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The rôle of organic matter in soil fertility

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Soil organic matter is a very heterogeneous mixture of substances, ranging from plant and root fragments, through the living bodies of the soil organisms, to brown amorphous humic substances produced by their activity. These materials have very different rates of decomposition in the soil and very different effects on the soil tilth and nutrient status. The method of soil cultivation used affects the stabilizing power of a limited addition of plant material.

The soil organic carbon content under a well fertilized arable rotation stabilizes at about 1 % on many loam and clay soils. Incorporating a 1 year ley in the rotation or ploughing in all the straw produced may increase this by just under 0.1 %, and using normal farm dressings of farmyard manure by just over 0.1 %. These increases may be additive, but the increases are considerably smaller than this on some soils. Incorporating a 3 year grass ley in a 5 or 6 course rotation increases the carbon by between 0.15 and 0.3 %, and there is some evidence that farmyard manure has a greater effect if used in a ley-arable than an all-arable rotation. A 3 year lucerne ley behaves more like a 1 year grass–clover ley except just after it has been ploughed out, though it increases the nitrifiable nitrogen in the soil for several years.

It has been suspected, ever since farmers started to think seriously about raising the fertility of their soils from the very low levels that characterized mediaeval agriculture, that there was a close relation between the level of organic matter, or humus, in the soil and its fertility. In consequence good farmers have always had as one of their goals of good management the raising of the humus content of their soils. But present day economic factors have forced many farmers to adopt practices which cause the humus content of their soils to fall to levels which they believe are lowering fertility. Thus a major problem facing the agricultural research community is to quantify the effects of the soil organic matter on the complex of properties subsumed under the phrase soil fertility, so that it can help farmers develop systems which will minimize any harmful effects this lowering brings about.

Soil organic matter contributes to soil fertility in several quite distinct ways. It helps to give a soil a good stable structure, which is particularly important in the surface soil. By its oxidation in the soil, plant nutrients such as nitrogen, phosphorus and sulphur are released in a form available for uptake by crop roots. In sandy soils it helps to increase the cation exchange capacity, so increasing the ability of the soil to hold cations against leaching but in a form available to the crop. On soils containing appreciable amounts of active iron and aluminium hydroxides it may help to increase the availability of added phosphate to the crop. A small part is soluble or dispersed in the soil water: this part contains trace elements such as copper and iron in chelation, and some components of this fraction serve as important sources of these elements for the crop (Mercer & Richmond 1970, 1971, 1972).

The maintenance of the soil organic matter level is primarily (though not always exclusively) a problem facing arable farmers. It is not possible to give a figure for the organic matter that should be aimed at, but the Strutt Report (1970), *Modern Farming and the Soil*, gave an organic matter content of 3 % (or 1.7 % organic C, as soil organic matter is assumed to contain 58 % C) as a fairly typical figure below which soil structure is likely to become unstable. Greenland, Rimmer & Payne (1975) found that, for a fairly large number of British arable soils, soils with more than 2.5% organic C usually had a very stable structure and those between 2 and 2.5% modestly stable. Yet many rotations used in the arable areas of England probably tend to maintain a level below 1.5%. In so far as the most important effect of soil organic matter is on the stabilization of soil structure, its maintenance will be desirable in soils of inherently low structural stability, such as soils high in fine sands but low in clay, and these include our most highly prized 'silt' soils. It may be less important in soils of inherently good stability such as many of our loams and clay loams, particularly if they are calcareous.

The composition of the soil organic matter

The soil organic matter consists of a very heterogeneous group of materials. First the growing crop has its root system in the soil, and these roots are adding to the soil in their immediate neighbourhood soluble substances and gums (mucigel) which are exuded from the growing root, as well as sloughed-off epidermal cells and short-lived root hairs. When the crop comes to maturity, the root system itself dies and becomes the energy supply for many members of the soil population. Dead plant leaves and crop residues left on the surface may be mixed with the surface soil through the agency of earthworms, or by cultivation, and so become accessible to the soil population. A second component is the soil population, principally microorganisms, whose living cells contribute about 2–4% to the organic carbon in the soil. The third principal component is products of microbial activity which are typically brown and amorphous, and form the bulk of the true humus fraction in the soil.

