in herbage utilization (Troughton 1961).

The same difficulties as with the grass species are met if one compares the effects of different crops on soil structure. Generally, however, it is found that grasses have a more favourable influence upon soil structure than cereals and that cereals are better in this respect than root crops (Ebert 1953). This seems to be caused chiefly by differences in the extent of the root-system (see Table 10). It must be emphasized that the differences between grass and other crops are somewhat smaller than Table 10 would suggest at first sight. Grass renews only a part of the root system (say 1/3) each year. A 3-years ley that was ploughed has brought during these 3 years a quantity of organic material into the top soil of $1^2/_3$ of its root mass or about 14500 kg/ha. For cereals this is three times about 2200 or 6600 kg/ha, which is still a big difference. Root crops contribute very little to the organic matter supply of the soil and have therefore not a favourable influence upon soil structure in the long run. They can have a certain favourable temporary influence on soil structure owing to the more intensive tillage that is associated with them (see section 6). Legumes are generally prefered with respect to the effects on soil structure than their root weights suggest. It seems that this is due to their covering action and their moisture uptake (see sections 2 and 4), perhaps sometimes also to their nitrogen effect. They seem however to have only a transitory effect on soil structure (Mortensen and Young 1960).

8. Crop Rotation and Soil Structure

From the results mentioned in the preceding section it follows that crop rotation enables us to influence soil structure. Since, however, the effects of rotation on soil structure depend on several other factors related to soil, soil fertility, cultivation methods, climate and weather, etc. they can only be broadly outlined.

Several authors (Peerlkamp 1950, Mazurak *et al.* 1954, Förgeteg 1957) report that a continuous cropping of potatoes causes a poor soil structure. Others (Woodruff 1939, Wilson *et al.* 1947) have observed the same for corn and (Jones 1961) soybeans. Generally, the structure could be improved by adding cereals, clover as catch crop, lucerne and ley in the rotation. Williamson *et al.* (1959) obtained a very good granulation with an 8 years rotation in which 4 years ley were included. Könekamp (1957) emphasized also the necessity of cropping arable crops alternately with legumes and grasses. Low (1955) has stated, however, that an improvement of a poor structure of arable land by means of ley farming often takes a long time, e.g. 50 years. It is commonly believed that the effects on soil structure of green manuring are smaller than of ley farming. Recently this is borne out by the results of a study made by one of the authors (Boekel 1963) on the influence of three different rotations upon the properties of a clay soil. These rotations were:

a) potatoes, peas, wheat, sugar beets, barley and flax, without any organic manure;

b) the same rotation with legumes or other green manuring crops after wheat and flax;

c) as rotation *a*, but with two years ley between flax and potatoes, with green manuring crops after wheat and flax and with about 20 tons/ha farmyard manure, applied in three out of the eight years, which is one cycle's duration.

After 10 years the organic matter content and the pore and air volume of the soil under rotation *b* appeared to be 0.1% of weight and 0.5—1.0% of volume higher than those of the soil with rotation *a*. For the soil under rotation *c* these differences were 0.5% of weight and 1.0—2.0% of volume respectively.

Different rotations with nothing but arable crops such as cereals, root crops, peas, flax, etc. in various frequencies seem to affect soil structure in about the same way.

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