Changes in soil organic matter content and aggregate stability under Canterbury mixed cropping rotations

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Abstract

The effects of previous cropping history on soil organic matter content and aggregate stability within the typical mixed cropping rotations used on the Canterbury Plains are discussed. An index of previous cropping history (number of years under pasture or arable immediately prior to sampling) is closely correlated with aggregate stability. However, measures of total soil organic matter content (organic C and total N) are only moderately well correlated with aggregate stability. The reason for this is that in many of the short-term mixed cropping rotations used, the total soil organic matter content remains relatively unchanged yet aggregate stability increases during the pasture phase and declines during the arable phase. Aggregate stability fell to low levels after four to six years of arable cropping and if crop production is continued beyond this period, deterioation in soil physical properties are likely.

During the pasture phase there is a build-up of microbial biomass in the pasture rhizosphere and also a build-up of hot water-extractable carbohydrate. Aggregate stability is closely correlated with hot water-extractable carbohydrate content of the soils. It is suggested that the increase in aggregate stability during the short-term pasture is due principally to the production of carbohydrates (which are hot water-extractable) by the large microbial biomass present in the pasture rhizosphere. When the pasture is ploughed under, the microbial biomass declines as does the aggregate stability.

Additional key words: *soil structure, pasture, hot water-extractable carbohydrate*

Introduction

Poor soil structure limits crop growth and thereby influences crop response to agronomic inputs such as insecticides, fungicides, herbicides and improved cultivars. In addition, structural breakdown contributes to loss of surface soil by wind and water erosion and to loss of agricultural chemicals through erosion and leaching. Agronomic practices such as tillage can greatly influence soil structure which, in turn, can effect both productivity arising from such practices and their impact on the environment (Kay, 1990).

The resistance of soil aggregates (crumbs) to the slaking and dispersive effects of water (aggregate stability) is important for maintaining a porous soil structure in arable soils. Soil organic matter has a particularly important role in relation to aggregate stability because of its binding and cementing actions (Tisdall and Oades, 1982; Oades, 1984). Typically, soil organic matter and aggregate stability build-up under pasture, due to decomposition of plant tops and roots, accumulation of mucigels in the pastures rhizosphere and deposition of animal excreta, but decline under arable cropping (Clark *et al.*, 1967; Tisdall and Oades, 1982).

The Canterbury Plains cover an area over one quarter of a million hectares and the dominant land-use is mixed cropping. In this system arable crops are commonly grown for two to five years and are then followed by grazed grass-legume pasture for two to five years. The period given over to either cropping or pasture within the rotation varies according to the relative profitability of the two forms of farming as well as the need to maintain soil structure. In recent years some farmers have moved to almost continual arable systems in which the pasture phase is represented only by grass and/or clover seed crops.

The development of cropping systems which sustain soil productivity and minimise deterioration of the environment is a major goal of the MAF

Technology research programme. With this in mind, the changes in organic matter content and soil structure that occur under existing Canterbury cropping rotations are reviewed and discussed in this paper using published data.

Soil Structure

Soil structure can be defined in terms of the arrangement of solid particles and of the pore space separating them (Marshall, 1962). A well structured soil possess pores of varying sizes which have varying functions. Large (>60 µm diameter) soil pores (macropores) are important for movement of water and air and root penetration whilst small pores store water which is used by the crop. As well as pore diameter, pore continuity is important, particularly in relation to aeration and the downward transmission of water and solutes through the soil.

An important attribute of soil structure is its stability. It must be able to maintain the pore characteristics described above against various stresses such as the effects of raindrop impact and contraction and swelling caused by drying and rewetting. The capacity of a soil to maintain its structure is commonly assessed by measurement of aggregate stability.

