ASSESSMENT AND MANAGEMENT OF INHERENT AND DYNAMIC SOIL PROPERTIES FOR INTENSIVE AGRICULTURE IN THE NORTH ISLAND, NEW ZEALAND AND TASMANIA, AUSTRALIA

A collection of Published Papers and a Review

Volume 1 – A Review and Part publications

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DECLARATION

The papers presented for the degree are the original works, either by the candidate alone, or written in conjunction with others. Where other authors are involved, the estimated percentage contribution of the candidate is shown in the list of publications submitted for the degree under ‘Contributions to joint publications by the candidate’ section of the thesis.

The thesis contains no material by the candidate that has been accepted for any higher degree or graduate diploma in any other Tertiary institution.

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ABSTRACT

The primary aim of the research reviewed in this thesis has been to provide information required by land managers on inherent and dynamic soil properties for sustainable intensive agriculture.

A soil survey in the Te Puke district, New Zealand, found the soils to be young with the majority having a layer of tephra in their profiles which gives rise to low overall nutrient status and free draining properties. Soils in north west Tasmania were found to be predominantly Red Ferrosols formed on basalt. The Ferrosols are characteristically strongly structured, strongly acid and have high organic carbon contents. The Ferrosols surveyed were being managed at their optimum land capability or better, with little evidence of soil degradation.

The importance of taking a morphological approach to the studies of soil health is illustrated by comparing data from similar paddock histories across the soil orders studied. The differences in physical properties and soil carbon contents between soil orders were pronounced. The measured effects of cropping on soils varied depending on inherent differences between the soils studied. Soil carbon levels were found to be falling with increased years of cropping on all soils studied. Strong correlations were found between soil carbon and a range of soil physical, chemical and biological properties. Target levels of soil carbon are suggested for cropping systems, which can be used as an indicator of sustainability. The soil properties and paddock variables found to be significantly correlated with crop yield varied, depending on crop and soil type. Two easily applied measures of soil structure were correlated to crop production on heavier textured soils.

Research into the off-site effects of agriculture in north west Tasmania found that there were high levels of water turbidity caused by soil erosion from cropped paddocks and high levels of nutrients emanating from dairy pastures on drained lowland areas.

There has been a positive change in farmer perceptions and soil management practices over a ten-year period in north west Tasmania. Several information

brochures have been published for farmers to assess and manage their soils for sustainable production.

The research undertaken and reviewed here has produced information on inherent and dynamic soil properties required by farmers for sustainable intensive agriculture. The work has played a major role in the understanding of how soil management has an impact both on and off site and in influencing soil management on farms in both Tasmania and the Bay of Plenty, New Zealand.

CONTRIBUTIONS TO JOINT PUBLICATIONS BY THE CANDIDATE

Sixteen of the twenty three publications and the unpublished report used as the basis of this thesis involved joint authorship. Of these the candidate was the senior author of eleven publications and the unpublished report, and is the second author in the remaining four publications. The estimated percentage contribution by the candidate is shown in parentheses in the list of publications submitted for the degree under the 'References' section of the thesis.

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Chapter 1 – Introduction

1.1 Chapter outline

Chapter one provides a description of the structure of this thesis, the aims of the work, some concepts used and a context for the work. The work reflects the progression by the author over a twenty five-year period from investigation and reporting on inherent soil properties in soil surveys to research on the effects of agriculture on dynamic soil properties and associated off-site effects. The more recent research presented has played a significant part in the understanding of how soil management can have environmental impacts both on and off site.

1.2 Background and structure of thesis

A detailed soil survey of the Te Puke district, Bay of Plenty, New Zealand, and a soil survey of the Pet and Guide catchments in north west Tasmania are described in order to represent the type of information on inherent soil properties required by agricultural managers for intensive agriculture. This information is interpreted in a number of ways including a locally specific interpretation for intensive horticultural production. The Te Puke survey includes quantitative data on the physical characteristics of the dominant soils. This type of quantitative information has not been included as routine analyses in any other soil survey report published in New Zealand. The style of presentation of this data has also not been seen in other soil survey reports.

Information from nine papers and one technical report is presented illustrating the effects of agricultural management on dynamic soil properties in Tasmania and in the Waikato district of New Zealand, plus the off-site environmental impacts on water quality under different land uses in north west Tasmania. Four themes are drawn from these papers summarising the effects of agriculture on soil organic matter, soil physical and chemical properties and the effects of erosion. The papers present information on a broad range of soil properties by soil order and so information on the inherent differences between soil orders is included. Relating soil properties to crop yields is a critical step in soil research for farmers, and so information from two papers is included that describe this for four soil orders in Tasmania. A review of the management challenges of Red Ferrosols is also included to put the problems experienced in Tasmania in an Australia-wide context (Isbell, 2002).

Farmer assessment of soil health is as relevant as assessment by scientists (Romig *et al*. 1995) and so farmer surveys were included in six of the papers describing the effects of agricultural management on soil properties in Tasmania. One paper reports on the findings of three surveys of farmer perceptions of soil management on Red Ferrosols in northern Tasmania carried out over a 10-year period.

Extending relevant management information to local farmers is the final critical step in this body of research. Four brochures are included which provide such information in an easy to read and pictorial format (Cotching 1997; Cotching 2000; Cotching and Sparrow 2000; Ashley and Cotching 2001). Some of this information is also available on the Internet (http://www.dpiwe.tas.gov.au). A paper about a new soil erosion control technique for use under annual cropping systems in north west Tasmania describes an implement and methodology invented by the author and developed over a 2-year period (Cotching 2002).

1.3 Aims

The research undertaken in this body of published work has improved the understanding of inherent soil properties by providing land managers with relevant information to make informed decisions in relation to intensive agriculture. Information about how dynamic soil properties are affected by agricultural practice, and the impacts on off-site values, has improved the information for farmers and the general community about the sustainability of modern agriculture in Tasmania. Six of the papers give the first comprehensive review of the effects of agriculture on soil properties in Tasmania. McKenzie *et al.* (2002) describes this series of soil order based health monitoring studies as one of the most comprehensive and useful in Australia. Examples are included of how information needs to be presented to farmers so that it is easy to read and readily understood.

The combination of two soil survey reports and maps, fifteen published papers, one technical report and five management information brochures presented in this thesis constitutes a significant original body of work that illustrates the information required by land managers on inherent and dynamic soil properties for sustainable intensive agriculture.

1.4 Context

Farmers have tilled the soil since settled agriculture originated some 10 to 13 000 years ago (Hillel 1991). Simple tools were developed to place and cover seeds in the soil, eradicate weeds and harvest grains (Troeh *et al.* 1980). A written record of a type of plough is found in Mesopotamia dated at about 3000 BC (Hillel 1998). Today's farmers use more sophisticated tools to manage the soil for crop and pasture production. These agricultural implements have the potential to both enhance soil conditions for increased crop productivity and to degrade soil properties if inappropriately used. Farmers and scientists are aware of these potentials and they value new knowledge on how the soil behaves under particular conditions and the means to optimise productivity. This awareness has driven the need for information on inherent soil properties which is given in soil surveys that provide soil maps and characterisation of soil properties.

Land managers can use the information in soil surveys to aid decision making on land use choices in order to reduce risks associated with production. They require information on inherent soil properties as these properties impose limitations on the type of enterprise that can be undertaken successfully. Land managers do not usually have the knowledge or skills to interpret primary soil survey or research information and so it is incumbent upon authors of such surveys to produce interpreted information relevant to potential users. Such interpretations have often concentrated on the limitations for particular broad-scale land uses such as cropping, forestry, horticulture or pastoral use. The financial return from intensive agriculture can justify far greater inputs to overcome inherent soil limitations in order to achieve profitable and sustainable crop yields. Land managers developing intensive agricultural enterprises require interpreted soil information that gives them information on the level of inputs required to overcome inherent soil limitations. This allows the land manager to decide whether to proceed on the basis that the economic returns justify a certain level of inputs.

Agriculture has become a large user of technology to aid production. For example, soil moisture monitoring for scheduling irrigation is a common practice. The use of this technology requires quantitative data on relevant inherent soil properties in order to optimise its use.

Farmers are generally keen to keep their soils in good condition because they believe that soil health has a direct impact on crop performance. Concerns over the health or condition of the general environment have increased in the wider community over the past 30 years (Cotching and Sims 2003). Managers need information on dynamic soil properties to test whether current systems of land use and management are sustainable or whether change is required. Increased community awareness of environmental values is bringing new constraints on agricultural enterprises. The community, as well as farmers, are increasingly concerned that agriculture is sustainable and that the dynamic soil properties are not being degraded by current management practices. Landholder and community concerns now include the effects of agriculture on off-site environmental attributes such as water quality. The broader community is requiring independent audits of soil and water health to ensure that production systems are sustainable, associated environmental attributes are being maintained, and that informed decisions are made when required (eg. Cradle Coast NRM Committee 2004).

Intensive agriculture has the potential to have dramatic off-site affects due to the consequences of high risk activities such as cultivating ground at a time of year when intense rainfall is likely to cause soil erosion, or applying fertilisers when surface runoff is likely. Providing information on off-site impacts of current soil management practices allows for the explanation of processes, the prediction of future impacts, and where changes to practices are likely to lessen these off-site impacts. Information on off-site impacts is likely to become an increasing part of industry reporting requirements as Environmental Management Systems and State of Environment reporting by Governments become more pervasive.

1.5 Agriculture in the districts studied

The Te Puke district in New Zealand is an area where intensive horticultural development has taken place with the town of Te Puke being known as "The

Kiwifruit Capital of the World". Citrus and other sub-tropical fruits are also grown. Considerable land areas are under pasture for dairying, sheep and cattle breeding and fattening, and deer farming. The main commercial centre in the area is the township of Te Puke and there is a strong demand for land for urban development approximately 20 kilometres to the north west at Mt Maunganui and the coastal resorts of Papamoa and Maketu.

The Waikato district in New Zealand's central North Island (Figure 1) is dominated by pastoral farming, particularly intensive dairying. Maize cropping for grain and green feed production expanded rapidly in the 1970's with more than 60% of all New Zealand's maize grown in the Waikato. Farming is rainfed rather than irrigated due to the even spread of rainfall throughout the year.

Many farm enterprises in Tasmania carry out a range of farming activities with livestock found on most farms. Dairying occurs mainly across the north and north west of the state. Barley and oats are the most popular broad-acre crops grown and these are mainly grown in the midlands and north east. Vegetables are primarily produced in the north west but also increasingly in other areas. Potatoes, onions, carrots, peas, beans and brassicas (broccoli, cauliflower, and cabbage) are the main vegetable crops grown. Poppies are a significant crop and are grown under tight regulations for the world pharmaceutical market. All of the vegetable and poppy crops are grown with supplementary summer irrigation with most grown under contract to locally based multi-national processing companies. The crops are grown in rotation for good disease management.

The north west coast of Tasmania is dominated by Red Ferrosols and is one of the most heavily cropped regions in Australia supporting a wide range of agricultural activities, particularly intensive vegetable cropping. The area is dominated by dissected basaltic plateaux with Red Ferrosols commonly found on flat to undulating slopes with many steep side slopes. Average annual rainfall in Tasmania's north west ranges from 900 to more than 1500 mm. Rainfall increases with distance from the coast as well as in a westward direction. A rainfall maximum occurs in winter when considerable areas of cropping are fallow with no vegetation cover. It is the combination of good climate and versatile soil that gives rise to a wide range of intensive uses and makes these Ferrosols the most productive agricultural soils in Tasmania.

1.6 Concepts

Landscapes and soil properties change with time both naturally and anthropogenically. Some change is slow and gradual while in other cases change is episodic and dramatic (McKenzie *et al.* 2002). Agricultural activity can result in changes in soil properties and it can also speed up the rates of change. Some soil properties are unlikely to change through agricultural operations and can for most practical purposes be considered to be inherent (eg. soil texture and mineralogy, presence of specific horizons), whereas other soil properties are dynamic (eg. organic carbon, available phosphorus). These dynamic soil properties are easily affected by human decisions and actions (Karlen *et al*. 2001).

Soils properties change due to spatial variations in the five soil forming factors of parent material, climate, topography, biological activity and time (Jenny 1941). Soils in different locations may also be the same due to the same five soil forming factors operating in the same manner. A soil survey provides a map and description of how different soil types are spatially distributed in a region according to the five soil forming factors.

Soil morphology, or the in-field determined properties of soils, which allows for their classification, can provide information that is significant to land use and soil management. The usefulness of a morphological approach to soil management was well illustrated by Chilvers (1996) who identified five principle soil types (Dermosols, Ferrosols, Sodosols, Tenosols, & Vertosols) used for cropping in Tasmania. Others have suggested that caution should be used with this approach (Butler 1980; Droogers and Bouma 1997). The five soil types identified by Chilvers (1996) should be managed in distinctly different ways in order to crop these soils sustainably.

1.7 Soil health

Soil health can be defined as the capacity of a soil to function, within land use and ecosystem boundaries, to sustain biological productivity, maintain environmental health, and promote plant, animal, and human health. Investigation of soil health is an important key to sustainable land management because it allows for:

- Evaluation of soil management practices in terms of effects on the soil,
- Determination of any trends in soil changes,
- Focusing conservation efforts by both farmers and others influencing land management decision making, and
- Guiding farmer decisions on best practices.

Agricultural use of land can have impacts that enhance or degrade soil health. Conclusions obtained from research into soil health may depend on the attributes investigated and so a broad approach has been adopted to assess impacts of agricultural use on the health of a range of soils in Tasmania. Overall these can be classed as chemical, physical and biological characteristics. This approach is consistent with current broad views of soil quality (Doran *et al.* 1994; Carter 1996; Sanchez *et al*. 2003).

The approach taken in Tasmania is to capture a snapshot in time of soil health in a number of paddocks with different histories, rather than to track changes at specific sites over several years. However, histories of the sites are not known precisely and there are no controls over such things as the number of passes used for tillage, or stocking rate. This has been compensated for this by selecting 5−7 replicate farms on each soil type.

This survey approach has the following features (McKenzie *et al.* 2002):

- It is assumed that soils at different locations were once the same in every respect.
- Some form of land use history is available for each location.
- Sampling of sites with different management histories allows inferences to be made about the impact of land management practices over time where space is substituted for time.

The main limitation of this survey approach is the assumption that space can be substituted for time. It is usually very difficult to confirm that sites with different management histories were once the same, and that the assumed starting point provides an appropriate baseline. Another difficulty is the general absence of reliable information on management history which limits the inferences relating to the observed differences.

Soil health is not an end in itself. The ultimate purpose of assessing soil health by research is not to ensure high aggregate stability, biological activity, or some other soil property. The purpose is to protect and improve long-term agricultural productivity, water quality, and habitats of all organisms, including people. We use soil characteristics as indicators of soil health, but in the end, soil health can only be identified by how it performs all of its functions. This production function of soil health can be related to the emerging concept of ecosystem services. Ecosystem Services are "the conditions and processes through which natural ecosystems, and the species that make them up, sustain and fulfil human life" (Daily 1997). They include: inputs to production; regeneration of ecosystems; stabilisation of soils, climates and weather; assimilation of wastes; amenity; and options for the future. Although sustainable human well-being depends on ecosystems, humans degrade them. A production function is the quantitative relationship among a set of physical inputs, human knowledge, skills and labour, technology and the physical quantity of an output (CSIRO Sustainable Ecosystems 2003). Probably the highest priority that soil health must perform for farmers, is to be able to produce optimum yields. A change in soil condition can greatly affect crop growth and economic return to farmers and so in order to provide relevant productivity information, this research attempted to link a range of soil properties to crop yields.

Chapter 2 – Examples of assessing inherent soil properties

2.1 Chapter outline

This chapter includes examples of two detailed soil surveys. A soil survey of the Te Puke district, Bay of Plenty, New Zealand (Figure 1), and a soil survey of the Pet and Guide catchments in north west Tasmania (Figure 3). These surveys represent the type of information about inherent soil properties required by agricultural managers for intensive agriculture. The Te Puke survey includes quantitative data on the physical characteristics of the dominant soils. Quantitative soil physical data is required by farmers in order to optimise the use of technology to aid production (e.g. soil moisture monitoring for scheduling irrigation). This type of quantitative information has not been included as routine analyses in any other soil survey report published in New Zealand. The style of presentation of this data also has not been used previously in other soil survey reports in New Zealand.