The organic matter content of a soil as usually determined includes the contributions from all these three constituents, but they have very different effects on the soil properties. In particular the contribution of the undecomposed and partially decomposed plant fragments should be separated from the true humic colloids. This can now be done in soil samples by dispersing the sample ultrasonically in a medium of suitable density and floating off these fragments. Ford, Greenland & Oades (1969) who developed this technique, chose a density of 2.0, but they found that the material which floated, which they called the light fraction, contained not only root fragments but many other partially decomposed plant fragments, many of which were microscopic in size and some of which were stained brown with humus. In the Australian soils they studied, 20–30% of the soil carbon was in this fraction, which also contained a considerable proportion of silica.

This fractionation procedure is based on the assumption that the true humic colloids are all bound to mineral particles, whose density is greater than 2; in fact this assumption is found to be valid for many soils. This means either that humus can only be formed in the presence of mineral particles which then absorb it on their surfaces, or that it is only long lived when so absorbed. A corollary to this is that it is difficult to maintain an appreciable humus content in well drained sandy soils because of the very restricted surface areas available for absorbing the colloids.

The decomposition of organic matter in the soil

There are still surprising gaps in our knowledge of the processes involved in the degradation of plant material and the formation and subsequent oxidation of the humus by the soil organisms. When finely divided fresh plant material is mixed with a soil there is an immediate flush of decomposition due to the soil organisms, predominantly microorganisms, attacking the more accessible and easily decomposable components, but this rate slows down as the organisms have to utilize the cellulosic and less decomposable cell wall constituents. In general this high rate only lasts a few months, depending on such factors as the soil moisture and temperature, and the stage of maturity of the plant material and whether the land is kept fallow or is cropped, for the rate of decomposition is probably less under a crop than in a fallow (Shields & Paul 1973; Jenkinson 1968*b*). Water-logging the soil during this stage can also have very serious consequences because the microorganisms will set up severely reducing conditions in the soil leading to the production of root and plant toxins and the reduction of ferric to ferrous iron in the soil which may result in a collapse of soil structure in the affected zone.

After this stage is over the soil microorganisms continue decomposing organic matter derived from the plant material at a much lower rate, but little is known in detail about the processes. Jenkinson (1965, 1966, 1968*a*) measured the rates of these decomposition processes by incorporating either fresh ryegrass leaves or roots labelled with ^{14}C into two Rothamsted soils kept fallow for 4 years. The rapid decomposition of the fresh plant material, whether tops or roots, was over after a few months; the rate then fell and followed a first order reaction with a half-life of about 4 years, while the rate of the soil humus decomposition also followed a first order reaction but with a half-life of about 25 years. These rates were the same for soil from the unmanured plot on Broadbalk, which contained about 1 % C, and from the plot receiving farmyard manure annually with about 2.5 % C. Even after 4 years much of the carbon originally in the ryegrass that is still in the soil is in a form that is decomposing appreciably faster than the humus itself, so it has not yet been incorporated into the main body of the soil humus. Little is known about the differences between the composition of the plant residues and the soil humus during this period.

The control of the level of soil organic matter in the field

The level of organic matter in a soil depends on the rate at which organic carbon compounds are being added to the soil on the one hand and the rate of oxidation of the soil organic matter on the other; the system of farming being practised affects both of these. The rate of oxidation, for example, is heavily dependent on the crop rotation used and the number of cultivations that are done. Reducing the intensity of cultivations by the use of minimum tillage or direct drilling techniques reduces the rate of oxidation, though this necessarily reduces the amount of organic nitrogen that becomes mineralized and so available to the crop. Thus more nitrogen fertilizer may be required particularly in the early years after such practices have been introduced.

The arable farmer has several ways of adding organic matter to his soil. He can grow good crops which will leave behind appreciable organic residues in or on the soil, he can plough in the straw produced by his cereal crops, he can use this straw to make farmyard manure, or he can put his land down to a grass ley. There is not very much quantitative information on the amounts of organic carbon returned to the soil under different systems of cropping but a cereal crop usually contributes appreciably more than a root crop and probably adds about 1½–2½ t/ha dry matter as roots and 2–3 t/ha as stubble, making a total of 4–5 t/ha in all; this amount is not very dependent on the level of fertilizer used. At Rothamsted, the unmanured plots on the classical experiments stabilize at about 0.9–1.0 % C and the plots receiving high levels of fertilizer at about 1.1 %; even on the sandy loam at Woburn well fertilized arable rotations, in which no leys or organic manures are used, will maintain about 0.9 % C for several decades.

Table 1. Effect of farmyard manure and leys on the soil organic carbon and crop yield

(Yields are given in t/ha.)