The breakdown of aggregate stability and soil structure is a frequently encountered phenomenon under intensive arable cropping. Aggregates with low stability can break down into fine particles (slake) under the action of rainfall or irrigation. There are two major practical implications of this:

1. Fine soil particles which are released at the soil surface move into inter-aggregate pores in the surface layer of soil and following a dry period a dense surface crust can form. This crust limits entry of further rainfall or irrigation water leading to ponding and/or runoff and erosion. If the crust forms after seeding it impedes seedling emergence and growth and may lead to greatly reduced stand density.
2. Extensive slaking and downward movement of fine particles through the surface horizon can, along with compaction from farm machinery, result in the formation of a dense plough layer. Such soil is difficult to work and comes up in massive clods which require extra cultivation.

In addition, a very fine tilth can be produced in poorly-aggregated soils during seedbed reparation. Such soils are vulnerable to 'windblow' particularly in periods of the warm, gusty northwest föhn winds common in Canterbury.

All the above problems are well known on Canterbury cropping farms. Indeed, continuous arable cropping in the 1880's resulted in a breakdown of soil structure, a decrease in crop yields and extensive losses of topsoil through wind erosion by northwest winds (Johnston, 1968). In the 1940's and 50's soil structural breakdown was identified as a major factor contributing to poor crop performance (Packard and Raeside, 1952) and to losses of soil through erosion (Raeside and Baumgart, 1947). More recently, wind erosion has been identified as a serious problem resulting in the loss of many tonnes of fertile topsoil (Hunter and Lynn, 1988).

Soil Aggregate Stability

Central Canterbury survey

In late spring (September-October) of 1987 a survey was made of the aggregate stability of the plough layer (0-20 cm) of farmers' paddocks in central Canterbury (Haynes *et al.*, 1990). Paddocks on three contrasting soil types were chosen. They were Barrhill sandy loam (27 samples), Lismore silt loam (26 samples) and Temuka clay loam (27 samples). The previous cropping history of each paddock for the preceding 5-10 years was recorded.

Aggregate stability of 2-4 mm diameter sieved aggregates was measured using a wet sieving method (Haynes and Swift, 1990). Results are expressed as a mean weight diameter, the upper and lower limits of which are 3.0 and 0.25 mm respectively. Oxidizable C and total N contents of samples were also measured (Haynes *et al.*, 1990).

Organic C content (Fig. 1) and total N content (Table 1) were moderately well correlated with aggregate stability. The significant correlation between organic C and aggregate stability demonstrates that over the wide range of cropping histories studied the binding properties of soil organic matter played a major role in soil aggregation. Many other workers have observed in a wide range of soils that organic matter content is well correlated with soil structure (Kemper and Koch, 1966; Clement, 1975; Chaney and Swift, 1984). Mucilaginous materials (mainly carbo-hydrates) produced by plant roots and soil microflora act as 'glue' in soils and contribute to aggregate formation (Oades, 1984). Humic substances (the dark, semi-stable, microbially synthesized fractions of organic matter) also act as binding agents for soil aggregates because they form stable complexes

