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EFFECTS OF MIXED CROPPING FARMING SYSTEMS ON CHANGES IN SOIL PROPERTIES ON THE CANTERBURY PLAINS

Summary: Before European settlement, most of the 750,000 ha of land comprising the Canterbury Plains was under native tussock grassland with pockets of podocarp forest. The dominant land use today is mixed cropping in which cereals and cash crops are grown for 2 to 4 years followed by grass-clover pasture for 2 to 4 years. These cropping rotations are generally too short for either a substantial build-up in soil organic matter under pasture or its breakdown under arable cropping to occur. Nonetheless, there is a cyclic improvement in both N-supplying capacity and soil structure under pasture and a decline in both properties under arable. Large N inputs (e.g., 100-300 kg N ha^{-1} yr^{-1}) occur through N2 fixation by the clover component of the pasture, but the potential for leaching losses of nitrate is substantial after the pasture is ploughed in. During the pasture phase there is an increase in temporary soil binding agents in the topsoil layer and consequently an increase in aggregate stability. There is also a change in soil porosity caused by pasture root growth and earthworm activity. In contrast, soil physical properties rapidly deteriorate under the arable phase of the rotation.

Keywords: arable; mixed cropping; nitrogen fixation; nutrient cycling; pasture; soil organic matter; soil physical properties.

Introduction

When European settlers first arrived in Canterbury, most of the land was under native tussock grassland with pockets of podocarp forest. Initially, extensive pastoral runs represented the main land use, but during the 1870's and 1880's continuous arable production became the dominant farming system. Late last century a mixed cropping system of farming was developed on the Canterbury Plains and it is still used today. In this system, fertility-depletive cereals and other cash crops are grown for 2 to 4 years after which the land is put back under grazed grass-clover pasture for 2 to 4 years. The length of time given over to either cropping or livestock within the rotation varies and depends principally upon the current relative profitability of the two forms of farming and the need to maintain soil structure.

Under the mixed cropping system of farming, man's activities have a large influence on soil properties since arable and pastoral farming have contrasting effects on nutrient cycling, soil organic matter content, soil fertility and soil physical properties. Generally, both soil fertility and soil physical properties improve under pasture and decline under arable. As a consequence, large fluctuations in soil properties occur under mixed cropping.

In this paper, the evolution of the mixed cropping farming system is outlined and its effects on soil properties are reviewed and discussed.

Although there have been a large number of agronomic trials carried out in Canterbury, few studies have attempted to characterize nutrient cycling, or changes in soil fertility and physical properties within the farming system. Thus, data from outside Canterbury is used in conjunction with local data in order to synthesize a picture of the dynamic nature of the soil system under mixed cropping. We also draw attention to gaps in our knowledge which are particularly relevant to low-input and organic farming systems of the future.

Historical development of Canterbury farming

Pattern of farm development

The historical development of Canterbury farming has been reviewed in detail by Johnston (1968). Briefly, European settlement of Canterbury began in earnest with the arrival of the first four ships in 1850. The Canterbury land was rapidly occupied principally in the form of leases for extensive pastoral sheep runs which were up to one thousand hectares in size. By 1860 runholders had penetrated into the high country of the Southern Alps. However, close to Christchurch, the centre of colonization, small farms of 8 to 20 ha proliferated during the 1860s and 1870s.

As leaseholds on pastoral runs expired throughout the later part of the 19th Century, over 80,000 ha were subdivided into farms of 8 to 100 ha in size. During the 20th Century further subdivision of large holdings by the Crown occurred under the impetus of the development of new irrigation schemes in Canterbury and a desire to settle returned servicemen. These subdivisions resulted in the pattern of farm holdings which exists in Canterbury today (Johnston, 1962).

Changes in vegetation cover

When Europeans first settled in Canterbury, the major vegetation form was tussock grassland (Johnston, 1968), with pockets of mixed podocarp forest. Much of the tussock grassland was burned and established in improved grass-clover pastures.