	3 year grass/clover	3 year lucerne	arable with 1 year ley	arable no ley	
percentage of C in soil	1.13	0.95	0.95	0.88	no farmyard manure given
crop yield:					
sugar	8.0	7.3	6.5	7.3	
barley	5.2	5.3	4.9	4.8	
percentage of C in soil	1.32	1.13	1.04	0.98	with 35 t/ha farmyard manure once every 5 years
crop yield:					
sugar	7.8	8.0	7.3	7.9	
barley	5.1	5.4	5.2	5.0	

Woburn, 5th cycle of a 5 course rotation.

THE USE OF FARMYARD MANURE

The traditional method of maintaining the organic matter content of arable soils was through regular dressings of manure. The quantity was controlled by the amount of straw available, and dressings of 20–30 t/ha once every 4–6 years was normal practice. Table 1 shows that on the sandy loam soil at Woburn, a dressing of 35 t/ha given once every 5 years to a well fertilized 5 course arable rotation maintained the organic carbon content of the soil 0.1 % higher than on land which did not receive the manure, but it failed to maintain the organic carbon at its original level of 1.2 %. It was not possible in this experiment to estimate how far the increase in yield due to the manure was the consequence of better soil physical conditions and how far to increased nutrient supply to the crop.

Table 2, taken from Short (1973), shows that on four experimental husbandry farms 30–60 t/ha farmyard manure given to the first crop of a 6 course rotation maintained the organic carbon content of the soil over the 18 years of the experiment at its initial content at three of the sites, though not on the silty loam at Terrington (Norfolk), while it fell by about 0.15 % on the plots receiving no manure at three sites and was little different from the manure plots at Terrington. The rotation used was potatoes, winter wheat, spring cereal, sugar beet, winter wheat, and spring cereal, and the manure which was given to the potato crop had only a very small effect on yield if adequate fertilizer was used, being of the order of 0.8 t/ha for potatoes and 1.5 t/ha for sugar beet roots on yields of the order of 30 and 40 t/ha. Farmyard manure may be rather more efficient than this on some soils, for at Saxmundham, Suffolk, two rotation experiments were started in 1899, in one of which 15 t/ha manure was given to one plot every year and in the other 25 t/ha was given every fourth year. The soil is a poorly drained sandy clay loam of the Beccles Series, and after 65 years the soil receiving 60 t/ha during each 4 year period contained 0.2 % more carbon than that receiving only 25 t/ha, but this contained 0.4 % more carbon than the soil receiving no manure (Mattingly, Johnston & Chater 1970; Williams & Cooke 1971). But this higher level of carbon could be due to the poorer drainage of the surface soil. Thus on well drained soils the evidence is that dressings of 20–30 t/ha of manure once every 4–6 years are likely to maintain the organic matter at about 0.1–0.2 % higher than if no manure is used.

Table 2. Effect of ploughing in straw or farmyard manure on soil organic carbon

(Percentage of carbon in soil after 18 years of a 6 course rotation at experimental husbandry farms.)

	initial value	farmyard manure	straw ploughed in	straw removed or burnt	effect of farmyard manure	effect of straw
Boxworth (calcareous clay)	1.67	1.68	1.61	1.51	0.17	0.10
Gleadthorpe (loamy sand)	1.20	1.24	1.21	1.17	0.07	0.04
High Mowthorpe (chalky silty loam)	2.26	2.24	2.18	2.09	0.15	0.09
Terrington (silty loam)	1.47	1.38	1.35	1.35	0.03	0.00

An important effect of appreciable dressings of farmyard manure, both at Rothamsted and Woburn, is that a proportion of the carbon added to the soil humus appears to be resistant to decomposition. Thus on the permanent barley experiment at Hoosfield at Rothamsted, one plot has received 35 t/ha of farmyard manure annually since 1852, and one plot received this dressing for 20 years only and has been unmanured since 1972. The farmyard manure increased the organic carbon in this plot from about 1.0 % in 1852 to 2.0 % in 1872, the carbon then dropping to 1.7 % in the next 30 years and to about 1.6 % after 60 years, though the experimental data are rather variable. The plot continuing to receive the manure had about 3.3 % after 100 years, and it is still probably increasing. The plots receiving no fertilizer now have about 0.9 % C and those adequately fertilized about 1.0–1.1 %. Jenkinson & Johnston (1977) have calculated that the half-life of the carbon in the soil receiving farmyard manure annually is 41 years, compared with the 25 years of the corresponding plot on Broadbalk, but that in the plot which ceased to receive farmyard manure in 1872 it is 128 years, and the corresponding figures for the half-life of the nitrogen is 32 and 87 years respectively.