This chapter also presents a succinct description of the different terminology used to define soil units in Australia and New Zealand and the differences between soil taxonomic and mapping units that are used in these soil surveys. This understanding is fundamental to the generation of a legend of soils in each survey and the production of the soil maps. Both aspects are described below.

2.2 Map units and taxonomic units

The main objectives of a soil survey are to identify, classify, evaluate and indicate the distribution of soils in a particular area (Gunn *et al*. 1988). The maps produced are a simplified representation of the soil pattern of an area and the associated information characterises each kind of soil so that the response to changes can be assessed and used as a basis for prediction (Taylor and Pohlen 1970).

A soil map unit is an area of soil that is of sufficient size to be represented as a discrete polygon on a soil map. Map units can be grouped into a physiographic legend (Table 1) according to the position they occupy in the landscape and to differences in natural drainage. Soils are classified on the basis of their characteristics determined from the soil profile. A soil taxonomic unit is a soil class with a clearly defined range of soil properties, commonly represented by a modal profile and a range of profile and site features. The taxonomic unit is referred to as a soil series in New Zealand and a soil profile class in Australia. The soil series concept arose in America where soils are mapped according to series, type and family (US Department of Agriculture 2003). The soil profile class is a concept originating in Australia that is thought to be suitable for soil surveys at a range of scales (Beckett and Webster 1971). The soil profile class is a group of similar profiles with the variation in some features within the class being less than the variation between classes (Isbell 1988). The soil properties used to define a particular soil profile class may vary widely, but they will include some or all of the field morphological properties normally described, together with certain laboratory-determined properties where thought desirable or necessary.

The relationship between map units and taxonomic units depends on the scale of mapping and the area mapped. In an extremely detailed survey (eg. 1:2 000), where every identifiable individual kind of soil could be mapped, the map and taxonomic units would be theoretically identical. However, at the mapping scales used in these surveys (1:15 000 & 1:25 000) it was not possible to map every unique soil. In order to avoid the proliferation of soil names, map units often contain a number of both named and unnamed soils. If inclusions constitute 15% or less of the map unit, the unit is given the single geographic name of the dominant soil taxonomic unit (Taylor and Pohlen 1970). The inclusions are described in the text and listed in the soil map unit descriptions (NZ) or soil profile class descriptions (Aust.).

The two examples of soil surveys in this thesis were undertaken at detailed scales of 1:15 000 and 1:25 000. Consequently, subdivision of the soil mapping units into soil types and phases was necessary to fully represent the landscape on the detailed maps. The soil type is named from the district or locality where it is first recognised, indicating the series or profile class to which it belongs, and by a textural name that indicates the texture of the topsoil (eg. Manoeka silt loam). Additional descriptive terms indicating colour, depth or other features of the profile may be added where necessary in order to distinguish it from other members of the soil series or class. The subdivision into soil phases is based on characteristics that are significant to land use (eg. slope or drainage). A soil with characteristics sufficiently different to be recognised as a new series but whose known area is not large enough to justify this, is designated a variant of the most closely related named type (eg. Te Puke sandy loam, mottled variant).

In New Zealand, where much of the landscape has slopes greater than 12 degrees (20%), complex soil patterns exist due to their occurrence on compound slopes (crest, midslope, toe). In order to avoid proliferation of soil names, the map unit is given a single geographic name, generally that of the taxonomic unit on the stable part of the slope, and the complex is indicated by the terms ‘hill soils’ and ‘steepland soils’ after the geographic name (Taylor and Pohlen 1970).

Where the map unit contains more than 15% of inclusions it is shown as a compound map unit such as a soil complex or soil association and is named after the two most abundant soils with both soil symbols on the map. The ‘+’ represents the presence of two distinct soil units whereas ‘–’ represents related soils passing into one another with a smooth transition.

2.3 Example 1 – The Te Puke district

This soil survey of 33 300 ha was conducted between 1978 and 1982 for use in planning future development and for describing characteristics important in the intensive use of the soils.

Soil parent materials

The Te Puke district lies within the geologic region known as the Taupo Volcanic Zone, and most of the landforms and rocks as well as soil parent materials result from the deposition of volcanic ejecta or erosion of these materials and subsequent deposition. The Taupo Volcanic Zone has seen continued volcanism since the early Pleistocene (2 million years ago) (Houghton *et al*. 1995).

Figure 1. Locality map showing the Waikato district and the area of Te Puke survey plus map sheet boundaries

The survey area consists of four main physiographic units:

- Plateau margins, terraces and hills;
- Alluvial plains, and valley and gully floors;
- Coastal estuaries; and
- Coastal dunes.

Tephra deposits are the predominant parent material of soils occurring in the Te Puke and surrounding districts. A knowledge of their occurrence and distribution is useful for understanding the nature and distribution of the soils, for understanding responses of different crops, and for predicting the material likely to be encountered in recontouring and engineering works. Tephra is the name for all unconsolidated volcanic materials which, during an eruption, are transported from the crater through the air or by gaseous flow across the landscape. The term implies no particular grain size but may be divided into ash (less than 4 mm diameter), lapilli (4–32 mm diameter) and blocks (greater than 32 mm diameter).

Many different tephras have contributed to the soils of the district but the Kaharoa Ash has a dominant role. The relationship of soil horizons to Kaharoa Ash in Ohinepanea, Paengaroa and Te Puke series is shown in Figure 2.

Figure 2. Relationship of soil horizons to Kaharoa Ash in Ohinepanea, Paengaroa and Te Puke series

2.4 Te Puke district soil profile characteristics

The properties of the dominant soil orders are summarised below (after Cotching 1998). The properties described are the characteristics that give rise to different soil behaviour, responses to management and potential use, as well as for their classification into soil orders (Hewitt 1992).

Organic soils **-** Maketu, Ohineangaanga, Parton and Pukehina series

Organic soils are formed from thick deposits of peat and occur in low-lying basins where water tables were high for most of the year prior to artificial drainage. The organic soils have one or more layers of' volcanic ash in their profiles. The Maketu series has up to 1m of peat overlying Kaharoa Ash whereas the other organic soils (Parton, and Pukehina series) have a silt loam or fine sandy loam A horizon with the Kaharoa Ash within 0.3 m of the soil surface.

Gley soils **-** Raparapahoe and Wharere series

Gley soils occur in low-lying areas where the water table is high and they are characterised by greyish colours in mineral horizons with many reddish brown mottles. Profiles have a black silt loam A horizon with moderately developed nut structure (subangular blocky) overlying a very thin layer of Kaharoa Ash, which is light grey or white sand. The Kaharoa Ash overlies very thin layers of peat and/or massive silt of' alluvial origin. The massive structured lower subsoils are either brown silts or greenish grey sands.

Podzols **-** Kairua series

The podzols have a bleached E horizon overlying B horizons enriched in humus and iron that have formed under prehistoric kauri forests. Topsoils are loamy sands with weakly developed nut structure which overlie a loose sandy E horizon. Subsoils contain a reddish brown, very firm sandy iron/humus pan of variable thickness in which white spherical mottles are common. In profiles with thin pans, subsoils are yellow, loose sands. The podzols are formed on coastal dune sands with very thin deposits of volcanic ash at the surface.

Allophanic soils - Oropi, Otanewainuku and Te Puke series

Allophanic soils are formed in the older more weathered tephras although they have some of the younger Kaharoa Ash in the A horizon and also in the B horizon of the Oropi series. Due to greater weathering these soils contain more allophane clay than the Pumice soils. Consequently they have higher P-retention values and better water retention properties. Profiles have black sandy loam A horizons overlying dark yellowish brown sandy loam B horizons. Lower B horizons grade into silt loams and silty clay loams. A horizons have weakly developed nut and granular structure and upper B horizons weakly developed blocky or nut structure.

Pumice soils - Waipumuka, Pukeroa, Parawhenuamea, Paengaroa, Ohinepanea and Takarangi series

Pumice soils have properties dominated by pumiceous and glassy materials with a small content of allophanic clay, which typically contains allophane. They are derived from 0.25 m to 0.35 m or more vitric material, often overlying more weathered tephra. Vitric material is coarser than allophanic material, being younger and less weathered. Diagnostic horizons are dark yellowish brown, yellowish brown or very pale brown, loamy sand to sand B horizons formed in Kaharoa Ash, often with fine dense lapilli. These pumice soils are weakly to moderately leached.

Recent soils - Papamoa, Te Matai, Waiari, Manoeka and Kopuroa series

Recent soils include a wide range of profiles classified together on the basis of their youthfulness. Recent soils are formed on a variety of parent materials, which have accumulated by fluvial and/or aeolian processes. Parent materials range widely but commonly include wind-blown sand, alluvium, tephra, diatomaceous earth and peat. Profiles have topsoils distinguishable by colour but they have weakly developed soil structure. Textures range from sands to silts. The group includes gleyed and mottled soils with high and/or fluctuating water tables, and well drained soils. The diagnostic horizon is a dark brown topsoil that is typically buried by up to 0.50 m of fresh sediment. Soils derived from wind-blown sand (Papamoa series) undergo slow accumulation and consequently lack a buried topsoil.

Raw soils - Muriwai and Ohope series

Raw soils are a group of soils that lack distinctive topsoil development. In this survey they are formed from wind-blown sand (Ohope series) or marine sediments (Muriwai series). Very thin indistinct topsoils are the diagnostic feature of raw soils in the Te Puke area.

TABLE 1. Soils of the Te Puke district arranged physiographically

	map symbol
SOILS OF THE DUNES	
on foredunes	
excessively drained	
Ohope sand	Oh
on inland dunes	
excessively drained	
Papamoa loamy sand	P
Papamoa loamy sand, rolling phase	Pr
Papamoa loamy sand on yellowish brown sands	Py
Papamoa loamy sand on yellowish brown sands, rolling phase	Pry
Kairua loamy sand	K
Kairua loamy sand, rolling phase	Kr
in interdune swales	
poorly drained	
Kairua sandy loam, poorly drained variant	Kw, Ka
SOILS OF THE TIDAL FLATS .	
on coastal estuaries	
poorly drained	
Muriwa silt loam	Muz
Muriwai silt loam, reclaimed phase	MuR
Muriwai shallow silt loam	MuS, MW
Muriwai shallow silt loam, reclaimed phase	MuSR
SOILS OF THE FLOODPLAIN	
on levees	
well drained	
Manoeka sandy loam	M
Manoeka silt loam	Mz
on low levees and in backswamps	
poorly drained	
Te Matai silt loam	TM
Te Matai silt loam, with sandy subsoil	Tms, Tml
Te Matai shallow silt loam	Tmv
in abandoned stream channels	
excessively drained	
Kopuroa sandy loam	KO
Kopuroa silt loam	Koz
SOILS OF THE SWAMPLANDS	
on flat lowlands	
poorly drained	
Parton fine sandy loam	Pt
Parton silt loam	Ptz
Pukehina silt loam	Po, Pk
Pukehina silt loam, woody phase	Pow
Pukehina silt loam with sandy subsoil	PoS
Raparapahoe silt loam	Ra
Raparapahoe silt loam, iron rich phase	Raf

Raparapahoe silt loam with sandy subsoil	RaS
Raparapahoe silt accumulation phase	Hz
Raparapahoe sand accumulation phase	Hs
Waiari silt loam	W
Waiari silt loam, woody phase	Rad
Ohineangaanga silt loam	Oa
Wharere silt loam	Wh, OaS
very poorly drained	
Maketu peat	Mk, Ap
Maketu silt loam	Mkv, Mkz
SOILS OF THE PLATEAU MARGINS, TERRACES AND HILLS	
on flat to gently undulating and rolling tops	
somewhat excessively drained	
Ohinepanea loamy sand	Ohi
Ohinepanea loamy sand, disturbed phase	Ohiv
Paengaroa sandy loam	Pg
Paengaroa sandy loam with sandy subsoil	Pgp
Paengaroa loamy sand	Pgc
Paengaroa loamy sand, rolling phase	PgcR
well drained	
Te Puke sandy loam	Tk
Te Puke sandy loam, rolling phase	Tkr
Te Puke sandy loam with sandy subsoil	Tkp
Te Puke sandy loam with sandy subsoil, rolling phase	Tkpr
Te Puke brown sandy loam	Tkb
Te Puke brown sandy loam, rolling phase	Tkbr
Oropi coarse sandy loam	Tkc
moderately well drained	
Te Puke sandy loam, mottled variant	Tkm
Waipumuka sandy loam, yellowish brown subsoil phas	Wpb
imperfectly drained	
Waipumuka sandy loam	Wp
on strongly sloping gully sides	
well drained	
Te Puke sandy loam, strongly sloping phase	Tks
on gully floors	
somewhat excessively drained	
Parawhenuamea sandy loam	Pa
Pukeroa sandy loam	Pu
Pukeroa loamy sand	PuS
well drained	
Takarangi silt loam	Tg
Takarangi sandy loam	Tgs
imperfectly drained	
Pukeroa sandy loam, mottled variant	Pum
on hill slopes, well drained	
Ohinepanea hill soils	OhiH
Te Puke hill soils	TkH
on steep slopes, well drained	
Otanewainuku steepland soils	OS

2.5 Example 2 - The Pet and Guide catchments

The Pet and Guide River catchments lie 14 - 32 km south of Burnie in north west Tasmania (Figure 3) with the landscape formed by river incision giving rise to steep-sided incised valleys between flatter intervening plateaux. Some of the steep valley sides have slumped to produce a step-like appearance. The area experiences a temperate marine climate with mild wet winters and cool dry summers. Beef and dairy production are the predominant land uses in the Pet catchment with commercial forestry predominating in the Guide catchment. The two catchments are the sources of water supply for Burnie City. The survey was carried out as part of a catchment management plan to ensure sustainable use of soils, stream and water resources. Soil parent materials are dominated by Tertiary age basalts (25–60 million years) overlying Devonian granites and Permian mudstones (Baillie *et al*. 1986). The basalts were erupted as lava sheets covering nearly all of the catchments. The depth of weathering in the basalt decreases from the warmer coastal areas where soils may be 2-3 m deep, to only 0.6-0.7 m deep in the Guide catchment.

2.6 Pet and Guide soil profile classes and mapping units

Soils developed on basalt predominate with two main soil associations mapped. All of the basaltic soils were classified as Ferrosols, which are characteristically strongly structured, acidic and have high organic carbon contents (7–12%).

Yolla soil profile class occurs at lower altitudes (<400m) and has a dark brown clay loam topsoil over a brown, or bright brown, friable clay on weathered basalt at approximately 1.2 m depth. Three phases were mapped:

- Yolla clay loam;
- Yolla stony phase; and
- Yolla steepland soils.

Oonah soil profile class occurs at higher altitudes (>400 m), has a very dark brown clay loam topsoil with a few stones over brown clay on weathered basalt (which looks like oatmeal due to the presence of white specks of possibly gibbsite) at 0.6–0.7 m depth.