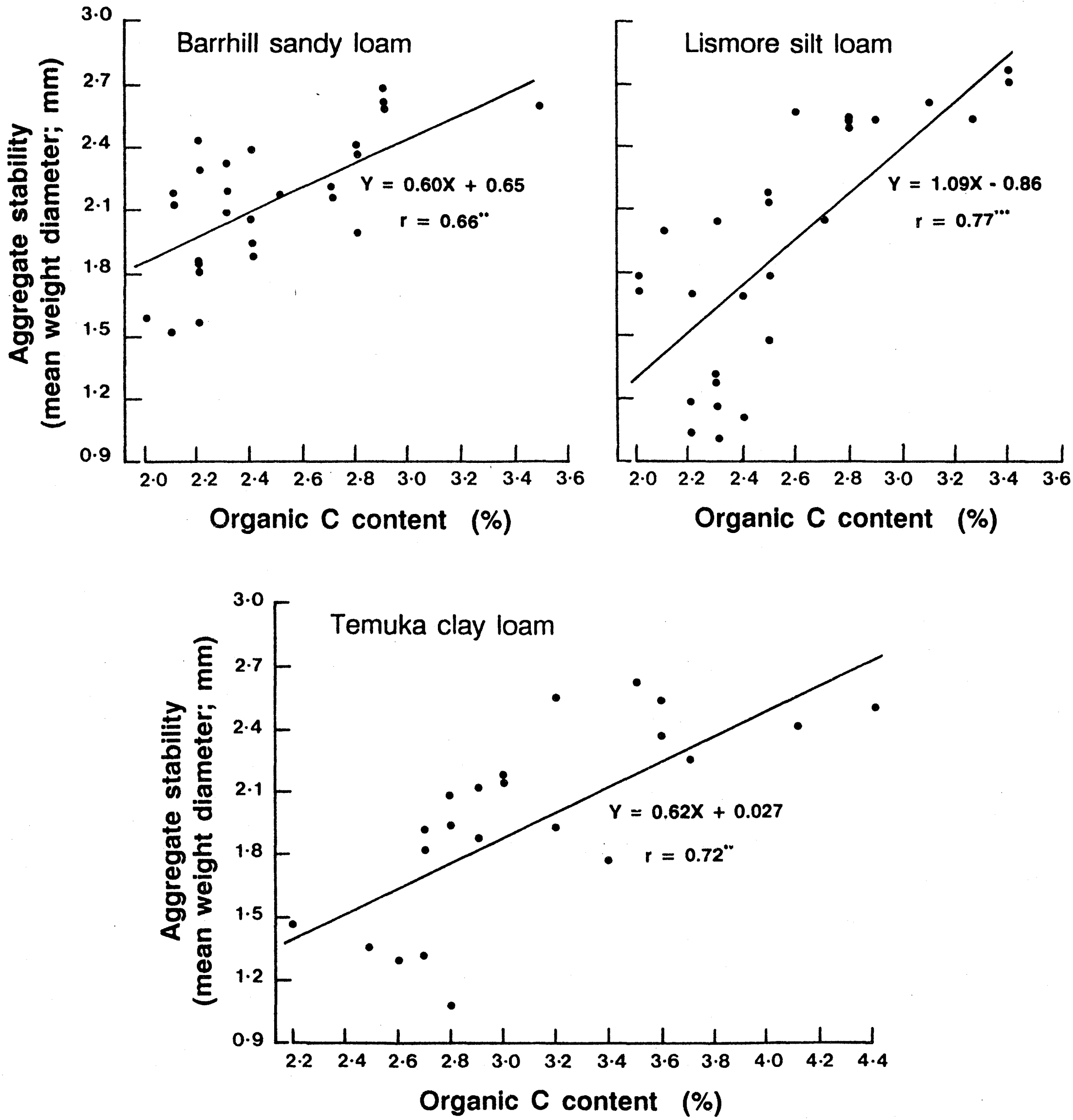


Figure 1: Relationship between organic C content and aggregate stability for three soils used for mixed cropping in the Canterbury region. Redrawn from Haynes *et al.* (1991).

with the mineral fractions of the soil (Theng, 1979). Additionally, fine roots, and associated mycorrhizal hyphae, induce aggregating effects by entrapment of soil particles (Tisdall and Oades, 1982).

TABLE 1: Linear correlation coefficients (r) between aggregate stability and total N, acid-hydrolysable carbohydrate and hot water-extractable carbohydrate content for three soil types.

Soil property	Barrhill sandy loam	Lismore silt loam	Temuka clay loam
Total N	0.68**	0.78***	0.67*
Acid-hydrolysable carbohydrate	0.67**	0.75**	0.76***
Hot water-extractable carbohydrate	0.83***	0.84***	0.79***

Data relating to previous cropping history was incorporated into a cropping index using an eight point scale based on the number of years the field had been under arable crops or pasture immediately prior to sampling. The index numbers refer to: 1 = >9 years arable, 2 = 6-9 years arable, 3 = 3-6 years arable, 4 = 0-3 years arable, 5 = 0-3 years pasture, 6 = 3-6 years pasture, 7 = 6-9 years pasture and 8 = >9 years pasture. Most of the paddocks sampled were in classes 3, 4, 5 and 6. Long-term arable samples (indices 1 and 2) originated mainly from leased land and a few continuous arable farms. Long-term pasture samples were taken predominantly from dairy farms.