In 1858 less than 300 ha of Canterbury were in arable crops, but the food demands of the rapidly-growing population and a developing Australian market provided the stimulus for arable production in the 1870's and 1880's. Consequently, by 1883 over 160,000 ha of tussock sod had been ploughed and put under crops, with wheat for threshing accounting for 60% of this area. Continuous arable cropping of the land resulted in a decline in soil fertility, a breakdown of soil structure, a decrease in crop yields and extensive losses of topsoil through wind erosion by the north-west winds (Johnston, 1968).

The planting of shelter belts and hedgerows went some way toward reducing soil loss through wind erosion, but the greatest effect came from a change in the farming system. The introduction of refrigeration late last century opened large overseas markets for the frozen meat industry and provided the impetus for the development of intensive sheep production on improved grass-clover pastures. This led to the adoption of the more sustainable mixed cropping system of farming that is still used today.

Nutrient cycling and soil organic matter levels

The two components of the mixed cropping rotation (viz. grazed pasture and arable cropping) have contrasting nutrient cycles and opposing effects on soil organic matter content.

Nutrient cycling

Under grazing, only a small proportion of the nutrients used in pasture production are actually removed from the system as agricultural products (e.g. wool and meat). In contrast, large quantities of nutrients are cycled within the ecosystem. Indeed, over 90% of the nutrients in pasture herbage that are ingested by grazing animals are returned to the soil surface in animal excreta (Barrow, 1987). Losses can occur during, and immediately following, this return (e.g. leaching of NO_{-3}, SO_4^{2-} and K^+ and volatilization of NH_3 in the urine patch), so that it is not a closed system (Floate, 1987; Steele, 1987). For example, in an intensively grazed pasture, Lambert *et al.* (1982) calculated that animal intake of N was 163 kg N ha^{-1} yr^{-1}. Of this, 120 and 34 kg ha^{-1} yr^{-1} were returned to the pasture in urine and dung respectively. Losses of N from the system were 9 kg N ha^{-1} yr^{-1} in animal products, 14 kg N ha^{-1} yr^{-1} by leaching and 11 kg N ha^{-1} yr^{-1} through gaseous losses. In the grass-clover pasture, the fertilizer-N input is usually zero and the N input comes predominantly from N_2 fixation by clover. Fertilizer nutrients, particularly P and S, are added to the pasture in order to maintain the clover component since it is generally a poor competitor with the grasses for nutrients (Haynes, 1980).

During the arable phase of the rotation the removal of nutrients from the soil can be large. For example, for wheat crops with grain yields of 5-10 t ha^{-1}, the amount of N removed in the grain is in the vicinity of 80-150 kg ha^{-1} and another 10-40 kg N ha^{-1} can be removed in the straw (Powlson *et al.,* 1986; Martin, 1987). Some of this N is supplied from breakdown of soil organic N following ploughing. Indeed, immediately following the ploughing-in of a grass-legume pasture, large amounts of N are made available through mineralization. (This aspect is discussed in more detail in a following section.) However, after 3 or 4 years of arable farming, fertilizer inputs of 100-150 kg N ha^{-1} yr^{-1}I are commonly required for optimum wheat yields (Stephen, 1982). Thus, an arable farming ecosystem is characterized by both large fertilizer inputs of nutrients and large losses in the harvested products.

Soil organic matter content

An equilibrium soil organic matter level is reached within a mature ecosystem which is dependent on the interaction of soil forming factors (climate, vegetation, topography, parent material and time). Since approximately 98% of soil N is present in organic form, an equilibrium level of soil N is also reached. Any alteration in the environment may lead to a change in the N content of the soil. Mixed cropping has the potential to have a particularly disturbing effect since pastoral development generally results in an increase in soil organic matter content whilst arable farming typically causes soil organic matter to decline.