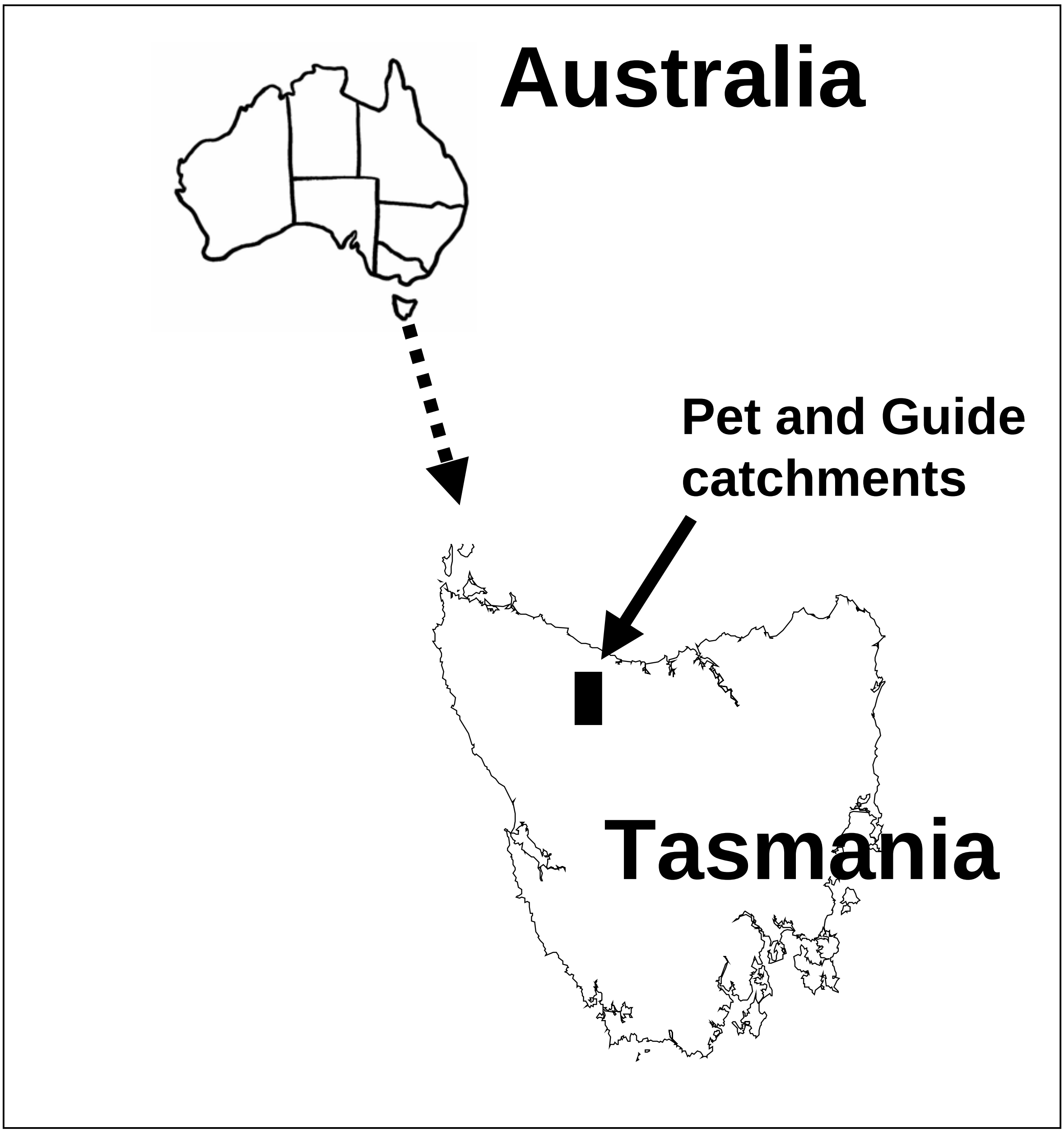


Figure 3. Locality map showing area of the Pet and Guide catchments

Mapped phases were:

- Oonah clay loam;
- Oonah bouldery clay loam; and
- Oonah steepland soils.

Takone soil profile class has a dark greyish brown clay loam to clay topsoil on massive clay and occurs in drainage depressions. This soil is imperfectly drained with reddish brown or reddish yellow mottles and manganese segregations in the B2 horizon. Takone soils are extremely acidic (pH 4.2–4.7).

Slump complex areas were mapped in both catchments. These areas have soils similar to Yolla or Oonah soils with shallow A horizons on steep back slopes and deeper A horizons on flatter accumulation sites. On benches and in hollows the soil type depends on the degree of internal drainage. On free draining sites, Yolla or Oonah soils occur, whilst on sites with impeded drainage, imperfectly to poorly drained Takone soils occur.

Natone soil profile class has a dark brown loam topsoil over strong brown, massive gritty clay on weathered granite. The parent materials are mixed basalt and underlying granite.

Hellyer soil profile class has brown medium clays with weakly developed structure formed on Permian or Precambrian age shale.

2.7 Information provided for intensive land use decision making and management

2.7.1 Soil chemical properties

The chemical analyses carried out for the Te Puke survey were made for characterisation in order to understand soil processes and to aid in classification of the soils. Because samples were taken from pits rather than being composite topsoil samples, the analyses do not represent the fertility of a particular paddock and so can not be used directly to formulate fertiliser recommendations. However, the data do provide baseline information on nutrient storage capacity (cation exchange capacity, CEC) and overall nutrient status of the soils (base saturation, %BS). The analyses were carried out according to methods described by Blakemore *et al*. (1981).

The differing chemical properties between and within the soils of the Te Puke district result mainly from the layered nature of the parent materials. These comprise air-fall rhyolitic tephra, alluvium from rhyolitic tephra, peat, estuarine sand and a recent contribution from Tarawera ash and Rotomahana mud in many of the topsoils. The majority of the soils analysed are formed from rhyolitic tephra of various ages and methods of deposition. These soils have some similarities, related to the predominance of silica in rhyolite, and paucity of Mg and K minerals.

Soils of the coastal dunes

The soils of the coastal dunes comprise a chrono-sequence as the sand dunes increase in age with increasing distance inland. An increase in leaching with age is shown by the reducing pH and base saturation levels (%BS) from the Ohope soil through to the Kairua soil. The increasing age of these relatively young soils is also demonstrated by the increasing amount of organic matter in the topsoils and throughout the profile. Inorganic phosphorus shows a decrease with soil age while organic phosphorus increases, particularly in the topsoils.

The Kairua soil is podzolised, which results from a soil process associated with acid leaching where sesquioxides (mainly Al and Fe compounds) and organic matter are leached out of the topsoil and accumulate to form a Bs horizon as shown by high oxalate-extractable and pyrophosphate-extractable Fe and Al. The accumulated sesquioxides form mineral-organic complexes, which have large surface areas and high charge density giving rise to high activity, as shown by higher P retention, CEC and exchange acidity than the other soils.

The nutrient status of the soils of the dunes is generally low, with low levels of acid-soluble phosphorus, exchangeable and reserve K and reserve Mg in all three soils with K probably being plant limiting.

Soils of the estuarine flats

Adequate soil drainage has allowed leaching of excess salts from the Muriwai soils, as demonstrated by the fact that there is only a small excess of exchangeable bases over CEC in the lower part of the profile. Very low pH values in the upper horizons are a result of sulfides present in the marine sediments oxidising to sulfuric acid as the soil dries when artificially drained. In the permanently reduced zone (below about 0.80 m) pH levels are high. The very low A horizon pH leads to high levels of exchangeable Al which are likely to be toxic to many plants.

Soils of the river floodplains and former swamplands

Analyses of the Manoeka silt loam and Te Matai silt loam are characterised by the layering of the flood-deposited parent materials. Properties which reflect this include organic matter, phosphorus and exchangeable bases all of which show irregular distribution down the profile. The Te Matai soil is not as well drained as the Manoeka soil, and it is more leached and acid. This probably is the result of more frequent flooding and rejuvenation of the Manoeka soil, raising the content of exchangeable bases and hence the %BS and pH.

The Parton, Pukehina and Wharere soils have peaty layers with very high levels of organic matter, while the Raparapahoe and Waiari soils have lower, but still high levels. Organic layers in the soils give rise to very high CEC values. The very low organic matter content of the Kaharoa ash layer in each of the soils demonstrates the lack of biological mixing of horizons in these soils. This is probably a result of low pH, saturated conditions in winter and unfavourable sandy particle size for earthworms in the Kaharoa ash.

Soils of plateau margins, terraces and hills

The Kaharoa ash parent material in near surface horizons gives rise to lower P retention and oxalate-Al and Si levels than in underlying older ash layers that have greater allophane contents. The three soils have similar pH levels throughout the profile ranging from moderately to slightly acid. With the exception of the topsoils, base saturation is low, which would normally indicate strong leaching. In these soils however, the effect of variable charge on the CEC measured at pH 7 means that the CEC levels are overestimated thus reducing base status to values that do not indicate the true state of leaching. The soils have generally low levels of exchangeable bases, which are related more to the siliceous nature of the rhyolitic parent material than to leaching of exchangeable cations.

The Takarangi soil has a thick accumulation of Tarawera ash and Rotomahana mud. The basaltic nature of these materials is reflected in the higher levels of Mg and K. The low levels of Mg and K in the soils derived from rhyolitic tephra suggest that deficiencies could become a problem under high production systems unless compensated for by the addition of appropriate fertilisers.

2.7.2 Soil physical properties

The use and management of soils is frequently limited by problems of soil water, either too little or too much. Water storage capacity and drainage of a soil is largely determined by soil physical properties. These physical properties can readily deteriorate through mismanagement but they are much harder to ameliorate than chemical fertility. Obtaining chemical analyses for use in calculating fertiliser requirements is now a routine operation and carried out with relative ease. However, determination of soil physical properties and soil water storage characteristics is not routine and so these analyses were conducted to provide a representative set of physical data for soils mapped in Te Puke District. Pore size distributions, water storage characteristics, and particle size analyses were determined on all the major soil types occurring in the Te Puke district. These data were presented in a pictorial manner for each set of results (Figure 4) allowing for visual recognition of the influence of parent materials/horizons on rooting depth. The pore size distributions allowed for calculation of available water storage capacities for each soil (Table 2) which have been invaluable for planning irrigation scheduling in the district.

Soils developed in volcanic ash are sandy, free draining, due to considerable volumes of large pores, have high to very high available water storage capacities (10-1500 kPa) and have no barriers to root growth. Non-plant available water storage capacity (>1500 kPa) is greater in older tephras which have greater clay contents than younger tephras (Cotching 1998).

The available water storage capacity of Ohinepanea soils is less than most other Yellow-brown Pumice soils because these soils are at the finer textured end of Pumice soils (Yellow-brown pumice). The available water storage capacity of Te Puke soils is greater than most other Allophanic soils (Yellow-brown loams) as the Te Puke soils are more coarsely textured than other Allophanic soils. All volcanic ash soils in the Te Puke district retain a significant proportion (one third - two thirds) of available water storage capacity in the readily available range (10–100 kPa) with actual amounts classed as very high (Cotching 1998).

Soils developed in wind-blown coastal sand have large air capacities and low available and non-plant available water capacities. Volcanic ash in surface horizons raises profile water holding capacities slightly. Soils on low-lying former swamplands and floodplains have restricted rooting depths due to high ground water and contrasting textures and pore-size distributions between horizons which inhibit drainage. Profile available water capacities of these poorly drained soils are low to medium.

Waterlogging of the surface layers of soils on the lowlands often occurs and gives rise to the mottles present in the topsoils. This waterlogging is often due to the contrasting nature of materials across horizon boundaries, at the top, between the two layers of, and at the base of the Kaharoa Ash.

TABLE 2. Available water storage capacities of Te Puke district soils (Cotching 1998)

Soil	Sampling Site NZMSlGR	Rooting depth (cm)*	Available water storage in root zone (mm)	Available water class	Readily available water storage in root zone (mm)
Measured values					
Papamoa loamy sand	N58/743584	100	75	low	28
Kairua loamy sand	N58/719587	100	135	medium	69
Ohinepanea loamy sand, disturbed phase	N68/985426	100	197	high	112
Ohinepanea loamy sand, mixed variant	N68/042418	100	181	high	97
Pukeroa sandy loam	N67/878438	100	214	very high	75
Parawhenuamea sandy loam	N67/791431	100	212	very high	65
Oropi coarse sandy loam	N67/761375	100	215	very high	87
Paengaroa sandy loam	N67/878437	100	220	very high	80
Waipumuka sandy loam	N67/895483	80	170	high	61
Te Puke sandy loam	N67/776474	100	238	very high	87
Te Puke sandy loam with sandy subsoil	N67/796422	100	209	very high	130
Wharere silt loam	N68/962451	20	59	low	18
Parton fine sandy loam	N58/792528	42	105	medium	35
Pukehina silt loam	N68/971431	19	60	low	14
Raparapahoe silt loam	N67/856497	28	70	low	18
Ohope sand	N58/745585	100	39	very low	8
Manoeka silt loam	N67/766484	100	196	high	88
Takarangi silt loam	N67/784394	100	247	very high	79
Te Matai silt loam	N67/823469	60	212	very high	42
Waiari silt loam	N67/820475	32	118	medium	21
Muriwai silt loam	N68/944475	19	76	low	13
Estimated values					
Otanewainuku steepland soils**	-	80	175	high	75
Ohineangaanga silt loam	-	28	70	low	18
Maketu peat	-	-	-	-	-
Kopuroa sandy loam**	-	50	30	very low	8

* derived from field observations of profile morphology

** estimated using method of Wilson and Giltrap (1982)

Figure 4. Physical characteristics of Raparapahoe silt loam

Chapter 3 – Interpretation of inherent soil property information

3.1 Chapter outline

Chapter three presents information on how soil survey information can be interpreted for use in land and water management decision making. The Te Puke district and the Pet and Guide catchment studies are used to provide examples. The information on the spatial distribution of different soils and their inherent properties is useful to determine how land can be used without destroying its long term potential for sustainable agricultural production. The soil information presented is factual and provides the community with an essential ingredient for rational resource evaluation and planning decisions. The soil information provided in the two examples has been critical in land management decision making. The information has provided information for planning rural and residential subdivision, land drainage, water management for irrigation design and scheduling, the potential for erosion and impact on stream water quality, and soil fertility issues such as acidity and phosphorus fixation. Soil resources are finite and so reliable soil resource surveys and their interpretation will become more important as we seek more efficient use of scarce resources to increase or even maintain productivity.

3.2 Te Puke district, Bay of Plenty, New Zealand

The Maoris were the first people to cultivate horticultural crops in the Te Puke district (mainly kumara – the Polynesian sweet potato). Although there were market gardens and very small fruit orchards operating in the early 1900s, the major horticultural developments have occurred since 1945. Up to 1965 the main commercial fruit crops were citrus, tamarillo, and passionfruit orchards, but since then kiwifruit has become the dominant commercial activity. During the 1950s and 1960s fruit growing spread slowly in areas south of Te Puke. Since 1970 fruit growing has expanded further east onto coarser Paengaroa and Ohinepanea soils which respond well to irrigation. Approximately 50 ha of kiwifruit have been planted on low-lying, poorly drained Parton, Pukehina and Raparapahoe soils where drainage control and irrigation is essential if crops are to be grown successfully. There are few orchards planted higher than 300 m above sea level. At this altitude, increased frost risk and higher rainfall make successful production more difficult.

3.2.1 Soil limitations for land use

Many plants have particular soil requirements for optimum growth. The soils of the Te Puke district differ to varying degrees in their suitability for a wide range of uses. The soils were classified for pastoral, cropping, horticultural, forestry and food production uses. These classifications can be used in making land-use planning decisions, but it should be noted that just because an area of land is classed as best suited for a particular use, e.g., forestry, this does not automatically mean that the best economic or social use of that land is for forestry. The actual choice between alternative uses depends on other factors, either socio-economic and/or political.

Pastoral Use. The pastoral use classification used in Te Puke followed that of Gibbs (1968). This classification considers nutrient requirements of pastures, productivity by sheep and/or cattle and generalised soil conservation aspects such as erodibility. The classification is limited to the consideration of pasture productivity. However, modern pasture production incorporates aspects of growing supplementary feed (eg. turnips), disposal of wastes (eg. dairy shed effluent) and stocking rates are higher than previously, which raises the potential for degradation. Consequently this classification has limited application in the modern pastoral farming context (Cutler 1977). More specific information on stock carrying capacity and recommended fertilisers is included in the survey report.

Most of the soils of the Te Puke district (89%, 29640 ha) have slight to moderate limitations for pastoral use. Slight limitations such as poor natural drainage occur on low-lying soils, but potential carrying capacities are still relatively high on these soils at 18–22 stock units/ha. Soils with moderate limitations to pastoral use have limitations of either poor drainage or droughtiness.

Cropping Use. The cropping-use classification used in Te Puke followed that of Cutler (1968) and applies to cash cropping. This classification is of value to show the limitations to broad acre cropping as a whole. It does not provide information about specific crops or specific soil properties. For example there is no differentiation between soil requirements for different crops so that a stone content limitation for potato production is not differentiated from a microtopgraphy limitation for bean harvesting.

Class 1 soils with minimal limitations for cropping cover 24% (8147 ha) of the survey area. Slight limitations include high nutrient requirements and imperfect drainage. Class lA soils are prone to wind erosion when cultivated. Soils on flat land with moderate to severe limitations for croppinq are either too wet or drought prone.

Horticultural Use. The classification followed that of Cowie (1974) and is a generalised scheme only. The suitability of different soils for horticultural use will vary according to the particular crop grown. There is a general lack of data on the relationship between soil characteristics and particular crops which means that reliable predictions about the success or otherwise of any particular horticultural crop is problematic. Many horticultural crops are of high commercial value which means that financial investment in ameliorating soil limitations to production becomes viable. This has led to the development of the interpretations for horticulture described in section 3.2.2.