Ploughing in straw

Instead of converting straw to farmyard manure through the use of livestock, it can be incorporated in the soil directly, although this is difficult to do satisfactorily whilst the straw is fresh and long. Ploughing in the straw produced by the cereal crops in a rotation has only a very small effect, which is difficult to measure, on the soil carbon. Table 3 shows that at Rothamsted in a 3 course rotation of potatoes, barley and sugar beet the organic carbon was 1.30 % after 19 years if no straw was ploughed in but 1.4 % if 6–7 t/ha of chopped straw was ploughed in every other year. Table 2 gives the result of similar experiments at four experimental husbandry farms. Straw at a rate of between 2 and 3½ t/ha was ploughed into the soil after each of the 4 cereal crops in the 6 course rotation, and its effect on the soil carbon is about one half of that from 30–60 t/ha manure given to the potato crop. The manure probably contained about as much carbon as the four straw additions, so its efficiency in increasing the organic carbon content of the soil is about double that of the straw, per unit of carbon added. However a proportion of the carbon in the straw used to make the manure is lost as carbon dioxide during the process, so the effect per unit of straw used is probably similar. On the assumption that the ploughed layer weighs 3000 t/ha, about one sixth of the carbon in the straw and one third of that in the manure will remain in the soil as soil organic carbon.

TABLE 3. EFFECT OF PLOUGHING IN STRAW ON SOIL ORGANIC CARBON AND CROP YIELDS

(Yields are given in t/ha.)

	first 18 years of experiment		years 19–24	
	straw ploughed in	fertilizer only	straw ploughed in	fertilizer only
percentage of carbon in soil, year 19	1.40	1.30	—	—
crop yield:				
potatoes	23.7	22.9	24.1	21.3
barley	3.9	4.1	3.9	3.9
sugar	5.1	5.4	5.4	5.2

Straw: 6.7 t/ha chopped straw ploughed in during alternate years.
Rothamsted; 3 course rotation.

However, ploughing straw into the soil, particularly if it is only worked in shallowly or left on the surface, can harm the succeeding crop whenever there is a serious risk of local anaerobic conditions developing in the soil, due for example to periods of prolonged rain. This is due to the production of a number of organic acids, particularly short chain fatty acids such as acetic (Iswaran & Harris 1968) which are toxic to plants at concentrations in the range of 10^{-2} to 10^{-4} M, dependent on the acid, and such concentrations are known to occur in soils in other parts of the world (Wang, Cheng & Tung 1967). Bullen has shown (this volume) the magnitude of the yield depressions that can be found in this country, and Lynch and his colleagues at the A.R.C. Letcombe Laboratory are measuring the concentrations and toxicity of these acids under British winter and spring conditions. As Bullen has shown, burning the stubble reduces this hazard and has little measurable affect on the percentage of carbon in the soil.

THE EFFECT OF LEYS

There are two types of ley commonly in use on arable farms: a 1 year grass/clover or a 1 year grass ley well manured with nitrogen, and a longer ley which will usually be grazed for at least part of its life and also cut for hay or silage. A number of experiments have been made to measure the effect of the longer leys in particular on the organic matter content of the soil and on the yields of the succeeding crops, though few have lasted more than one rotation. I will use two of these to illustrate the kind of result that has been found.

Table 1 shows the effect of these two types of ley on the sandy loam soil at Woburn. A 1 year ryegrass/red clover ley in a 5 course arable rotation increased the organic carbon by just under 0.1 % over a similar rotation that did not contain a ley. On the other hand a 3 year grazed grass/clover ley followed by 2 years of arable cropping increased the percentage of carbon over the arable rotation with a 1 year ley by about 0.2 %, after 5 cycles, that is 25 years. However, 35 t/ha farmyard manure given once per rotation put up the organic carbon by 0.2 % under a 3 year ley but only by 0.1 % under the arable rotations, implying that added organic matter decomposes slower under leys than under arable, in agreement with Jenkinson's results already quoted. The 3 year leys did not affect the yields of the two arable test crops if farmyard manure had been used, but *may have* increased them in its absence, probably because the amount of nitrogen fertilizer added to the crops in the arable rotation was inadequate to compensate for the high level of soil derived nitrogen in the ley rotation. A 3 year lucerne ley, on the other hand, had only a small effect on the organic carbon compared with the continuous arable though it raised the yields of the two succeeding crops, probably because of the high nitrogen root residues it left behind.