There are many reports of a build-up in soil organic matter under long-term heavily-stocked, adequately-fertilized grass-clover pastures (e.g. Jackman, 1964; Sears *et al.,* 1965). Organic matter inputs comprise decomposition of plant tops and roots, deposition of animal excreta, exudation of organic compounds from pasture roots and turnover of the large microbial biomass in the pasture rhizosphere. The N input arises from N_2 fixation by the clover component of the pasture.

Under arable cropping the soil is often tilled several times a year. Tillage breaks up soil clods and exposes previously inaccessible organic matter to microbial attack. As a result, soil organic matter typically declines under continuous cropping (Jenkinson, 1988). During the decomposition of soil organic matter there is a release (mineralization) of organic N in mineral forms (ammonium and nitrate). Much of the mineralized N is taken up by arable crops and then removed as crop products (e.g. grain).

The farming system in Canterbury is normally reasonably well-balanced (e.g. 2 to 4 years arable followed by 2 to 4 years pasture). As a consequence, the total organic matter content of the soil remains relatively unchanged throughout the cropping rotation (Haynes and Swift, 1990; Haynes *et al., in press)*. For example on Lismore silt loam the initial soil organic matter content (as estimated from a wilderness area that has never been under agricultural activity) is about 3% C. Under normal cropping rotations it has equilibrated at about 2.5 to 2.7% C (Haynes *et al., in press)*.

Nitrogen economy

Nitrogen inputs

When supplies of soil water are adequate, N is most commonly the key limiting factor for crop production. The availability of this nutrient fluctuates greatly under mixed cropping. The two major N inputs into mixed cropping farming are N_2 fixation during the pasture phase and fertilizer N inputs during the latter part of the arable period.

In well-managed grass-clover pastures rates of N_2-fixation in the range of 100 to 300 kg N ha^{-1} yr^{-1} are common (Edmeades and Goh, 1978; Ledgard, 1989). Greater rates of N_2 fixation of up to 700 kg N ha^{-1} yr^{-1} have been measured when conditions favour legume growth and the rapid build-up of soil organic N (Sears *et al.,* 1965). This can occur, for example, after a soil has been cropped for many years and available soil N levels are low, but only if other nutrients are adequately supplied and productive legumes are present (Hoglund and Brock, 1987). However, much of the N_2 fixed during the pasture phase can be lost through both gaseous losses (NH_3 volatilization and denitrification) and leaching of nitrate. The amounts of N_2 fixed by the short-term grass-clover pastures used in mixed cropping in Canterbury are not well documented although Crush (1979) calculated them to be in the range of 106-145 kg N ha^{-1} yr^{-1} under dryland and 152-226 kg ha^{-1} yr^{-1} under irrigation. In the MAF fertilizer recommendation model for mixed cropping, the rate of fixation is assumed to be about 200 kg ha^{-1} yr^{-1} (Metherell *et al.,* 1989).

Although there is often no significant increase in the organic matter or N content of the soil under short-term pastures this does not necessarily mean that no accumulation of soil organic N occurs. For example, an increase of 0.02% in total N content in the plough layer is unlikely to be analytically or statistically significant, yet it is equivalent to an accumulation of about 400 kg N ha^{-1}. Recently incorporated (immobilized) organic N is generally the most readily mineralized (Haynes, 1986) so that large quantities of N may be immobilized during the pasture phase and mineralized during the arable phase. Further research on this aspect of the N cycle under mixed cropping is required.

There is often a substantial build-up in the microbial biomass in the soil under pasture. The microbial biomass acts as an agent for the decomposition of organic matter as well as being a large pool of readily mineralizable soil N. An increase in microbial biomass in the plough layer from 230 kg N ha^{-1} at the end of the arable period to 300 kg N ha^{-1} during the pasture phase has been measured (Haynes *et al., in press)*.