Class 1 soils for horticultural use occupy 25% (8400 ha) of the survey area. These soils are all derived from air-fall volcanic ash and are deep, friable and well drained with good aeration and moisture characteristics. Class 2 soils (15% of survey area) are drought prone and require irrigation for successful plant growth in all seasons. Those soils classed as 2A (32% of survey area) have moderate limitations of imperfect to poor drainage and, as shown in Table 3, require a major management input for water table control. Severe limitations to horticultural use include very poor drainage, excessive droughtiness and tidal flooding.

Forestry Use. The classification of soil limitations for forestry used in Te Puke followed that given by Cutler (1968) and is for commercial forestry and farm woodlots, generally under exotic species. It is a generalised classification suitable for use in regional planning but with limited application at the farm level. More specific forest productivity data is included in the survey in the form of a site index which is based on the standard height of the 250 largest trees per hectare at 20 years old. Other forestry use interpretation schemes have been developed with information on specific soil and site limitations to forestry for use in areas where forestry is a predominant land use (Adams and Mew 1975, Laffan 1994)

Soils derived from tephra and lower lying soils of the Te Puke district are generally too valuable, too wet, or too saline to be considered for commercial forestry. However, the adjacent hill country, steep land and gully sides could be considered for woodlots as they have few limitations to forestry use. The sand dunes at Papamoa have moderate limitations to forestry use, due to droughtiness. Growth rates of *Pinus radiata* on these sandy soils are not as high as they are in some parts of New Zealand, but these soils are considered to be well suited to use as seed orchard sites for *Pinus radiata*.

Urban Use. The urban use classification used in Te Puke is a generalised scheme only and followed that of Cowie (1974). The classification lacks any specific information on engineering properties of soil that are relevant in the urban context. Information on some soil properties useful to engineers (eg. bulk density) is included in the section on soil physical properties but no attempt was made to evaluate this information for limitations to foundations for buildings, suitability for septic tanks or stability under building loads.

The soils best suited for urban use are those occurring on sand dunes at Papamoa or on plateaux margins and terraces. The soils on the sand dunes (Papamoa and Kairua soils), which cover 2038 ha, are of low value for food production and have been appropriately zoned for future urban use by the Tauranga County Council. Those on the plateaux margins and terraces are of high value for food production, so careful consideration should be given before urban subdivision is allowed on these soils, particularly around Te Puke township.

Value for Food Production. The classification of soils according to their value for food production used in Te Puke follows that of Cowie (1974) and is in the terms of the Town and Country Planning Act 1977. Soils of Class lA (26%, 8563 ha) are deep, well-drained, friable soils with stable soil structure and are generally on flat to easy rolling land. These physical properties provide excellent soil conditions for plant growth. The nutrient requirements are readily corrected by fertilisation, details of which depend on the particular plant grown. These soils can be cultivated at most times of the year. They are very versatile and can be used for a wide range of horticultural crops. The soils are also suitable for field crops and intensive dairying for factory or town milk supply.

Soils of Class lB (1.3%, 433 ha) are generally on flat to easy rolling land (most slopes less than 5^o) and commonly have a limitation of imperfect to poor natural drainage. This limits the choice of crops which can be grown, affects yields in a wet year, and limits the period during which the soil can be cultivated. This limitation can, however, be overcome by artificial drainage, although these soils will still be slightly less versatile than those of Class lA.

Soils of Class 2 (53%, 17,500 ha) are generally on flat to rolling land and have limitations of poor drainage and poor physical properties or of stoniness and droughtiness that restrict the kind and amount of use of the soils. Some of these soils may give high food production, but with less reliability than the soils of Class 1.

Soils of Class 3 (20%, 6,660 ha) have limitations which may include frequent flooding, stoniness, droughtiness, slope or susceptibility to erosion. These limitations would be difficult to correct and these soils are considered unsuitable for food production.

3.2.2 Soil management for intensive horticultural use

The suitability of land for the growing of specific crops has historically been a matter of producing high yields with relatively low inputs. However, with increasing financial returns from horticultural crops it has become apparent that land-owners are prepared to spend an increasing amount of both time and money on managing soil and landscape properties in order to produce high crop yields on soils which are not innately suited to those crops. This investment of time and money into soils is considered justified only if crop yields are sustainable in the long term. The level of profitability from a crop remains critical when soil management inputs are high. Land owners should consider the long-term level of profitability of a particular crop before embarking on a soil management system with a high input, as it is often physically very difficult to change crop or land use once an horticultural operation has been established.

Table 3 presents the soil and landscape properties that need to be managed for intensive horticulture, together with the degree of management input required (minimum, moderate or major) for some of the soils occurring in the Te Puke district. Specific management actions required to manage the soil and landscape properties are described in the soil survey report. This approach to interpretation of inherent soil properties follows principles outlined in the Food and Agriculture Organisation's 'Framework for land evaluation' (1976) and has been developed due to the high value of the crops grown. It must be noted that overriding all of these soil and landscape properties is a consideration of the suitability of the climate for growing a particular crop in a specific locality. Management of the local micro-climate by the provision of shelterbelts for protection of crops from wind damage is considered essential to the success of any horticultural enterprise in the Bay of Plenty.

The degree of management input described in Table 3 is only a qualitative estimate and is based upon field observations. The management input required must ensure horticultural use on a sustained basis without progressive or severe degradation of soil properties. It is acknowledged that some crops may be grown successfully for some years on certain soils without the degree of management indicated in Table 3. However, this will probably be at the expense of the continued long-term, highly productive use of these soils. It may be possible for economists to assign monetary values to the different levels of management input, but cost estimates will need to be continually revised due to the development and use of new technologies to overcome the soil problems.

Included in Table 3 are soils which are considered to be unsuitable for intensive horticultural use, and the soil and landscape properties which make those soils unsuitable. The soil and landscape properties considered in this section are mainly physical ones, because these are considered to be of far greater importance than chemical properties. Chemical deficiencies can normally be corrected with appropriate fertilisers, but physical properties are harder to manipulate and change.

3.2.3 Recontouring land

The high cost of horticultural land in the Te Puke district resulted in the recontouring of land that is too steep for easy crop management. Recontouring involves the reshaping of the landscape or the removal of hills and knolls to fill in gullies and swamps using large earthmoving machinery. The prime motivation for recontouring land is the potential profit to be made from growing horticultural crops. Considerable areas of the Bay of Plenty have been recontoured because the volcanic ash soils are relatively easy to manipulate with large earthmoving machinery. Some land developers and entrepreneurs have recontoured land and sold it as being eminently suitable for the growing of horticultural crops. Unfortunately much of this recontoured land is far from being suitable for the growing of horticultural crops, but this fact is often not realised by land buyers and may not become apparent for several years after crops have been planted. This is because soil conditions may progressively deteriorate, or plants may not show signs of stress until they are older and considerable seasonal variations of climate have been experienced. This approach by land developers became of concern to the Tauranga County Council who exercised a degree of control by introducing ordinances for determining the suitability of land for horticulture when that land is to be subdivided. A Technical Working Group was set up by the Council following concerns raised during the course of this soil survey and a set of guidelines for recontouring has been published (Orbell, 1987).

Alternatives to recontouring land should be considered on land with gradients too steep for easy horticultural management because poor plant growth and low crop yields have been observed on many recontoured areas.

Table 3. Soil properties in the Te Puke district requiring management for intensive horticultural use

Soil type / Management Input limitations	Map symbol	Hwt	Fwt	Sd	Rd	Sud	Lbc	Pta	F	S	Lss	E	Other
		Soil property*											
Minimum Input													
Te Puke sandy loam	TP												
Moderate Input													
Manoeka silt loam	Mnz			X					X				
Paengaroa loamy sand	Pgl			X									
Paengaroa loamy sand, rolling phase	PglR			X						X	X		
Pukeroa loamy sand	Pul			X								X	
Waipumuka sandy loam	Wp		X	X									
Major Input													
Kairua loamy aand	Ki			X							X		
Kopuroa sandy loam	Ka	X	X	X								X	
Muriwai silt loam, reclaimed phase	Mun	X	X		X						X		salinity
Ohineangaanga silt loam	Wiq	X	X	X	X			X	X				
Papamoa loamy sand	Pp			X							X		
Papamoa loamy sand, rolling phase	PpR			X						X	X		
Parton fine sandy loam	Pt	X	X	X	X	X	X	X			X		
Pukehina silt loam	Ph	X	X	X	X	X	X	X			X		
Pukehina silt loam, woody phase	Phq	X	X	X	X	X	X	X			X		
Raparapahoe silt loam	Rp	X	X	X	X	X	X	X	X		X		stumps
Te Matai slt loam	TM	X	X					X	X				
Waiari ailt loam	Wi	X	X		X			X	X				
Waiari ailt loam, woody phase	Wiq	X	X	X	X	X	X	X		X			stumps
Wharere silt loam	Oas-Wh	X	X	X	X			X					
Unsuitsble Soils													
Maketu peat	Mk	X			X	X	X	X			X		
Muriwai silt loam	Mu	X			X			X	X		X		salinity
Ohope sand	Oe			X						X	X		low organic matter
Otanewainuku steepland soils	Os									X	X		
Takarangi silt loam	Tg									X		X	
Te Puke hill soils	TPH									X	X		

* Hwt - High water table   Fwt - Fluctuating water table   Sd - Summer droughtiness   Rs - Restricted drainage   Sud - Shrink upon drainage   Lbc - low bearing capacity
Pta - Poor trafficability   F - Flooding Drainage   S – slope   Lss - Lack of structural stability   E – Erodibility   Lae - limited areal extent

3.3 Pet and Guide catchments, north west Tasmania, Australia

Interpretation for land use in the Pet and Guide catchments was made using the Land Capability Classification of Tasmania (Noble 1992). Land capability may be defined as a rating of the ability of land to sustain a range of land uses without degradation of the land resource. It takes into account the physical nature of the land (geology, soils, slope) plus other factors (climate, erosion hazard, land management) which determine how that land can be used without damaging its long term potential for sustainable agricultural production. Land capability does not take into account the economics of agricultural production, distance from markets, or social or political factors. The system in Tasmania gives an indication of the inherent capability of the land for broad scale grazing and agricultural use. It does not evaluate land for growing a particular crop, rank the value of any agricultural land use above another, or incorporate capability for forestry use.

There are three levels to the land capability classification:

Class	Ranks land from best to worst based on the general degree of limitations to use
Subclass	Identifies the dominant kind of limitation
Unit	Groups land within each subclass with similar management and conservation requirements.

Class 3 land on Yolla clay loams was mapped in the Pet catchment (16% of area mapped) on the basis that a variety of crops are being grown in the area even with the shortened growing season at elevations up to 380m and moderately high rainfall (1248 mm annually). With careful management this land could be cropped three to five years in ten although frequent periods under pasture are recommended to prevent excessive soil structure degradation.

Class 4 land is the most extensive in both the Pet (51%) and Guide (69%) catchments with the major limitation to agricultural use being climate. Nearly all of the Guide catchment lies above 400m altitude resulting in cool temperatures and a relatively short growing season. Yolla and Oonah clay loams predominate in this class with minor areas of more poorly drained Takone soils (4w) in depressions. Three different slope classes were identified (0–5%, 6–12%, 13–18%). The land is not subject to erosion when under perennial pasture or mature forest but is subject to sheet and rill erosion when cultivated. It was recommended that harvesting of crops on these areas should occur before the soils become too wet as soil structure damage may then occur (Cotching 1995). Cropping on steeper slopes should incorporate minimum tillage techniques, cultivation on the contour, adoption of soil erosion control methods such as mulched rip lines and growing cover crops.

Class 5 land was mapped in the Guide catchment in areas above 500m altitude (5c) with a cool climate and infrequent snow falls. Class 5 land had either slopes of 15-30% (5e), were slump complex areas (5e), were stony (5s), or had a wetness limitation (5w). It was recommended that steep slopes and slump complex areas not be cultivated for crop production due to the high risk of erosion. Cultivating the stony soils could result in damage to equipment and/or low productivity levels and so stony soil were not considered suitable for crop production.

Class 6 land occupied a minor part of the Pet (10%) and Guide (8%) catchments. Limitations of steepness with slopes over 30% (6e), presence of boulders (6s), or prolonged wetness (6w) were mapped. Poorly drained areas may require fencing to exclude stock due to potential pugging of soils leading to fouling of waterways. Stock access may need to be restricted on steep slopes to minimise any erosion.

The land use in the Pet and Guide catchments was considered to be near optimum at the time of survey. There was little evidence of degradation caused by poor management practices apart from trampling by stock around gateways and water points. However, there was some concern as to the potential impacts resulting from any change of land use to more intensive cropping and to the effects of forest clearance at maturation.

The land capability classification allowed for the partitioning of the landscape into areas with similar limitations to overall agricultural use. However, the method used did not record land and soil attributes for individual land parcels and so the information and maps produced are not as useful as those produced using the unique mapping area technique adopted by (Eldridge 2000) for the area immediately to the north of the Pet and Guide catchment survey. The recording of information for each land parcel allows for future interpretations of raw data to be undertaken to determine suitability for specific uses rather than implied interpretations by experts of the land capability maps.

Chapter 4 – Effects of intensive agriculture on soil organic matter

4.1 Chapter outline

Chapter four presents information on the inherently different levels of soil carbon between different soil orders in Tasmania. The dynamic nature of soil organic matter is discussed with a summary of the effects of intensive agriculture on five soil types in Tasmania and two soil types in New Zealand. The relationships between organic matter and other soil properties are discussed and results of the correlation of soil carbon to crop yield in Tasmanian soils are presented.

4.2 Inherent soil differences

The amount of organic matter in a soil depends on a range of factors, and reflects the balance between accumulation and breakdown. The factors influencing soil organic matter content are climate, soil type (clay content), vegetation, topography, and management (length of fallows and tillage). Soils high in clay content tend to have greater organic carbon contents (Christensen and Johnson 1997). Under Tasmanian conditions, average values of organic matter (as measured by soil carbon concentration) for different soil orders have been found (Figure 5).

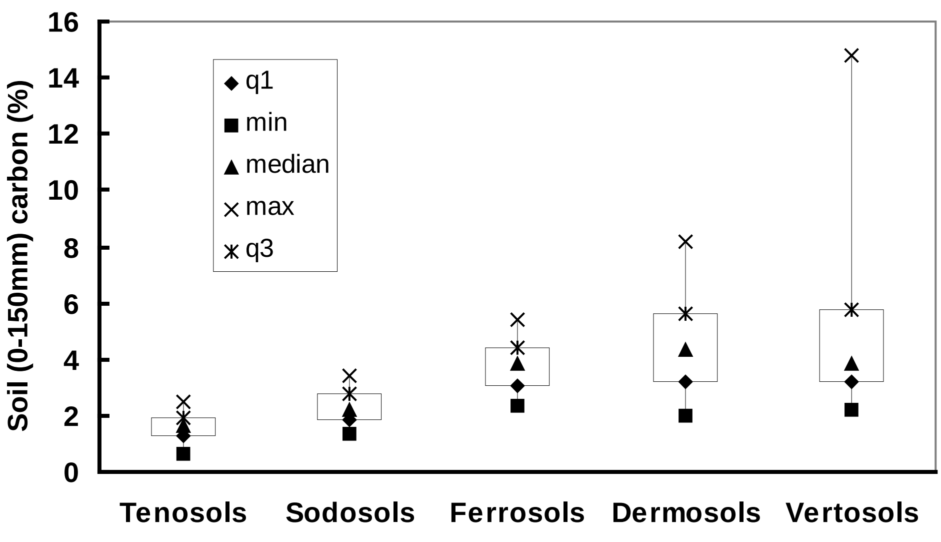


Figure 5. Organic carbon concentrations in Tasmanian soils used for agriculture.
Data sources: Sparrow *et al.* 1999; Cotching *et al*. 2001; 2002a; 2002b; 2002d.

Organic carbon levels in some Tasmanian soils are greater than those found in similar soils in other states of Australia. For example Tasmanian Vertosols have organic carbon concentrations of 2.5–7.7% whereas those in Queensland have been reported as 0.8–2.2% (Dalal and Mayer 1986), and in New South Wales as 0.4–1.3% (Chan 1997). Organic carbon concentrations in the top 100 mm in Queensland Ferrosols for continuously cropped sites was 1.5 –2.0% (Bell *et al.* 1995) compared to those in Tasmania of 2.5–4.3% in the top 150 mm (Table 4). Northern Tasmania's water balance allows for greater net primary productivity than in other states giving rise to greater organic carbon inputs. Lower temperatures could also contribute to greater organic carbon levels than in other States, as organic matter decomposition is slower in temperate than in subtropical regions (Dalal and Chan 2001). The levels of organic carbon in Tasmanian Sodosols and Tenosols were found to be in a similar range to other mainland soils under similar rainfall of 500-800 mm/year (Spain *et al.* 1983).