TABLE 4. EFFECT OF LEYS ON PERCENTAGE OF SOIL ORGANIC CARBON

	old arable			old pasture		
year...	6	12	18	6	12	18
old pasture				3.17	3.74	3.36
new pasture	1.75	2.10		2.97	3.36	
all arable	1.47	1.34	1.46	2.67	2.14	2.08
3 years arable after 3 years of:						
(i) grass/clover	1.55	1.48	1.61	2.66	2.35	2.22
(ii) grass with nitrogen	1.50	1.44	1.62	2.60	2.27	2.18
(iii) lucerne	1.51	1.34	1.54	2.62	2.21	2.06

Rothamsted; 6 course rotation; sampling depth 0–22 cm.

Somewhat similar experiments were carried out both at Rothamsted and on several experimental husbandry farms. A 6 course rotation was used; a 3 year grazed ley and a 3 year ley cut for silage or a 3 year lucerne ley were compared with an arable rotation containing a 1 year ley.

The Rothamsted experiment (Johnston 1973) was carried out on two sites: one was an old arable field and the other was ploughed out of very old pasture. The three ley treatments were a 3 year grass/clover ley receiving small dressings of nitrogen fertilizer, a 3 year grass ley receiving large dressings and a 3 year lucerne ley, followed by three years of arable; they were compared with an all arable rotation containing a 1 year ryegrass/red clover ley. In addition some plots were sown to a grass ley that was left down for 12 years. Table 4, taken from Johnston (1973), shows that after 3 complete rotations, that is after 18 years, the organic content of the soils in the two grass ley rotations was 0.15 % higher than in the arable rotation at each site, but whereas the level of organic carbon in the old arable was maintained in the ley rotations, it decreased by about 0.6 % in the old pasture land. The effect of lucerne again was not much different from the all arable rotation. The corresponding results from the experimental husbandry farms are given in table 5, taken from Eagle (1975), which shows that the soils on the arable rotation lost between 0.1 and 0.3 % C, the soils under the leys had 0.1–0.3 % more C than the arable, but the ley was only able to maintain the initial percentage of C on 3 out of the 5 sites.

The effect of the leys on the yields of the succeeding crops depended on the soil. They had no effect at Rothamsted if adequate fertilizer was used (Boyd 1968), nor on the well structured calcareous clay at Boxworth. However, in the third cycle, that is after 15 years, crop yields were increased by about 20 % on the loamy sand soil at Gleadthorpe and barley yields were increased by between 6 and 13 % at Bridget's, High Mowthorpe and Rosemaund; Eagle considered at least some of this benefit was due to the greater drought tolerance of the crop on the soil that had been in ley.

TABLE 5. EFFECT OF 3 YEAR GRASS/CLOVER LEY ON SOIL ORGANIC CARBON AND CROP YIELD

	Boxworth (silty clay loam)	Bridget's (silty loam)	Gleadthorpe (loamy sand)	High Mowthorpe (silty loam)	Rosemaund (silt loam)
percentage of carbon in soil, year 17:					
in ley rotation	2.13	2.40	1.01	2.24	1.66
in arable rotation	1.91	2.21	0.89	1.97	1.52
benefit of ley	0.22	0.19	0.12	0.27	0.14
percentage of carbon lost from the soil between years 6 and 17:					
in ley rotation	0.02	0.18	(0.03) gain	(0.04) gain	0.26
in arable rotation	0.16	0.23	0.10	0.14	0.31
crop yields in 3rd cycle/(t/ha)					
wheat:					
after ley	6.0	4.1	4.1	5.2	4.4
after arable	6.2	3.9	3.4	5.5	5.0
2 barley crops:					
after ley	4.4	4.2	3.7	3.9	4.1
after arable	4.5	3.9	3.1	3.5	3.8
mean benefit from ley per crop	−0.11	0.28	0.62	0.18	−0.07

Experimental husbandry farms; 3 year leys in a 6 course rotation.

Eagle has not published the effects of the lucerne ley on either the organic matter content or the crop yields in the third cycle, but an observation by Cooke & Williams (1972) is worth noting. They observed on the poorly structured sandy clay loam at Saxmundham that a 2 year lucerne ley improved the soil structure most noticeably after it had been ploughed out, but this effect was short-lived and had disappeared by the following season.