The release of mineral N into the soil following the ploughing in of pasture occurs through mineralization of organic N derived from pasture residues, readily mineralizable soil organic N and dead microbial cells. At present, the relative importance of these sources is unknown. Although the mineralization rate will be greatly affected by environmental factors (Haynes, 1986), no applied fertilizer N is generally required to achieve optimum yields of arable crops such as wheat in the first year after pasture (Stephen, 1982). During the second year there is a smaller supply of mineral N through mineralization and consequently a fertilizer input of about 50 kg N ha^{-1} is normally required. For the third and following years, a high fertilizer input of 100 to 150 kg N ha^{-1} is usually required since the supply of mineral N from the soil is low.

The above relationships are illustrated by the data presented in Table 1. Nitrogen applications markedly increased grain yields in third-year winter wheat crops but had little effect in the first crop after several years of pasture. A large number of fertilizer trials have demonstrated similar results (Lynch, 1959; Stephen, 1982), and fertilizer-N recommendations during the arable phase are now normally based on an index of previous cropping history (Metherell *et al.,* 1989).

As yet, no studies have attempted to quantify the N inputs that occur following the ploughing-in

Table 1: *Grain yield response to applied nitrogen for first- and third-year winter-sown wheat crops after several years grazed pasture.*

Wheat crop	Rate of applied N (kg N ha^{-1})		
	Nil	60	120
First	4850	5020	5050
Third	3850	4460	5090

[1]*Data from McLeod (1974)*

of grass-legume pasture in New Zealand. Such studies are, however, required in order to fully characterize the farming system. For example, if the N input in the first season following ploughing-in is equivalent to about 150 kg N ha^{-1} of readily soluble fertilizer N and about *25070* of organic N is made available to the crop in the first year then a total organic N input of at least 600 kg N ha^{-1} would have been required. If such a large N input occurs and the farming system is not accumulating N, then large N losses are likely to be occurring.

Leaching losses of nitrate

A major loss of N from the mixed cropping system is suspected to be through nitrate leaching immediately following the ploughing-in of the grass-clover pasture. Indeed, mineralization of N-rich leguminous plant residues has been suggested as the major source of nitrate pollution of Canterbury groundwater (Adams and Pattinson, 1985). However, the amount of nitrate leached from Canterbury mixed cropping rotations following the ploughing-in of grass-legume pastures has not yet been measured experimentally.

Leaching of nitrate into the groundwater represents an economic loss to the farmer as well as an environmental concern. Enrichment of lakes and estuaries with N can bring about a proliferation of algae, a decrease in water clarity and a depletion of dissolved oxygen in bottom water. In addition, a high level of nitrate in groundwater used for drinking is considered a potential health hazard (Shuval and Gruener, 1977). High nitrate concentrations in potable water have been implicated in the occurrence of infant methemoglobinemia, gastric cancer and hypertension (Burden, 1982). The World Health Organisation and the EEC have set a maximum allowable concentration of 50 mg NO_3 l^{-1} (11.3 mg NO,-N 1"1) with a guideline of 25 mg NO, l^{-1} or lower (Cameron and Haynes, 1986). Concentrations of nitrate-N in Canterbury groundwater have been reported to exceed 10 mg NO_3-N 1^{-1} in several locations (Adams *et al.,* 1979). Indeed, a major reason for Lincoln township changing from private wells to a municipal water supply several years ago was the high nitrate levels in drinking water

The quantity of nitrate passing from arable land to aquifers each year is largely determined by the nitrate content of the soil just before the start of winter leaching (Jenkinson, 1986). The soil nitrate content at this time is dominated by the mineralization of organic N which has occurred through the growing season rather than by the amount of fertilizer N applied earlier in the year. In Britain, Macdonald *et al.* (1989), for example, observed that for 11 winter wheat crops which received between 47 and 234 kg N ha^{-1} of ^{15}N-labelled fertilizer in spring, on average only 1.3% of fertilizer N remained in mineral form in the soil at harvest. Between 79 and 98% of the mineral N in soil at harvest was unlabelled, being derived from the mineralization of organic N. In addition, the amount of unlabelled mineral N was much greater where wheat was grown after ploughing-in grass-clover leys than that where it was grown in all-arable rotations.