4.3 Dynamic soil organic matter

Organic matter is widely regarded as a vital component of a healthy soil. It is an important part of soil physical, chemical and biological fertility. The maintenance of organic matter is critical in the long-term management of soils because of its contribution to the cation exchange capacity, as well as to soil physical properties. For example, approximately 70% of the soil cation exchange capacity in Ferrosols can be accounted for by an organic matter content of 7% (Moody 1994). Thus, organic materials are not only the major reservoir of nitrogen, phosphorus and sulphur but they retain nutrients against leaching.

Changing from a pasture system to cropping usually results in less carbon being produced. More carbon is removed in crop yield and carbon is also lost by oxidation following tillage and so less carbon is returned to the soil. Sparrow *et al.* (1999) showed that soil carbon concentration of Red Ferrosols decreases with increasing years of cultivation (Figure 6). The data in Figure 6 are not sufficiently long term to show a new equilibrium (Baldock and Skjemstad 1999; Dalal and Chan 2001) which can take 50–100 years, although most of the change usually happens in the first 10–20 years. In practice, the almost constant readjustment by farmers in Tasmania of their crop rotations means that equilibria may hardly ever be reached before the cropping system changes. On top of this, weather conditions can be drier or wetter than average for extended periods (eg. 5-10 years), and this variation in rainfall can also prevent soils from reaching a steady state.

Similar reductions in soil carbon levels have been found in other soil types in Tasmania as shown in Table 4 (Cotching *et al.* 2001, 2002) and when management has changed from perennial systems to annual cropping in other parts of Australia (Dalal and Mayer 1986; Moody 1994; Skjemstad *et al*. 1994; Oades 1995; Janzen *et al*. 1997; Young *et al*. 2005).

In most of the soil types studied in Tasmania and New Zealand the greatest change in organic carbon was found in the near surface soil (0-75mm) with minimal change in the 75-150 mm layer. This finding concurs with research by Chan and Mead (1988).

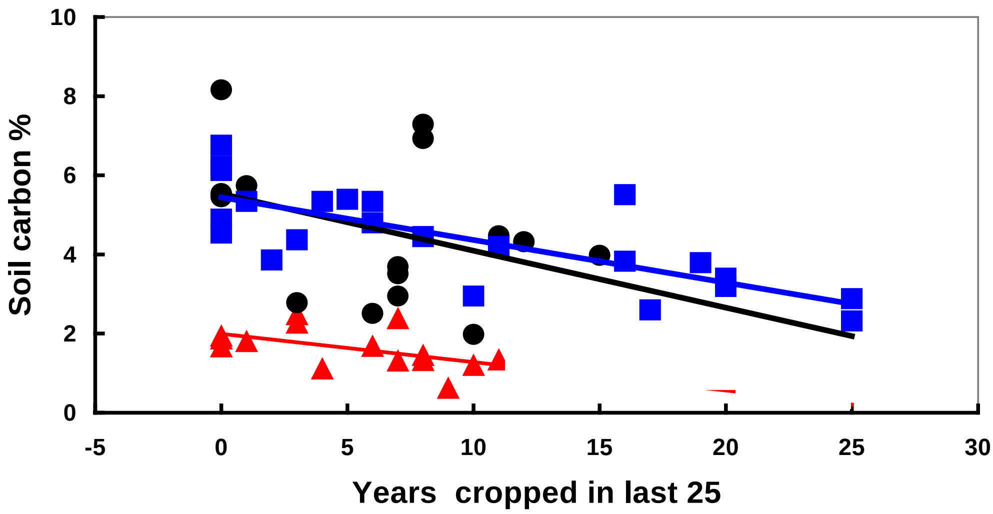


Figure 6. **Carbon change with increasing cropping in Tasmanian soils** (squares = Ferrosols (r = -0.77, *P*<0.001); circles = Dermosols (r = -0.63, P<0.05); triangles = Tenosols (r = -0.73, *P*<0.01)). Data sources: Sparrow *et al.* 1999; Cotching *et al*. 2002a; 2002b.

Table 4. **Organic carbon concentrations (%) in Tasmanian soils subject to different agricultural management**

(All tests were LECO furnace except for Ferrosol which were Walkley-Black and are likely to be approximately 80% of that determined by LECO furnace (Rayment and Higginson 1992))

Soil (depth)	Pasture	Intermittent cropping	Frequent cropping
Ferrosol (0-150 mm)			
Average	6.4	4.9	3.8
Range	4.5 – 6.8	2.6 – 5.4	2.3 – 4.5
Dermosol (0-75 mm)			
Average	7.0	4.3	4.2
Range	3.3 – 10.6	2.8 – 7.1	2.0 – 7.4
Sodosol (0-150 mm)			
Average	2.7	2.3	1.8
Range	1.8 – 3.3	1.6 – 2.9	1.4 – 2.5
Tenosol (0-75 mm)			
Average	2.6	2.1	1.1
Range	2.4 – 3.0	1.3 – 2.8	0.4 – 1.4
Vertosol (0-75 mm)			
Average	7.7	8.0 rainfed	4.6 irrigated
Range	3.7 – 11.9	2.6 – 15.9	3.3 – 5.8

Data sources: Sparrow *et al.* 1999; Cotching *et al*. 2001; 2002a; 2002b; 2002d.

Despite the organic carbon in the top 150 mm being approximately 30% less in cropping and pyrethrum paddocks than pasture paddocks on Red Ferrosols, the absolute values in cropping paddocks were of a magnitude which suggests that Tasmanian Ferrosols (Table 4) still have relatively high levels of soil carbon (Bridge and Bell 1994; Cotching *et al.* 2004; Sparrow *et al.* 2005). The 'equilibrium' organic carbon concentrations in the top 100mm in Queensland Ferrosols for continuously cropped sites was 1.5–2.0% (Bell *et al.* 1995). Concentrations of 1% have been associated with serious physical degradation on Red Ferrosols in Queensland (Bridge and Bell 1994). Concentrations of organic carbon of less than 2% are viewed with concern as these levels have been associated with severe soil structural deterioration and soil based impediments to plant productivity (Greenland *et al*. 1975); Geeves *at al.* 1995).

A negative correlation between land slope and soil carbon content was found on Red Ferrosols (Cotching *et al.* 2002c). Soil carbon content was significantly lower (P<0.001) on slopes of 13–18% and 19–28% compared to level or accumulating sites which was attributed to erosion on the steeper slopes. Steeper slopes (19–28%) had more variable carbon contents (2.1–4.7%) than less steep slopes and this variability was attributed to non-uniform effects of rill erosion which removes furrows of organic rich topsoil whilst leaving inter-rill areas unaffected. The loss of soil organic matter through erosion is possibly the single greatest impact of erosion on soil health (Pennock 1997) because of the relationship of organic carbon to other soil properties.

Lower organic carbon and poorer physical properties on Sodosols were associated with paddocks which had grown potatoes (Cotching *et al.* 2001), which adds weight to the view that cropping rotation and associated soil management practices are critical for sustainable management of Tasmanian Sodosols. Soil degradation associated with growing potatoes arises from deep mixing of profiles, overworking during seedbed preparation, compaction by heavy machinery during harvesting, and harvesting in wet conditions when soils are more susceptible to compaction.

Intensive agriculture was found to have similar effects on soil carbon in New Zealand (Cotching *et al.*1979). There was a 40% reduction in organic carbon at 0–5 cm on the Horotiu soil after 9 years of continuous maize cropping. There was a 15% reduction at 6–16 cm depth and little change at 25–35 cm depth. On the Puniu soil there was a 53% reduction in organic carbon at 0–5 cm after 6 years of continuous maize cropping, a 15% reduction at 6–16 cm depth and little change at 25–35 cm depth. The reductions in organic carbon on both soils after a change to maize cropping from pasture were attributed to a combination of:

- Low return rates of plant residues due to harvesting and grazing of the maize stubble,
- Discontinuous plant growth throughout the year providing irregular and reduced returns of plant material both above and below ground, and
- Increased oxidation of organic matter through cultivation and aeration.

These results plus other studies in Tasmania (Sparrow *et al.* 2002; Sparrow *et al.* 2005) suggest that soil organic carbon levels can be used as a primary tool in diagnosing the overall health of a soil. The soil carbon contents for intermittent cropping could be used as target levels for cropping systems as an indicator of sustainability. Lower values associated with poorer soil physical properties and in some cases lower crop yields from continuous cropping paddocks could be considered to be diagnostic of unsustainable farming systems in the long term.

Consideration of organic carbon content and management histories of Tasmanian soils has led the author to the view that different management has different effects on soil organic carbon content as shown in Figure 7.

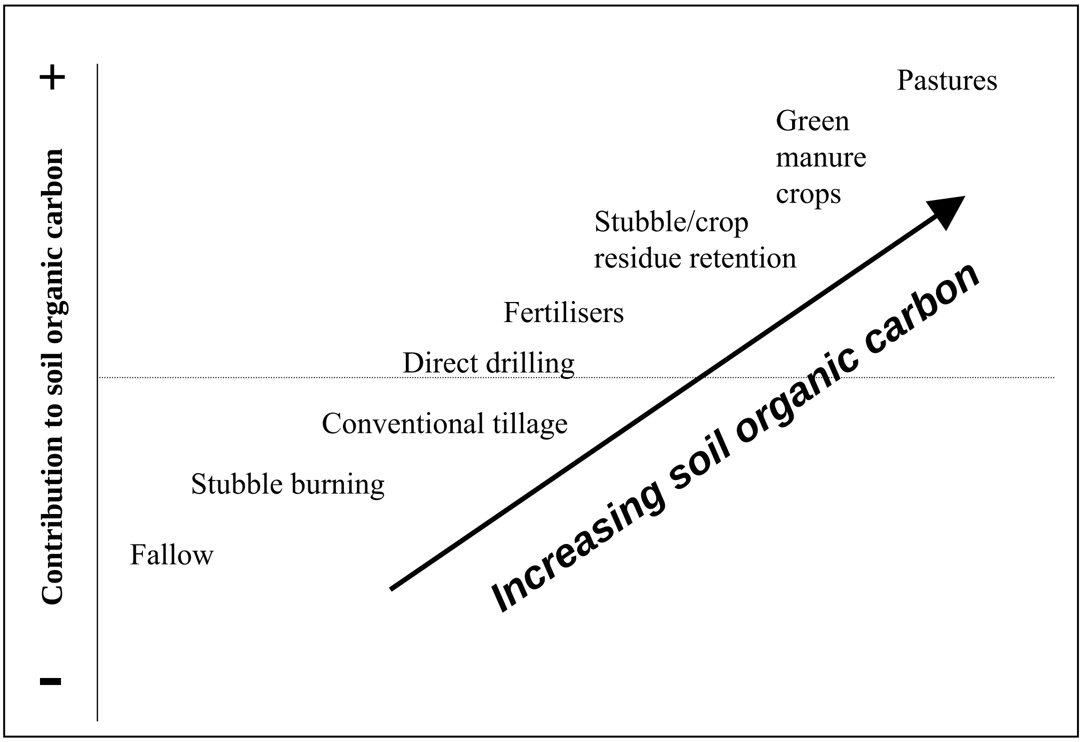


Figure 7. Conceptual model of the effects of different agricultural management in Tasmania on soil organic carbon contents.

4.4 Organic matter interactions with other soil properties

Research in Tasmania over the last 8 years has shown strong associations between soil carbon and a range of soil physical, chemical and biological properties in all the main soil types (Table 5).

Table 5. Soil properties that have been strongly associated (positively correlated) with soil carbon in Tasmanian soils.

Soil order and type	Soil properties correlated to soil carbon
Ferrosol - Burnie clay loam	• % of water stable aggregates • Plastic limit • Bulk density (↓) • pH (↓) • Years of cultivation (↓) • Subsoil field capacity • Microbial biomass
Sodosol - Brumby sandy loam	• Cation exchange capacity • Microbial biomass • Plastic limit • Bulk density (↓) • Porosity • %Water stable aggregates • Infiltration rate • Field capacity (↓)
Dermosol – Cressy clay loam	• Microbial biomass • Plastic limit • Bulk density (↓) • Salinity • Years of cultivation (↓)
Tenosol – Panshanger sand	• Bulk density (↓) • Cation exchange capacity • Clay • pH
Vertosol - Canola & Churchill clay	• Bulk density (↓) • Plastic limit • Total available water • Readily available water • Extractable P & K • Total exchangeable bases • Readily oxidisable carbon

↓ means a decrease with increasing carbon, whilst all other properties showed an increasing trend with increasing carbon.

Data sources: Sparrow *et al.* 1999; Cotching *et al*. 2001; 2002a; 2002b; 2002d.

Organic matter has a strong influence on soil physical properties, such as bulk density with all of the soils studied having significant negative correlations between soil organic carbon and bulk density. A significant correlation between organic carbon and visible structure score (described in Chapter 9) was found on Red Ferrosols (Figure 8) (Cotching *et al.* 2004).

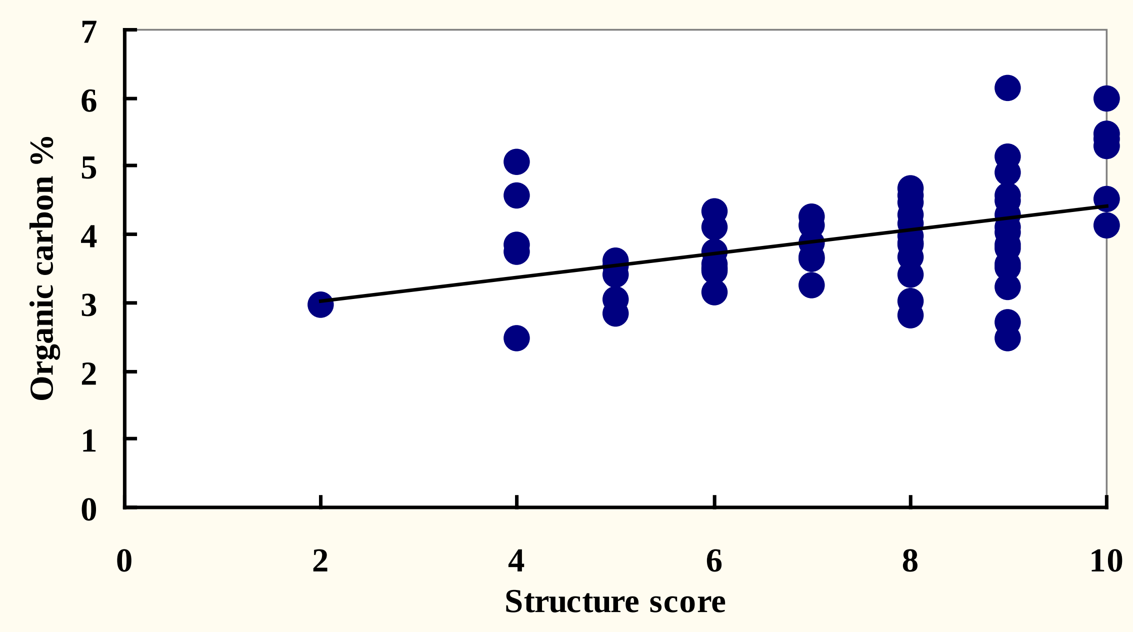


Figure 8. Relationship between organic carbon and visible structure score on Red Ferrosols (r = 0.42, *P*=0.01) (Cotching *et al*. 2004)**.**

Plots of median diameter of dry soil aggregates against total organic carbon on two New Zealand soils indicated that higher organic carbon contents promote the creation of aggregates 2–4 mm in diameter which are the most suitable for a seedbed (Cotching *et al*. 1979). Thus low organic carbon contents on the coarser textured Horotiu soil results in greater amounts of small aggregates (<2mm diameter), whereas on the finer textured Puniu soil, low organic carbon levels resulted in greater numbers of large aggregates (>4 mm diameter), ie. clods.

The different pools of soil organic carbon that relate to different turnover rates (Baldock and Skjemstad 1996) have not been fully investigated in Tasmanian soils. Significant correlations were found between total soil organic carbon and other measures of soil organic activity (microbial biomass carbon and readily oxidisable carbon) on several soil types in Tasmania (Table 5). This is in agreement with Jenkinson (1987) and Lupway *et al.* (1999). However, total organic carbon appears to be as sensitive an indicator of change in soil health as other more expensive indicators such as microbial biomass carbon and readily oxidisable carbon. This has been corroborated by further Tasmanian studies (Sparrow *et al.* 2005). It would be valuable to quantify the amounts of charcoal organic carbon in Tasmanian soils in order to be able to better model the carbon dynamics using models such as Black Magic (Sparrow *et al*. 2002), however, this work has not yet been undertaken.