The grass ley, however, does not add organic matter uniformly throughout the root zone. Clement & Williams (1964, 1967) showed that even after land had been down to a grass ley for $3\frac{1}{2}$ years at the Grassland Research Institute, nearly all of the added organic matter was in the top 2 cm of soil, and with Garwood (Garwood, Clement & Williams 1972) showed that nearly half of this was root fragments that passed a 2 mm mesh sieve but were retained on a 0.25 mm mesh. Clement estimated that at Hurley a grazed ley adds about 4 t/ha C, and a ley cut for silage about 2.5, annually to the soil as roots and stubble, which corresponds to an annual increase of about 0.16 and 0.10 % C in the top 15 cm. However, after $3\frac{1}{2}$ years under ley the actual increase in the soil carbon is about 0.2 % and of humic carbon about 0.1 %, suggesting that about one third of the carbon added to the soil by the ley contributes to the humic carbon, which is a similar figure to that for farmyard manure.

Effect on soil physical conditions

The effects of raising the soil organic matter appreciably on the physical properties of a soil are well established: it reduces the bulk density of the soil and increases its water holding power; it increases the porosity of the soil clods so making them easier to shatter and it increases their resistance to slaking and so the stability of the soil structure; it reduces the moisture content of the soil at its lower plastic limit and may also reduce the moisture content of the field soil in wet conditions through better drainage, both of these effects allowing earlier cultivation after rain. The important problems concern the magnitude of the effects which can be brought about by changes in commercial farm management practice. The A.D.A.S. soil scientists organized a discussion in 1972 which contained reports on the effects of leys and farmyard manure on soil physical conditions. (Ministry of Agriculture, Fisheries and Food 1975). The conclusions were that over periods of up to 20 years, the effect of dressings of 20–30 t/ha farmyard manure given once in a 5–6 year rotation was only large enough to be measured on some sites and only rarely was it of practical significance (Eagle 1975; Williams 1975; Low 1975). The beneficial effect of a 3 year ley was also usually small in the third year after it had been ploughed out. Yet it is often found in practice that fields on neighbouring farms but with similar soils can have widely varying contents of organic matter, which may be reflected in their ease of management, without it always being possible to account for these differences, although the length of time out of old grass could be important (Davies 1975; Wilkinson 1975).

Summary of the effects of organic manuring of soils

The experimental data so far available show that, in practice, it is difficult for a farmer using traditional cultivation methods based on ploughing the land to 15–20 cm deep, but using adequate fertilizers and good management, to vary the organic carbon content of his soil by more than 0.1–0.2 % over a period of about 20 years, unless he is using long leys or frequent dressings of farmyard manure.

Different forms of added organic matter differ in the contribution each unit of added carbon makes to relatively stable humic carbon in the soil, probably due to the amount of added carbon the soil organisms must decompose to bring its C/N ratio down to that of the microbial cells and their metabolic products. Thus one unit of straw carbon is not as efficient as one of farmyard manure carbon in raising the level of humic carbon. However, this conclusion needs the qualification that the soil organisms can adapt their metabolism to changing food supplies to some extent, so there need be no quantitative relation between the C/N ratio of the added organic material and the increase in soil carbon. Once this first stage of the decomposition has been completed, the decomposability of the newly formed humic material is probably independent of the type of material added.

The beneficial short term effects of leys are often due to their increasing the readily nitrifiable nitrogen in the soil, and this is sometimes a more effective method of supplying nitrogen to a crop than a single large dressing of a nitrogen fertilizer, because the nitrogen may be released slowly over a period of time. Their short term effects on the soil structure are sometimes due to the partially decomposed plant fragments mechanically protecting some of the coarser pores from collapse and to ephemeral products of decomposition that stabilize the structure.

In so far as structure stabilization is important, the efficiency of the ley or green manure is dependent on the depth of soil in which the plant material is incorporated. In general, the more plant or other organic residues are kept near the surface, the greater their effect on the surface layer is likely to be. However, these practices will be least applicable when the whole soil has an unstable structure, as for example in some soils high in the very fine sand or coarse silt fraction, and these soils now probably pose some of the most difficult problems in soil management when long periods of grass or large frequent dressings of farmyard manure are not available. Thus discussions on the level of organic matter needed in a given soil to maintain tilth in good condition must take account of the methods of cultivation being used, and conversely the choice of the cultivation techniques used will affect strongly the structure improving power of a given level of additions of plant residues to the soil.

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