In Canterbury, Adams and Pattinson (1985) estimated leaching losses of nitrate under a four-year rotation (white clover, peas, wheat, wheat) (Table 2). They observed the greatest loss (90 kg N ha^{-1}) in the year following ploughing-in of the white clover ley, with a significant loss (60 kg N ha^{-1}) occurring in the following year. Most of this leaching loss originated from mineralization of the N-rich white clover residues (and to a lesser extent the pea residues). Since a three- or four-year-old grass/clover pasture will probably have a greater N input than a one-year-old white clover ley, nitrate leaching losses following the ploughing-in of pastures may be greater than those recorded by Adams and Pattinson (1985). Research under New Zealand conditions is required in order to quantify such losses.

Overseas research has shown that significant control of nitrate pollution from arable land can only be achieved by management practices that minimize the opportunities for nitrates to accumulate in autumn from mineralization of soil organic N (Jenkinson, 1986; Powlson, 1988). The most promising strategy for decreasing the loss of mineralized N during winter is to absorb as much as possible into a crop before leaching starts. Thus,

Table 2: *Estimated annual nitrate-N leaching losses under afour-year crop rotation*[1].

Crop order	Annual nitrate-N leaching loss (kg N ha^{-1} yr^{-1})
White clover	10
Peas	90
Wheat	60
Wheat	35

an autumn-sown crop retains more N in the crop-soil system than one sown in spring and the earlier it is sown the less N remains at risk in the soil. If spring-sown crops are unavoidable, then a winter "catch crop", which is ploughed under in early spring can be used to withdraw some nitrate from the soil during winter (Nielsen and Jensen, 1985).

The trend toward more "sustainable" farming systems and, in particular, toward organic farming, has raised concerns about nitrate pollution of groundwater. Because fertilizer N is not used, organic systems rely on symbiotically-fixed N_2 as their major N-source. It is, therefore, likely that leguminous residues will be incorporated on a more frequent basis than under conventional mixed cropping and there will be increased opportunities for leaching losses of nitrate. This is particularly so since the leguminous pasture is often incorporated into the soil in late summer and the paddock is then fallowed over winter as a weed control measure.

Soil structure

Soil structure can be defined as the arrangement of the solid soil particles and of the pore space located between them (Marshall, 1962). Well-structured soil possesses pores of varying sizes which display different functional characteristics. Large (>60 mm equivalent spherical diameter) soil pores (macropores) are important for the movement of water and air for root penetration, while smaller pores store water which is subsequently available for crop growth. In addition to pore diameter, pore continuity can also be important, particularly in relation to aeration and the downward transmission of water and solutes through the soil.

Soil structure is dynamic in character, changing through the year in response to tillage as well as to the natural process of wetting/drying, freezing/thawing, earthworm burrowing and root extension. The ability of a soil to maintain its structure is commonly assessed from the measurement of the stability of soil aggregates to the degrading action of water. The breakdown of soil structure is a frequently-encountered phenomenon under intensive arable farming but it is seldom encountered in natural ecosystems.

Consequence of structural breakdown

Aggregates with low stability can break down into fine particles under the action of rainfall or irrigation (slaking). There are two major practical implications of this:

(1) A dry period following rainfall or irrigation can result in the formation of a dense surface crust. This occurs when fine soil particles, which are released during aggregate breakdown, move into inter-aggregate pores in the surface layer of soil. The presence of a surface crust can limit the entry of further rainfall or irrigation water leading to ponding and/or runoff and erosion. Perhaps more importantly, if the crust forms after sowing it can impede the emergence of seedlings, thus leading to greatly reduced stand density (Payne, 1988).

(2) Extensive slaking and downward movement of dispersed soil particles into the surface horizon can block macropores, and along with compaction from farm machinery, can result in the formation of a dense plough layer (Greenland, 1977). The soil is then difficult to work and comes up in large massive clods. This is a particular problem on heavy textured soils (e.g. clay soils). Further cultivation and rolling can break up the large clods resulting in the formation of small massive clods surrounded by a matrix of very fine particles.