4.5 Linking crop yield to soil carbon

Does more carbon mean that crops grow better? There are factors which affect crop performance and so this question was investigated in two ways on a range of Tasmanian soils (Cotching *et al*. 2002c; Cotching *et al.* 2004): firstly, how crop yields and soil properties vary in different parts of the same paddocks, and secondly, how crop yields and soil properties vary from paddock to paddock. Results comparing different poppy paddocks (Figure 9) show no clear relationship between soil carbon and yield (Cotching *et al.* 2004). This is perhaps not surprising because other important factors like water, fertiliser, pest and disease management also varied from paddock to paddock. Good management of these factors would tend to even out any differences due to organic matter.

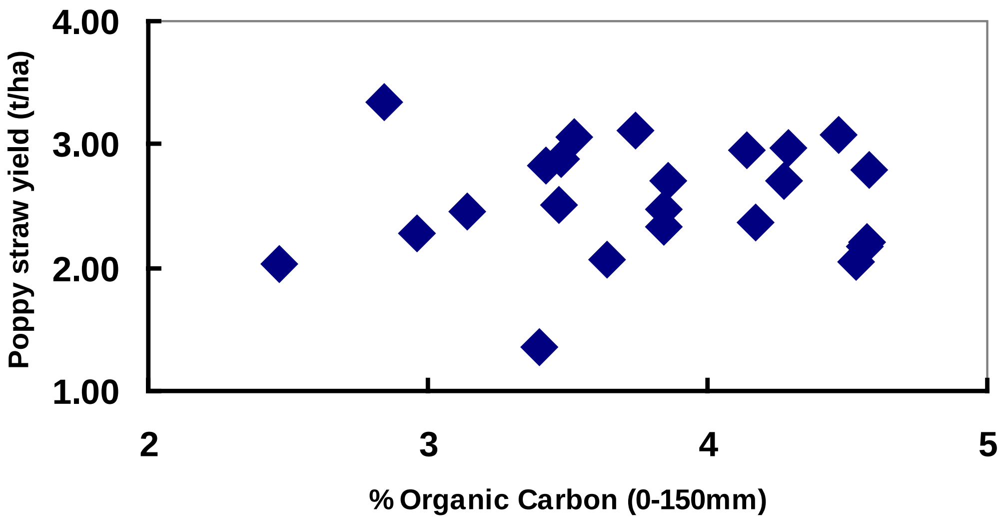


Figure 9. **Lack of association between poppy straw yield and soil organic carbon on Ferrosols** (Cotching *et al*. 2004). Each point is from a separate paddock.

When yields were measured at a number of points <u>within individual paddocks</u> a stronger but still variable effect of carbon could be seen (Figure 10 and 11). The within-paddock results were also confounded by the fact that the sample points were affected to varying extent by previous soil erosion. Nevertheless, in 4 out of 5 cases higher carbon was associated with higher yield. The r^2 values are low and so although there may be some cause and effect relationship between soil organic carbon and crop yield, there is little predictive value in the soil carbon values.

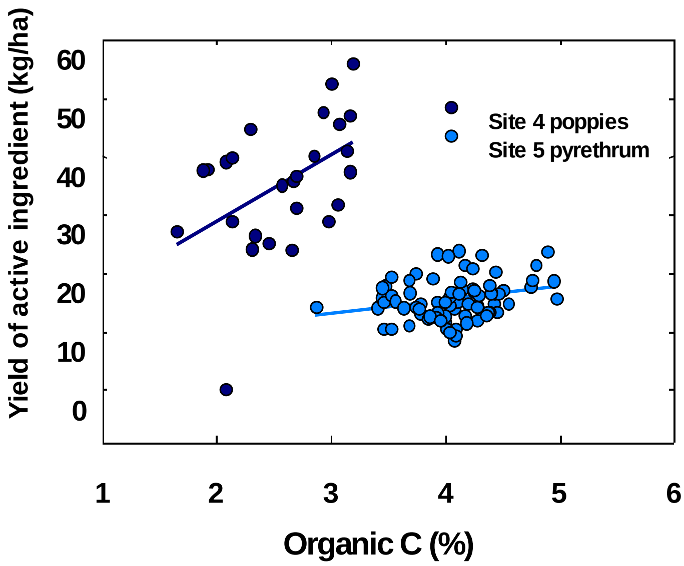


Figure 10. Association between poppy and pyrethrum active ingredient yields and soil organic carbon on Ferrosols (Cotching *et al*. 2002c), (site 4, $r^2 = 0.19$, $P = 0.016$; site 5, $r^2 = 0.024$, $P = 0.035$) (Each point with the same symbol represents a sampling point within the same paddock.)

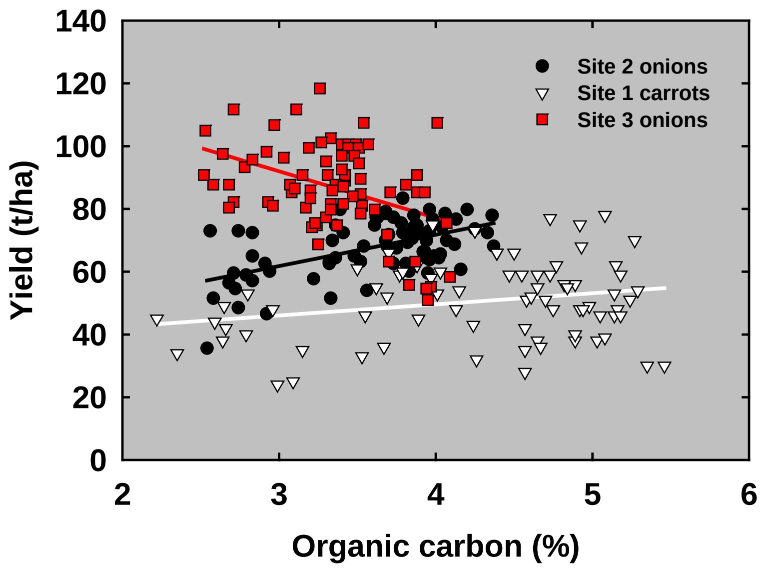


Figure 11. Association between crop yields and soil organic carbon on Ferrosols (Cotching *et al*. 2002c). (site 1, $r^2 = 0.04$, $P = 0.043$; site 2, $r^2 = 0.29$, $P < 0.001$; site 3, $r^2 = 0.16$, $P < 0.001$). (Each point with the same symbol represents a sampling point within the same paddock.)

4.6 Conclusions

- Organic matter is a critical soil property. It is associated with a variety of other important soil physical, chemical and biological characteristics.
- Organic matter levels vary between soils depending on climate, clay content, topography and management.
- Organic matter is declining under current cropping rotations in both Tasmania and New Zealand.
- Declining organic carbon levels associated with cropping will put soils at greater risk of degradation.
- Total organic carbon appears to be as good a measure of the impact of agriculture as other more expensive indicators but further work needs to be done in order to understand the dynamics of different carbon pools more.
- It is not easy to show a clear link between soil organic carbon concentrations and crop yield and quality. Many other factors potentially affect yield and quality to a greater extent.
- Nevertheless, there is sufficient evidence linking organic matter and yield to suggest that farmers should strive to maintain or increase organic matter in their soils.
- Maximising inputs of organic matter by incorporating crop residues and including green manures and pastures in the rotation, whenever practical, should be a goal for all farmers.

Chapter 5 – Effects of intensive agriculture on soil structure

5.1 Chapter outline

Chapter five examines data on the inherent soil structure differences between various soils from New Zealand and Tasmania. Due to these inherent differences, the dynamic nature of soil structure is discussed by soil order or soil type, with a summary of the effects of intensive agriculture on five soil orders in Tasmania and two soil types in New Zealand. Three basic aspects of soil structure described as form, stability and resilience by Kay (1990) were considered in this thesis. Form includes field descriptive properties of structure grade, size and shape, and laboratory determined attributes of dry aggregate size distribution and bulk density. Stability was measured by a wet sieving technique. Resilience of the soils studied in Tasmania is described as 'resistance to change' and the 'potential for degradation resulting from different agricultural land uses.' The relationships between soil structure and crop yield are also discussed. These two measures are currently qualitative but numeric indicators could be developed from a suite of soil structure measurements.

5.2 Inherent soil structure differences

The two soils studied in New Zealand had distinctly different structural characteristics with the Horotiu soil having a greater percentage of water stable macro aggregates. In contrast, the micro-structure of the Horotiu soil was shown to be less stable that that of the Puniu soil. This was supported by quantitative values of structural stability that showed the Horotiu soil to require 20 J/g and the Puniu soil at least 47 J/g for complete dispersion (Cotching *et al*. 1979). This illustrates the importance of including a morphological aspect to this type of soil study, as the two soils behave in quite different ways.

The differences in physical properties between soil orders in Tasmania is also pronounced. Examples of the differences in porosity and moisture holding properties between soil orders are presented in Tables 6 and 7 respectively. These differences become readily apparent when the values in Table 6 are presented in pictorial form (eg. Figures 12 and 13 for Sodosol and Dermosol profiles). These diagrams illustrate the importance of horizons and horizon boundaries in determining physical behavior of soils, particularly in relation to water movement.

The relevance of using a morphological approach in soil management has been well demonstrated in Tasmania by the work of Chilvers (1996) and Cotching and Chilvers (1998). This work laid out clear differences in management between soil orders in tillage practices, drainage options and irrigation practices.

Table 6. Pore space in topsoils used for agriculture in Tasmania

Data sources: Sparrow *et al.* 1999; Cotching *et al*. 2001; 2002a; 2002b; 2002d.

Soil order	**Tenosol**	**Sodosol**	**Dermosol**	**Vertosol**	**Ferrosol**	Suction to remove water from pores (kPa)
A horizon texture	Sandy loam	Loam	Clay loam	Clay	Clay loam	
% Clay	6	30	34	47	60	
Pore size (mm)	% Total soil volume in topsoil (5-7 cm)					
>0.03	30	16	20	13	16	< 10
0.03- 0.003	6	8	7	5	7	10-100
0.003 -0.0002	6	15	10	23	15	100-1500
<0.0002	7	11	19	15	23	>1500
Total pore space	49	50	56	56	61	

Table 7. Moisture holding properties of soils used for agriculture in Tasmania (all values are on a volumetric basis)

Soil series	Order	Depth (cm)	Total porosity %	Macro porosity %	Total available water (%) TAW	Readily Available water (%) RAW	Field Capacity at 100mm depth (%)	Rooting depth (cm)	TAW in rooting depth (mm)	RAW in rooting depth (mm)
Brumby	Sodosol	5 to 7	50.1	15.9	22.9	7.8	28.4	28	62	25
	(duplex)	20 to 22	41.1	11.8	20.5	10				
		38 to 40	48.5	5.3	11.4	5.6				
		50 to 52	57.2	1.6	-	7.6				
		70 to 72	56.9	1.8	-	8.1				
Burnie	Ferrosol	5 to 7	60.1	8.5	26.1	8.9	38.9	60	137	46
	(gradational)	18 to 20	59.7	9.9	22.4	6.6				
		28 to 30	59.5	13	22.2	7.6				
Canola	Vertosol	5 to 7	56.1	13.4	27.5	5.2	44.5	60	160	22
	(uniform)	10 to 12	34.8	8.5	27.7	4.5				
		28 to 30	50	2.7	26.3	3.2				
Cressy	Dermosol	5 to 7	56.1	19.6	16.7	6.8	41	60	79	39
	(gradational)	10 to 12	55.9	19.6	16.7	6.6				
		20 to 22	53.8	15.7	17.2	5.4				
		50 to 52	46.7	21.8	7.6	7				
Panshanger	Tenosol	5 to 7	49.1	30.3	11.6	5.7	24.1	60	55	39
	(uniform)	10 to 12	46	27.3	11.2	6.6				
		20 to 22	43.6	26.2	9.3	6.7				
		40 to 42	47.8	33	7	6				
		60 to 62	46.4	33.3	9	7				

RAW = (water content at 10 kPa (w/w) – water content at 100 kPa (w/w)) x bulk density.
TAW = (water content at 10 kPa (w/w) – water content at 1500 kPa (w/w)) x bulk density.
Data sources: Sparrow *et al.* 1999; Cotching *et al*. 2001; 2002a; 2002b; 2002d.

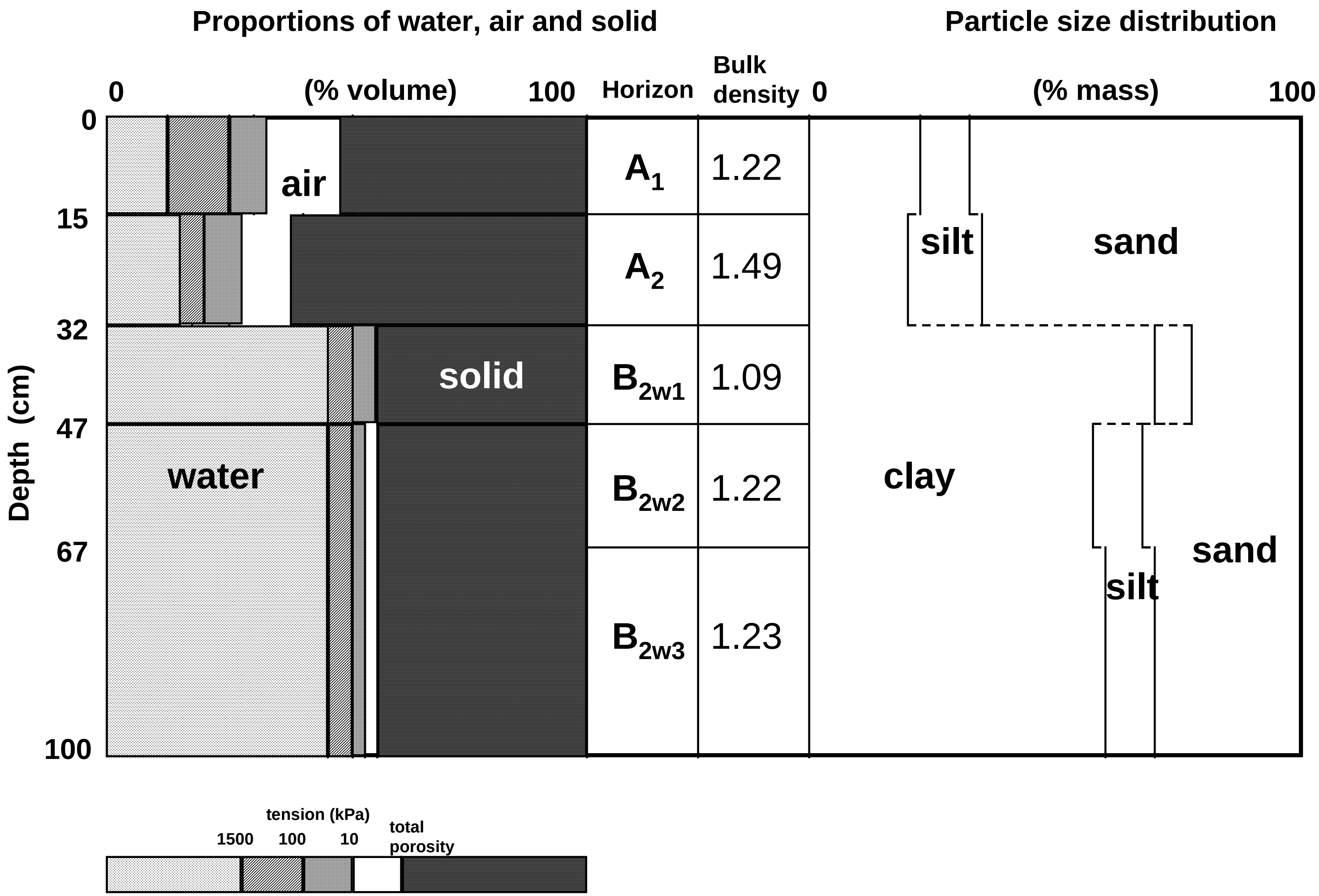


Figure 12. Physical properties of a representative Sodosol profile (Brumby sandy loam) Grid reference 521400E 5371700N