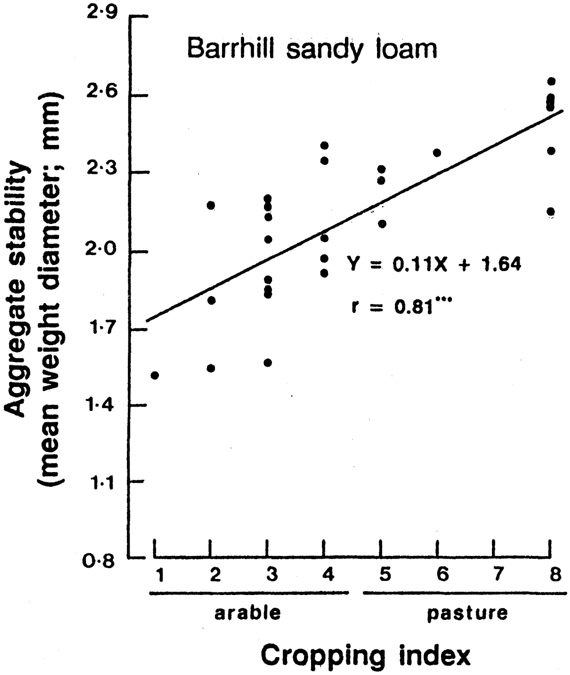
For each soil, cropping index was more strongly correlated with aggregate stability (Fig. 2) than with organic C content (Fig. 1). Thus, changes in aggregate stability occurred in response to cropping history but were not being reflected in changes in organic C content. Indeed, the short-term cropping rotations commonly used in the region appear reasonably well balanced (i.e., 3-5 years pasture followed by 3-5 years arable) in that the total organic matter content of the soil remains relatively unchanged throughout the rotation (Haynes and Swift, 1990; Haynes *et al.*, 1990). In contrast, aggregate stability improved during the pasture phase and declined during the arable phase. This is shown in Table 2 which refers to samples taken from the Winchmore Irrigation Research Station. The long-term (18 year) pasture had a high aggregate stability and high organic C content. By contrast, the 10 year arable site had both a low aggregate stability and a low content of organic C. Within the 4 year rotation, soil organic matter content remained virtually unchanged whilst aggregate stability varied considerably being higher under pasture than in arable in the order; 4 year pasture > 1 year pasture > 1 year arable > 4 year arable. Other workers have also measured short-term changes in aggregate stability in response to crop management without significant changes in total soil organic matter content (Baldock *et al.*, 1987; Angers and Mehuys, 1989; Haynes and Swift, 1990).