In addition, a very fine tilth can be produced in poorly-aggregated soils during seedbed preparation. Such soils are vulnerable to 'windblow' particularly in the warm, gusty, drying northwest fohn winds which are common in Canterbury. Wind erosion of soil can be a serious problem, resulting in the loss of many tonnes of fertile topsoil (Hunter and Lynn, 1988; McGuigan, 1989). A loss of 10 mm depth of topsoil from the paddock is equivalent to a loss of about 100 t ha^{-1} of soil, containing about 350 kg N ha^{-1}. Some examples of soil losses through wind erosion on Canterbury paddocks are presented in Table 3.

All the above problems are well known on Canterbury cropping farms today and, as already noted, they were also prevalent in the 1870's and 1880's. Under present cropping rotations they are apt to develop toward the end of the arable period and they can become a major problem if, for some reason, the arable period is extended beyond four or five years.

Restorative effect of pasture

Soil structure generally improves under pasture

Table 3: *Quantitative assessments of soil loss from paddocks over several days through wind erosion in northwest winds in the Canterbury region*[1].

Date	Location	Soil Type	Quantity removed (tonnes/ha)
Aug 1975	Darfield	Chertsey silt loam	61
Nov 1975	Rakaia	Paparua silt loam	20
Apr 1981	Waipara	Glasnevin stony silt loam	71
Nov 1984	Cust	Waimairi peat	107

[1]*Data from McGuigan (1989)*

since structural pores are created by the extensive ramified pasture root system. Indeed, plant roots have been identified as the most important agents in the creation of pores in undisturbed soils (Payne, 1988). Roots grow by forcing their tips into small pores and as the young roots swell the pores are enlarged. Root growth can also cause movement of structural units of soil, resulting in the enlargement of the pores between them. In addition, plant roots extract water from the soil and as the soil dries it shrinks causing cracks to develop. Earthworms are also important in the creation of soil pores through a considerable depth of soil, and characteristically high rates of earthworm activity are observed under pasture.

Under pasture, not only are structural soil pores created but in addition soil aggregates are stabilized (Robinson and Jacques, 1958). Mucilaginous materials (mainly polysaccharides) which are produced by plant roots and the rhizosphere microflora, are important "glues" involved in aggregate formation (Cheshire, 1979). The extensive root growth and very large microbial biomass (Hart *et al.,* 1988) in the surface soil under pasture results in a large supply of these mucilaginous binding materials during the pasture phase of a mixed cropping rotation (Oades, 1984). In general, polysaccharides in soils are readily degraded by microorganisms so that their effect on aggregation can be shortlived (Chaney and Swift, 1986) unless there is a continuous supply such as in the rhizosphere.

Fine roots and associated mycorrhizal hyphae also have aggregating effects because they physically enmesh soil particles (Tisdall and Oades, 1982). Such binding agents build up in the soil within a few weeks or months of plant establishment as root systems and hyphae grow and form a three dimensional network which holds soil particles together. Following plant death, these binding effects disappear as roots and hyphae decompose.

As already noted, under permanent pasture the total soil organic matter content characteristically increases. This occurs through an increase in soil humic substances (the dark semi-stable microbially-synthesized fractions of organic matter) which act as binding agents for soil aggregates through the formation of persistent, stable complexes with the mineral fractions of the soil (Theng, 1979).

In contrast, under continual arable production soil organic matter breaks down (Packard and Raeside, 1952; Gradwell and Arlidge, 1971). The decrease in soil organic matter content results in a decrease in aggregate stability and this contributes to a general decline in soil structure (Gradwell and Arlidge, 1971; Cotching *et al.,* 1979).