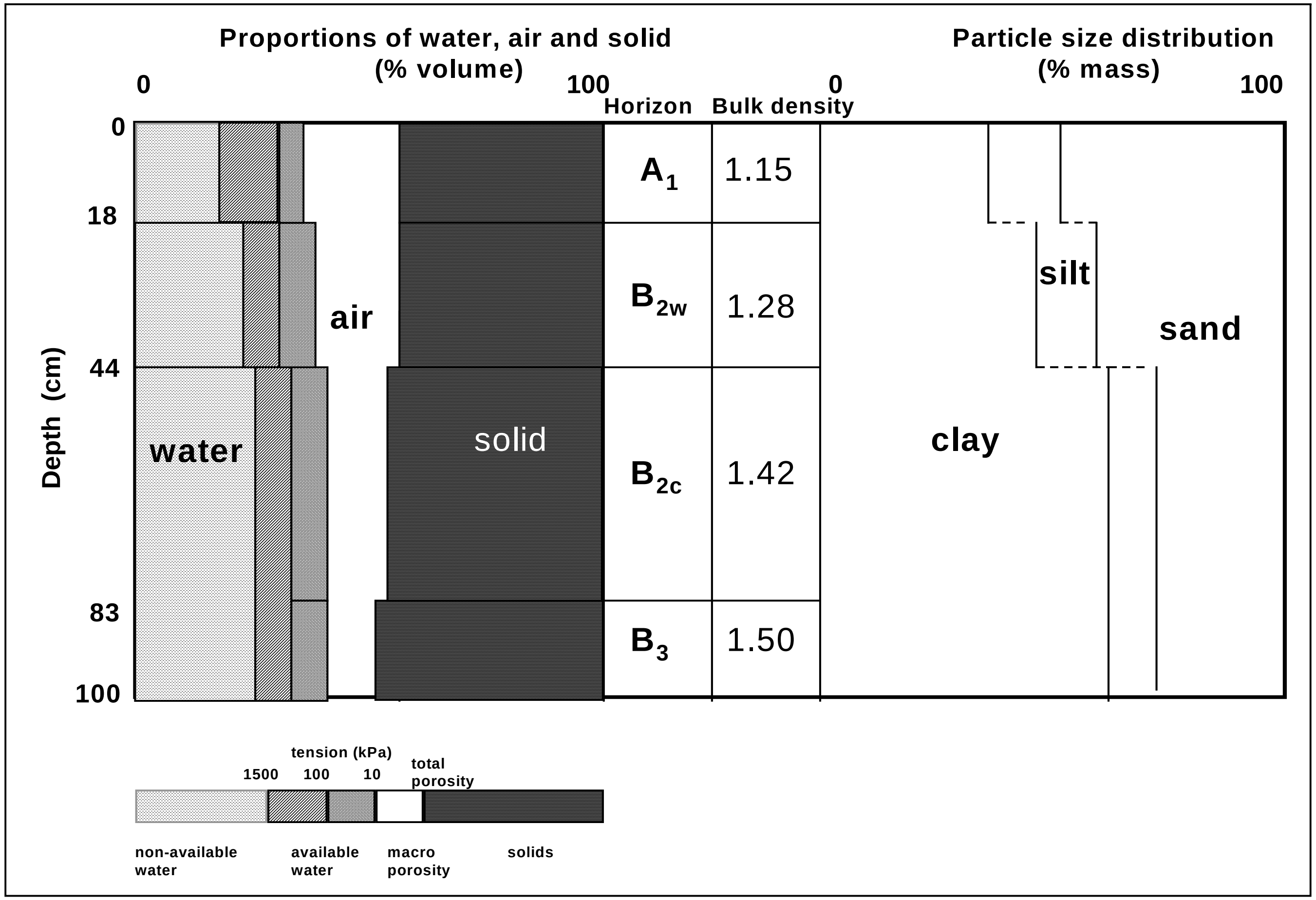


Figure 13. Physical properties of a representative Dermosol profile (Cressy shaley loam) Grid reference 501050E 5390300N

Bulk density and aggregation are distinctly different between the soil orders studied in Tasmania (Figures 14 and 15 respectively).

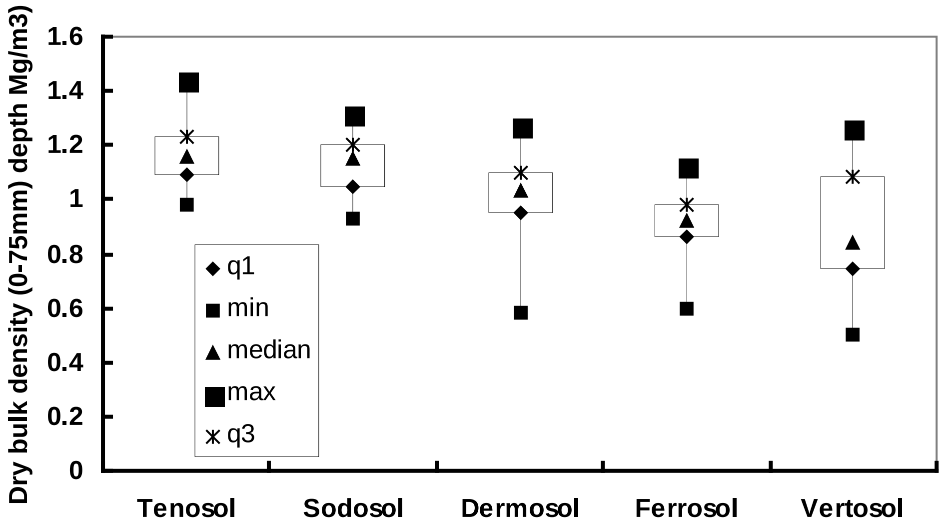


Figure 14. Bulk density of Tasmanian soil orders (0−75mm depth) under long term pasture
Data sources: Sparrow *et al.* 1999; Cotching *et al*. 2001; 2002a; 2002b; 2002d.

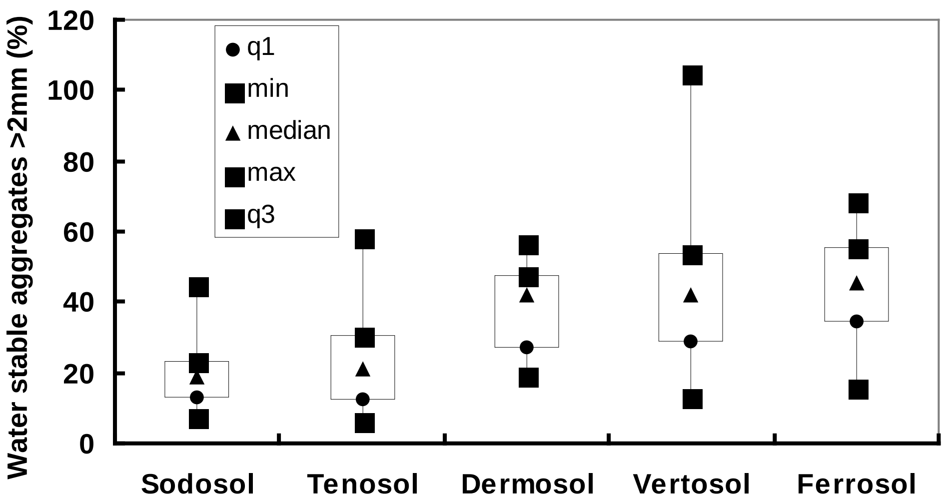


Figure 15. Water stable aggregates (>2mm) in topsoils (0−75 mm) from Tasmanian soil orders under a range of management histories
Data sources: Sparrow *et al.* 1999; Cotching *et al*. 2001; 2002a; 2002b; 2002d.

5.3 Dynamic soil structure

Dermosols (Cressy shaley loam)

Long term pasture paddocks showed stronger structural development and had smaller clods than cropped paddocks (Figure 16). Greater bulk densities were found in the surface layer of cropped paddocks but these were not associated with increased penetration resistance or decreased infiltration rate and are unlikely to impede root growth. Vane shear strength and penetration resistance were lower in cropped paddocks than under long term pasture which may have been due to greater root densities under long term pasture. High penetration resistance values in subsoils indicate that tillage below 300mm depth may be beneficial to root growth. Many Dermosol attributes showed no significant differences associated with different management histories. Including potatoes in the rotation did not appear to affect the Dermosols studied indicating a degree of robustness in these soils (Cotching *et al.* 2002a). This robustness may be due to strong aggregate bonding resulting from the presence of non-crystalline iron and aluminium oxides and hydroxides (El-Swaify 1980) plus electrostatic, van der Waals and hydrogen bonding interactions between the sesquioxides and kaolin (Tama and El-Swaify 1978).

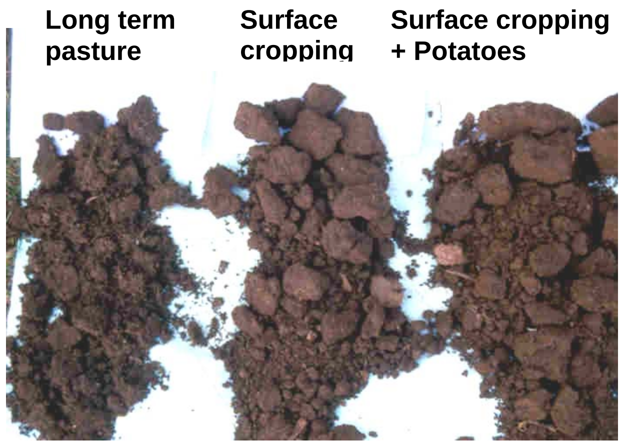


Figure 16. Visible differences in soil structure on Dermosols between long term pasture(left), surface cropping (centre) and cropping including potatoes(right). The larger clods are 50-100 mm in size.

Ferrosols (Burnie clay loam)

Soil structural decline due to compaction and decreased aggregate stability has been identified as one of three major challenges for the sustainable management of Ferrosols (Cotching 1995). The macroporosity associated with strongly structured Ferrosols is sensitive to compaction both by machinery and livestock. When soils are wet due to seasonal rainfall they are often wetter than their plastic limit and any working or loading results in plastic deformation and compaction. The most significant aspect involved in soil structure degradation on Ferrosols appears to be soil compaction. Changes associated with, but not necessarily solely due to soil compaction (Sparrow *et al*. 1999) include:

- Increased cloddiness
- Reduced infiltration resulting in increased runoff and soil erosion
- Poorer drainage and reduced trafficability
- Increased mechanical root impedance through increased soil strength

Degradation of Red Ferrosol physical properties due to intensive agriculture has also been reported by Bridge and Bell (1994) and Lobry de Bruyn and Kingston (1997).

One of the difficulties in convincing farmers who are managing Ferrosols of the importance of soil structure is that these soil have inherently better physical attributes than many other soils (Table 6; Figures 14 & 15). Even following years of poor husbandry, resulting in significant soil structural decline, degraded Ferrosols can still have better attributes than other soils, and can still be in relatively good condition (Sparrow *et al*. 1999). Favourable soil structural attributes are essential for Ferrosols to remain under intensive use. Amelioration of increased bulk density and compaction arising from poor cropping practices, can only be achieved by mechanical means, or active plant growth, as Ferrosols have no natural repair mechanisms, such as shrinking and swelling of clay minerals (Bridge and Bell 1994).

Cropping on steep (5 – 28%) slopes of Red Ferrosols resulted in redistribution of soil to concave or toe slope positions resulting in over-thickened topsoils (Cotching *et al.* 2002c). There was little apparent difference in topsoil thickness between level and eroded slopes but this was probably due to the uniform depth of cultivation evenly mixing the upper part of the soil profile. Clay content was not significantly different between slope classes at the 3 depths sampled. However, mean clay content on land with 19-28% slope was the highest over all depths which was attributed to preferential removal of lighter textured surface soil by erosion. Subsequent mixing of higher clay content subsoil with the remaining topsoil may also have occurred due to regular cultivation.

There were significant differences in penetration resistance between slope classes and the accumulation sites had profiles with the lowest mean values of penetration resistance. Penetration resistance increased gradually with depth on all Red Ferrosols, indicating no compacted layers or plough pans. Penetration resistance fluctuated around 2000 kPa below 400mm depth, indicating that root growth may be restricted as the soil dries (Cass 1999). However, under irrigated cropping, root growth is unlikely to be restricted.

There was little evidence of significant differences in other soil physical properties between eroded and flat sites as measured by bulk density, total porosity, macroporosity, total and readily available water storage, field capacity, soil moisture tension at field capacity, plastic limit, infiltration rate, vane shear strength, and dry aggregate size distribution. This result was unexpected because anecdotal evidence suggested increased cloddiness on steeper eroded slopes. At all sites, the 200–275mm depth range typically had a greater percentage of large aggregates than the 0–75mm depth. Thus it was expected that following erosion of the topsoil, more of the larger aggregates would be incorporated into the topsoil by cultivation.

Plastic limit was weakly but significantly correlated with organic carbon ($r = 0.517$). This means that areas with lower carbon contents, i.e. steeper eroded slopes, are more likely to be more susceptible to traffic damage because they require longer drying times to reach a friable state (moisture content below plastic limit).

Sodosols (Brumby sandy loam)

Significant degradation of soil structure was found on Sodosols used for intensive cropping in Tasmania (Cotching *et al*. 2001). Infiltration rate on Sodosols was greater in paddocks with shallow tillage cropping than long term pasture but was 43% less in paddocks which had grown potatoes and 70% less after a wet potato harvest (Figure 17).

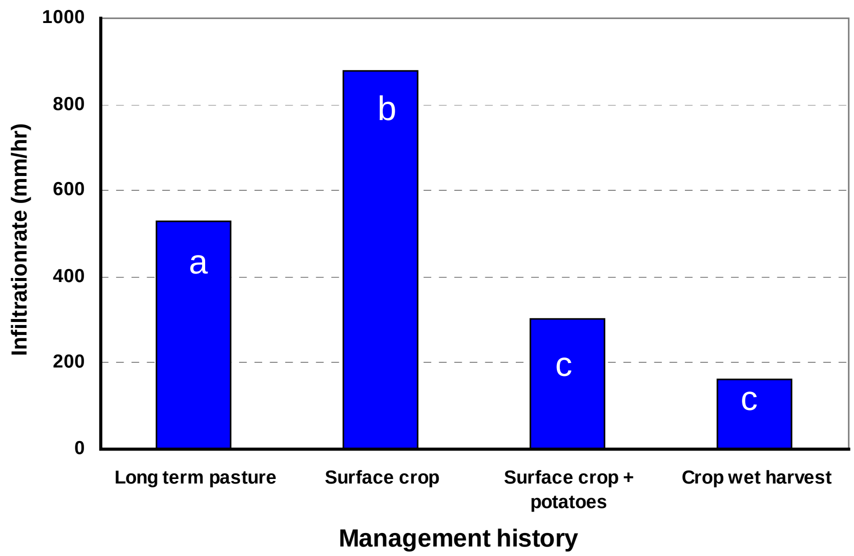


Figure 17. Infiltration rates on Sodosols in Tasmania's Midlands
Values followed by the same letter are not significantly different at $P = 0.05$.
Data source: (Cotching *et al*. 2001).

Dry aggregate size showed no change under shallow tillage cropping compared to long term pasture but decreased significantly in more rigorously tilled potato cropping paddocks. Aggregate stability in all cropped paddocks was nearly 50% less than in long term pasture paddocks, with values in intensively tilled potato cropping paddocks approaching relatively low levels as defined by Laffan *et al.* (1996). Farmers who managed the sites studied were able to identify more healthy than unhealthy soil attributes under all management histories on Sodosols when surveyed on their perceptions of soil, plant and water properties for each site (Cotching *et al* 2001). However, they reported more unhealthy soil attributes when potatoes were included in their rotation. Poorer physical properties (infiltration rate, number of large aggregates, aggregate stability) were associated with paddocks which had grown potatoes, which adds weight to the view that cropping rotation and associated soil management practices are critical for sustainable management of Tasmanian Sodosols.

Results of a study on Sodosols to determine differences in soil properties between soil in raised beds and soil in conventionally managed areas (Cotching and Dean 2003), showed that raised beds had significantly better physical properties than conventionally managed sites. One to two years after installation, the raised beds had greater infiltration, lower bulk density, lower shear strength at 100–200 mm depth and lower penetration resistance. The reduced penetration resistance was confined to the upper 270 mm of the soil profile. Dry soil aggregates were smaller in these beds indicating that some of the soil physical benefits were probably derived from the greater tillage intensity associated with forming the beds. These soil physical benefits generally remained 3 to 4 years after bed forming.