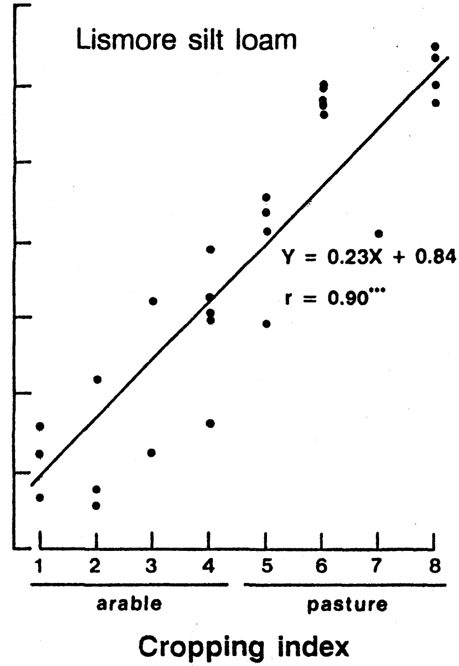
Short-term stability changes

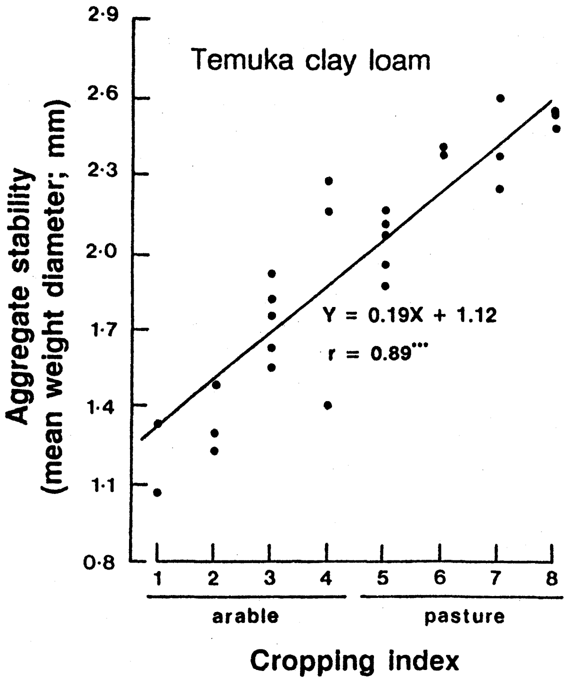
In the short-term, the rate at which aggregate stability changes under different cropping systems is likely to be related more to changes in specific organic constituents than to changes in total organic matter content. Carbohydrates released by growing roots and the rhizosphere microflora, are the organic constituents known to be most closely associated with soil aggregation. Total (acid hydrolysable) carbohydrate was not significantly better correlated with aggregate stability than was organic C (Table 1). However measurement of total carbohydrate does not differentiate between active and inactive carbohydrate binding agents. The hot water-extractable carbohydrate fraction, however, appeared to represent the pool involved in aggregation since it was more closely correlated with aggregate stability than organic C (Table 1) and it showed marked short-term increases under pasture and decreases under arable even when soil organic matter remained unchanged (Table 2).

Thus during the pasture phase of the rotation the development of a dense ramified root system, and the large associated microbial biomass (Table 2) result in the production of large amounts of carbohydrate binding agents in the surface soil. This is reflected in a build-up of hot water-extractable carbohydrates which causes an increase in aggregate stability. Carbohydrates are readily degraded by soil microflora so that their aggregating effect can be short-lived unless there is a replenishing supply such as that in the pasture rhizosphere. When a paddock is returned to arable cultivation, the dense pasture system is replaced by a more sparse and deeper-rooting crop root system. With successive arable cropping the density of roots,

Figure 2: Relationship between previous cropping history (cropping index) and aggregate stability for three soils used for mixed cropping in the Canterbury region. Redrawn from Haynes *et al.* (1990).







Cropping index

1 =	> 9 years	arable
2 =	6 - 9 years	arable
3 =	3 - 6 years	arable
4 =	0 - 3 years	arable
5 =	0 - 3 years	pasture
6 =	3 - 6 years	pasture
7 =	6 - 9 years	pasture
8 =	> 9 years	pasture

TABLE 2: Effect of previous cropping history on aggregate stability, organic C, hot water-extractable carbohydrate and biomass C content of Lismore soil samples taken from the Winchmore Irrigation Research Station.

Previous cropping history	Aggregate stability (MWD, mm)	Organic C (%)	Hot water-extractable carbohydrate ($\mu g\ C\ g^{-1}$)	Biomass C ($\mu g\ C\ g^{-1}$)
18 year pasture	2.7	3.2	208	1018
4 year pasture[1]	2.5	2.5	169	890
1 year pasture	2.0	2.4	152	801
1 year arable	1.3	2.4	140	738
4 year arable	1.2	2.4	134	712
10 year arable	1.0	2.0	127	610

[1] The 1 year and 4 year pasture and 1 year and 4 year arable soils came from a cropping rotation of 4 years arable followed by 4 years pasture.

size of the microbial biomass and production of binding agents in the plough layer is reduced and both hot water-extractable carbohydrates and aggregate stability decline.