Effect of cropping rotations

Although much is known regarding the changes in soil physical properties under long-term arable versus long-term pasture, considerably less information is available in relation to the changes that occur under Canterbury mixed cropping rotations. Since there is little build up of total soil organic matter under the grazed pasture phase, the short-term binding process involving mucilaginous glues and root enmeshment is probably the major mechanism involved in stabilizing soil structure. Under the arable period of the rotation, the pasture is ploughed under and the dense pasture root system is replaced by a sparser and deeper crop root system. Consequently, the density of roots, size of the microbial biomass, production of mucigels and aggregate stability in the plough layer are all decreased (Haynes and Swift, 1990; Haynes *et al., in press).*

An example of the effect of previous cropping history on the aggregate stability of a Canterbury soil is shown in Fig. 1. The data are taken from a survey of commercial farms. These results show that aggregate stability increased with increasing time under pasture, but conversely decreased with increasing time under cropping. Below a mean weight diameter (MWD; see Table 4 for definition) of about 150, soil structural problems are likely to occur (K.C. Cameron, personal communication 1988) and this often happens after 4 to 6 years' arable cropping.

An increase in aggregate stability under short-term pasture is illustrated in Table 4. The long-

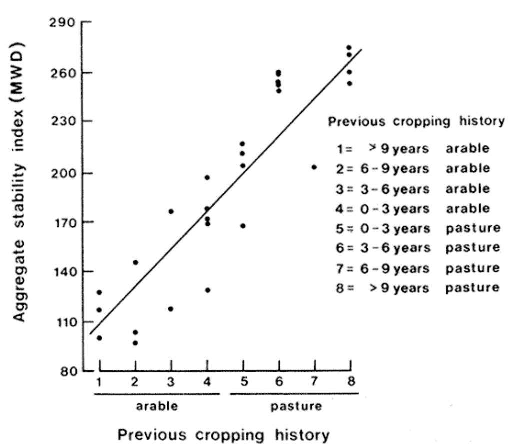

Figure 1: *Relationship between previous cropping history and aggregate stability index (mean weight diameter; MWD) for Lismore silt loam. Data from Haynes* et al. in press.

Table 4: *Effects of cropping history on aggregate stability, total N, organic C, and hot water-extractable carbohydrate content of samples of Wakanui soil.*

Cropping history	Aggregate stability (MWD)	Total N (%)	Organic C (%)	Microbial biomass C (μg C g^{-1})	Hot water-extractable carbohydrate (μg C g^{-1})
Pasture (20 yr pasture)	266	0.38	3.6	996	294
Arable (IS yr pasture)	130	0.19	2.0	711	106
Regrassed (13 yr arable plus 2 yr pasture)	248	0.19	2.0	876	136

[1]*Data from Hayes and Swift (1990)*
[2]*MWD = (% soil retained on sieve x mean intersieve size).*
A value of 300 represents no aggregate breakdown; 25 *represents total disruption*

term pasture sample had a much greater aggregate stability, organic C, total N, microbial biomass and hot water-extractable carbohydrate content than the long-term arable site. However, after the long-term arable site had been regrassed for two years, the aggregate stability had increased greatly yet there had been no measurable change in organic matter content (organic C or total N content) of the soil. There was, however, an increase in the size of the microbial biomass and in the hot water-extractable carbohydrate fraction (which represents mainly the mucilaginous carbohydrate binding agents in soil).

Short-term changes occur, not only in the aggregate stability but also in the porosity of the soil, as was recently demonstrated by Francis and Kemp (1990) using micromorphological techniques. Soils were sampled from a cropping rotation in which four years of pasture were followed by two years of arable crops. Samples were taken in spring from paddocks in their second (P2) and fourth (P4) year under pasture and the second year of crop (C2). Samples were also taken from under a 35-year-old pasture (P35). Horizontally-oriented blocks of soil at a depth of 60 mm were impregnated with polyester resin and the polished surface of the block was photographed (pores appear white and soil solids are black). Although the (C2) and (P2) soils had identical soil organic matter contents (2.30/0 organic C) their soil structural conditions were visibly different (Fig. 2). The cropped soil (C2) was loosely packed and voids were often horizontally oriented (leading to large areas appearing white). During the season, however, natural compaction would be expected (Packard and Raeside, 1952). After only two years of pasture (P2) the soil was much denser but a considerable number of vertically-oriented biopores (macropores created by pasture root growth and earthworm activity) had formed. After four years of pasture an even larger number of biopores had been created whilst in the 35 year pasture soil a network of biopores and fissures had developed.

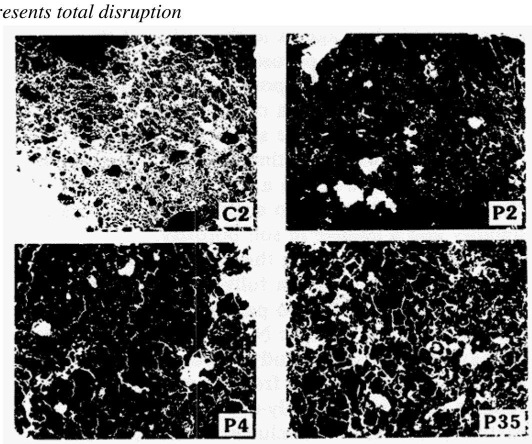

Figure 2: *Images of horizontally-oriented resin-impregnated blocks at 60 mm depth from soil under* 2 *ears cropping (C2),* 2 *years pasture (P2),* 4 *years pasture (P4) and* 35 *years pasture (P35). Data from Francis and Kemp (/990).*

Thus, soil structure undergoes a cyclical buildup and breakdown under mixed cropping (Haynes and Swift, 1990). Under the short-term pasture there is a buildup in short-term binding agents (and a consequent increase in aggregate stability) and also an increase in macroporosity caused by pasture root growth and earthworm activity. When the paddock is cultivated there is an initial increase in porosity caused by the breakup of the plough layer. With time, aggregate stability declines as short term binding agents decomposed, and as a consequence of slaking and natural compaction there is a decrease in soil porosity and diminution of soil structure.

Recently, interest has developed in organic farming systems and the use of mixed herb leys (which consist of a range of legumes, herbs and grasses) to restore fertility and soil structure. Such leys are claimed to be of more benefit to soil structure than conventional grass-clover pastures although few, if any, quantitative data exist to substantiate this. Leguminous crops such as peas, lentils and lupins are also known as "restorative crops" and although they are known to have benefits for soil N status, their effects on soil structure are ill-defined. Research into these aspects of soil structural/crop interactions is required.

Conclusions

The mixed cropping farming system used extensively in Canterbury has a particularly disturbing effect on soil properties. During the pasture phase there is a large input of N through N_2 fixation by the clover component, a build-up of temporary binding agents in the soil, and there can be an increase in the porosity and/or the number of vertically-oriented biopores in the topsoil. Under arable cropping there is a rapid decline in the N-supplying power of the soil due to N mineralization which is stimulated by ploughing-in the pasture. There is also a rapid decline in soil physical properties due to a decrease in aggregate stability and a change in soil porosity.

The N inputs during the pasture phase via N_2-fixation have not been fully quantified and the partitioning of the N into pasture biomass, readily mineralizable soil organic N and microbial biomass is unknown. Only one study has documented leaching losses of nitrate from Canterbury cropping systems but the commonly-used grass-clover pasture phase was not included in the rotation. With the trend towards low-input and organic farming systems, which will rely heavily on N_2 fixation during the pasture phase, such information is vital in order that sustainable cropping systems can be devised.

Soil physical properties are another important area where research is required. High inputs of fertilizer and irrigation can often mask the adverse effects of poor soil physical environments on crop growth. Under low input systems, soil physical impediments are likely to become more important determinants of crop yields. Strategies to maintain an optimum soil physical environment are therefore needed. The relative effects of mixed-herb leys on soil physical properties in comparison with the traditional grass-clover pastures require scrutiny.

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