Under pasture, not only is the stability of aggregates increased but structural pores are created by the extensive ramified root system (Payne, 1988; Francis and Kemp, 1990). Roots penetrate soils by forcing their tips into small pores and then enlarging them as they grow. In addition, extraction of water from the soil by roots may cause soil shrinkage and cracking. The characteristically high earthworm activity under pasture is also important since this creates soil pores through a considerable depth of soil.

Thus, during the pasture phase there is a build-up in short term binding agents (and consequently aggregate stability) and an increase in porosity. Under arable there is a decline in both these properties and a loss of soil structure.

Direct drilling is a way of preserving an already well structured soil (i.e. that from a long-term pasture) and is a particularly effective method of minimising soil losses by wind erosion (Baeumer and Bakermans, 1973; Cannell, 1985). Since the plough layer is not inverted under direct drilling the organic matter content in the surface soil is higher than under conventional tillage (Haynes and Knight, 1989). As a consequence, under direct drilling aggregate stability remains higher in the surface soil. This is shown in the results of a 5 year experiment comparing direct drilling and conventional cultivation (Fig. 3). Direct drilling also maintains surface-connected soil pores and sometimes water infiltration to depth can be greater than that under cultivation (Francis *et al.*, 1988).

Future Implications

Soil structural problems are likely to develop where the mean weight diameter value for aggregate stability is less than about 1.5 mm (K.C. Cameron pers comm.). In the case of the paddocks sampled, the

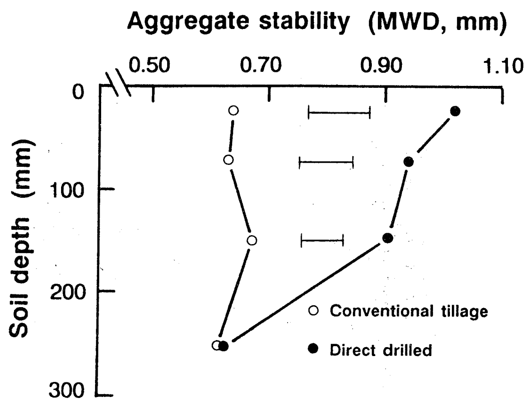


Figure 3: Effect of 5 years of conventional tillage and direct drilling on aggregate stability in the profile of a Wakanui soil. Redrawn from Haynes and Knight (1989). LSD (P<0.05) is shown at each sampling depth.

mean weight diameter was less than 1.5 after 4 to 6 years of continuous arable cropping. On many Canterbury farms paddocks are resown in pasture after 4 or 5 years of arable and aggregate stability is increased again. Such a balanced cropping rotation where arable crops and pasture are alternated maintains soil structure.

In periods when arable cropping is considerably more lucrative than sheep farming and arable cropping is continued successively for more than about 5 years soil physical problems are likely. Already on some mixed cropping farms where there are few sheep, and the period of arable crops is broken mainly by seed crops of grass or clover. Seed crops of grass will have some restorative effect on aggregate stability and soil structure (although this is yet to be quantified) but their effect is likely to be less than that of a grazed pasture. This is because they are generally present for a much shorter period (one year) than a pasture and secondly because under grazed pasture large amounts of organic material are returned to the soil surface as dung. Thus, although continuous arable farming may be more lucrative, at least in the short-term, it is unlikely that it will be sustainable in terms of maintenance of soil structure.

In order to formulate cropping rotations that allow extended arable periods whilst still maintaining soil structure, quantitative information is required as to the effects of pasture seed crops on soil structure in comparison with grazed pasture. The effects of 'restorative' legume crops such as peas, lupins, lentils and lucerne (which are used to preserve or improve soil N supplying ability) on soil structure also need quantifying. Such measurements are currently being made by MAF Technology researchers at Lincoln.

Direct drilling is a possible way of preserving soil structure for a longer period of arable cropping. It has been used successfully under Canterbury conditions (Janson, 1984; Francis *et al.*, 1987). Nonetheless, overseas experience has shown that prolonged use of direct drilling can result in the leaching of herbicides into groundwater and consequent pollution of aquifers (Canter, 1987; Libra *et al.*, 1987). Thus, in the long-term such a practice may not be environmentally sustainable.

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