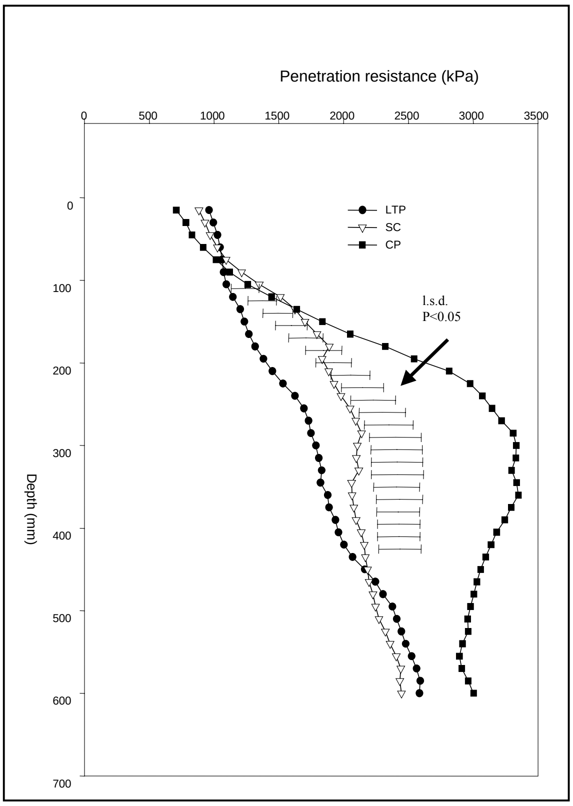
The amount of tillage used in forming the raised beds was not detrimental to soil physical properties, such as infiltration and aggregate stability, which had previously been found to be associated with potato production on Tasmanian Sodosols (Cotching *et al*. 2001). The extra inputs associated with cropping plus enhanced drainage and aeration on raised beds are improving soil physical properties so that better plant growth is likely compared to conventionally managed sites. Modification of surface water flows along inter bed furrows may impact on local catchment hydrology and water quality and this warrants further investigation.

Several other studies have also found degradation of soil structure associated with cropping on texture-contrast soils in Australia (Tisdall and Oades 1980; Packer *et al.* 1992; Murphy and Flewin 1993; Macks *et al.* 1996). As well as surface sealing, this degradation can include hardsetting, declining aggregate stability, compaction and increased runoff and erosion. Chan and Mead (1988) concluded that it is very important to conserve the structural stability of the surface layer in these texture-contrast soils and that structure degradation can be more rapid and severe than in clay textured soils due to faster loss of organic matter and rupture of the soil fabric.

Tenosols (Panshanger sand)

Dry bulk density was greater, total porosity and macroporosity were less, and subsoil compaction was apparent in paddocks with Tenosols that had grown potatoes (Figure 18) (Cotching *et al.* 2002b). The high penetration resistance values (>2000 kPa) indicate that subsoil tillage may be beneficial to root growth in paddocks after potato harvesting as deep ripping has increased root density and crop yields on sandy soils in South Australia (Peake and Watt 2000). Infiltration rate was greater, and shear strength less, in cropped paddocks compared to long term pasture which may have been due to stock trampling on the long term pasture sites and tillage on the cropping paddocks opening or enlarging pathways for water movement. Many soil physical properties showed no ill effects due to cropping which may be due to these sandy soils having inherently weak structure even in a healthy state (Cotching *et al*. 2002b).

Figure 18. Penetration resistance on Tenosols under long term pasture (LTP), cropping with shallow tillage (SC), and cropping including potatoes (CP)



Vertosols (Canola and Churchill clay)

Long-term pasture paddocks showed stronger structural development, more stable aggregates and had smaller aggregates (less clods) than cropped paddocks (Cotching *et al.* 2002d). Cultivation associated with cropping reduced shear strength and penetration resistance but these benefits were not apparent on irrigated paddocks where smearing and compaction, due to tillage at moisture contents greater than the plastic limit, is more likely to occur. The strong correlation found between plastic limit and organic C means that declining OC levels associated with cropping will exacerbate the problem of Vertosols having a narrow window of opportunity for tillage at friable moisture contents.

Rainfed cropping paddocks had significantly greater infiltration rates than long term pasture paddocks which was attributed to loosening of the soil surface by tillage.

This result is consistent with findings on other Tasmanian soils (Sparrow *et al*. 1999; Cotching *et al*. 2001) but is contrary to findings on Vertosols in southeastern Queensland (Connolly *et al*. 1997). The beneficial effect of tillage on infiltration rate was not apparent on irrigated cropped paddocks. We attribute this to the more problematic timing of tillage operations on these paddocks as opposed to drier rainfed sites (Isbell 1996) which can result in smearing and compaction.

Degraded soil structure has also been found in Vertosols under both rainfed and irrigated farming in other regions of Australia (McGarry and Smith 1988; McKenzie *et al*. 1991).

Soils in the Waikato district, New Zealand

Significant degradation of soil structure was found on soils used for maize cropping in New Zealand (Cotching *et al*. 1979). Morphological description of soil profiles found that A horizon soil structure and consistence deteriorated under maize cropping. This deterioration in structure was confirmed with measurements of bulk density but values were still relatively low on the Horotiu soil (0.79 T/m^3) after 9 years of maize cropping and values on the Puniu silty clay loam (1.07 T/m^3) were not considered to be root limiting. On both soils there was a trend for the percentage of water stable aggregates to decrease with increasing years under maize. Micro-aggregate stability decreased with the change in land use from pasture to maize cropping but there was little apparent trend with increasing years of cropping.

Management implications arising from this study were that under the then current management practices maize cropping on the Horotiu soil was not causing deterioration of soil structure to any great degree. The Horotiu soil appeared to be relatively resistant to change and so maize cropping can probably be continued on soils of this type for many years without serious soil structural problems arising. The Puniu soil was considered to be in a relatively poor physical condition at the sites sampled. Due to its low level of natural resilience, maize cropping may have to be discontinued on the Puniu soil.

5.4 Linking crop yield to soil structure

The soil physical properties and paddock variables found to be significantly correlated with crop yield and assay varied depending on crop and soil type (Table 8) (Cotching *et al.* 2004). The simple visual assessment of structure (Figure 19) and the measurement of penetration resistance were correlated to paddock scale crop production on heavier textured Dermosols and Ferrosols (Figure 20). The visual assessment of soil structure follows that of Peerlkamp (1967) and Batey (2000), with the concept also having been developed for agriculture in New Zealand (Shepherd 2000), the UK (National Soil Resources Institute 2002) and for use on Vertosols in Australia by McKenzie (2001). None of these authors related visual soil attributes to crop yield but visual assessment of soil structure has also been found to be correlated with crop yields in New Zealand (Beare *et al.* 2000; Reid *et al*. 2001, 2002).

Average potato yields on Ferrosol paddocks with structure scores of 9 or 10 (i.e. good structure) were 61.5 t/ha (n=14), whereas on paddocks with structure scores of 6 or less average yields were 46.6 t/ha (n=6). If this difference in yield and proportion (21%) of paddocks with structure scores of 6 or less is consistent across all potato paddocks on Ferrosols, the total cost to Tasmanian potato farmers (at $220 /tonne) from degraded soil structure could be of the order of $M 3.5 / year. In other words, soil structure degradation is costing farmers money in lost production.

If soil structure degradation, such as cloddiness, is visible on clay loam topsoils of Dermosols and Ferrosols, then crop yield is probably being limited and this may be having a considerable impact on farmers' returns. No correlation was found between the soil properties tested and paddock scale crop production on sandier textured Sodosols and Tenosols (Cotching *et al.* 2004). This may have been due to the inherent variability of soil types within the paddocks sampled.

Table 8. Soil structure properties correlated to crop yield parameters

Soil type	Crop	Yield parameter	Correlated soil properties	r value (P < 0.05)
Dermosol	Potatoes	Tuber yield (t/ha)	Depth to 2000 kPa	0.60
	Poppies	Capsule yield (t/ha)	Structure score	0.59
		Capsule assay (%)	Resistance 0-150mm	0.52
Ferrosol	Potatoes	Tuber yield (t/ha)	Structure score	0.57
	Poppies	Capsule assay (%)	Resistance 0-600mm	0.40
Sodosol	Potatoes	Tuber yield (t/ha)	No significant relationships	
	Poppies	Capsule yield (t/ha)	No significant relationships	
		Capsule assay (%)	No significant relationships	
Tenosol	Potatoes	Tuber yield (t/ha)	No significant relationships	

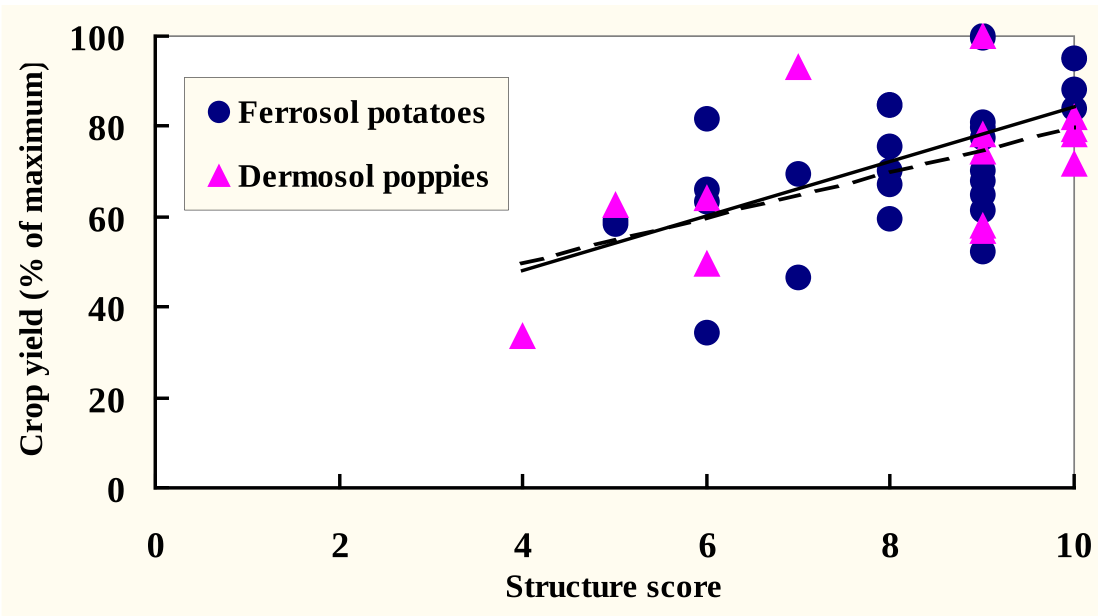


Figure 19. Relationship between crop yield and soil structure score on Ferrosols (r = 0.57, *P*<0.05) and Dermosols (r = 0.59, *P*<0.05) (Cotching *et al*. 2004).

Figure 20. Soil structure scorecard for clay loam textured topsoils in Tasmania

<u>Score 1 – 2</u>

Large compact clods (50 – 100 mm) with few fine aggregates.
Clods are angular or plate-like with smooth sides and no pores.

<u>Score 3 – 4</u>

Mainly firm large clods (20 – 50 mm) that are angular with smooth faces and no pores. Clods and overworked soil break into loose powdery soil.

Score 5 – 6

Few medium and large firm, rounded aggregates (5 – 30 mm) with mostly finer aggregates (< 2 mm) and some powdery unaggregated soil.

Score 7 – 8

Friable soil with many rounded aggregates (5 – 20 mm). Many fine rounded aggregates (< 2 mm) but little powdery unaggregated soil.

Score 9 – 10

Porous loose soil with many rounded, irregular shaped aggregates (2 – 10 mm). Large aggregates have many holes for good aeration and drainage. Little or no powdery unaggregated soil.
Often has abundant very fine roots.

Crop yield declined with increasing slope on Red Ferrosols (Cotching *et al*. 2002c). Crop yield was not significantly different on land up to 18% slope but relative crop yield was 16-18% lower on the steepest land (19-28% slope) which had the greatest soil loss. The amount of erosion that has occurred on slopes up to 18% slope has not been great enough to significantly impact on crop yield but it is anticipated that continued erosion at current rates on this land will inevitably reduce crop yields. Crops grown in concave slope positions, that had accumulated soil, did not compensate with increased yields.

5.5 Conclusions

Morphological evidence of the effects of intensive agriculture was found on soils with clay loam or clay textured topsoils but not on sandy loam to sand textured topsoils. Sandy loam to sand textured topsoils are the soils (Sodosols, Tenosols) with the least clay and organic matter contents, making their structures inherently weak and very susceptible to physical damage. The clay loam textured Dermosols and Ferrosols are more resistant to structural degradation. This knowledge has led the author to devise a relative order of resistance to change by soil order in Tasmania (Figure 21). Subsequent work by Sparrow *et al*. (in prep.) adds weight to the hypothesis that light textured soils are at risk of degradation, while the heavier textured Ferrosols are more resistant. The Tenosols have greater sand contents than Sodosols but the latter are rated as being less resistant to change because of the duplex morphology compared to the Tenosols being gradational. Sodosols soils have the potential for mixing of the strongly contrasting A1 and A2 horizons that can result in serious degradation of topsoils as the A2 horizon has poor physical and chemical properties compared to the A1 horizon.

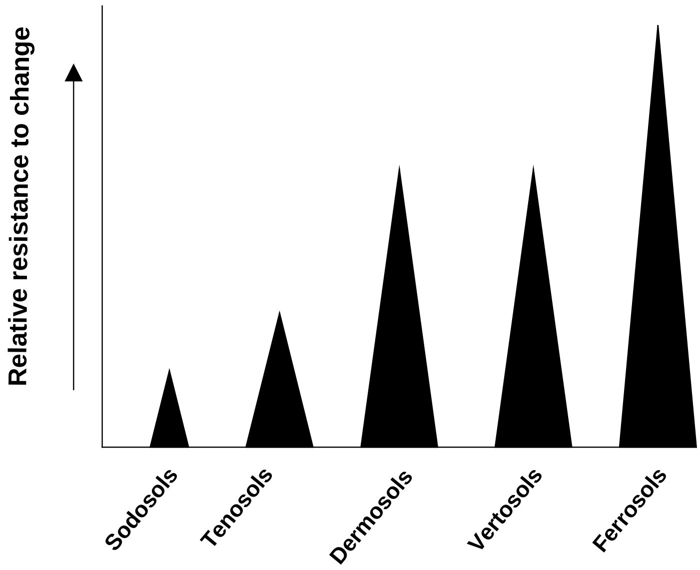


Figure 21. Relative levels of resistance to structural change – by soil order

The timing of soil operations can often separate good soil managers from poor soil managers but it is the author's view that different land uses result in different broad scale soil impacts (Figure 22). It is acknowledged that severe soil degradation can occur in specific locations with any land use, but the potential for degradation at a broad scale is described below. Morphological differences between soil orders are a useful way of differentiating between form, stability and resistance, the three basic aspects of soil structure (Kay 1990).

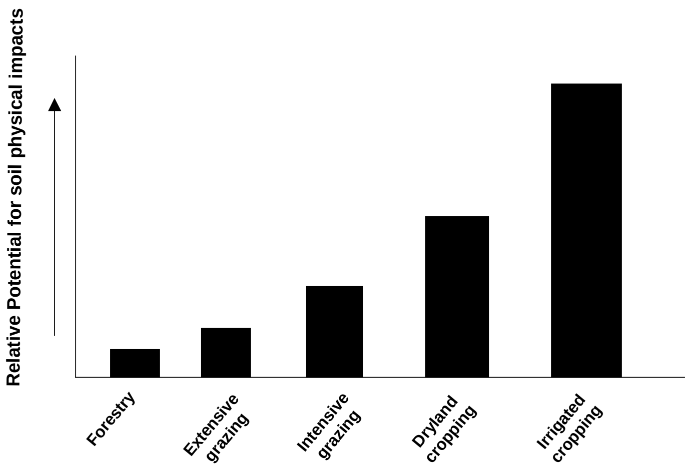


Figure 22. Relative levels of potential for broad scale physical soil impacts resulting from different agricultural land uses

Current land use trends are for greater intensification of use and the more intensive the land use, the greater is the likelihood for soil damage. Farmers have greater need for production due to financial pressures and smaller crop gross margins. There has been continued growth in the area under irrigation used for cropping in Tasmania. The lower rainfall (<800mm/yr) areas in Tasmania are dominated by duplex soils with sandy textured topsoils. These soils are the most vulnerable to damage and so greater management skill is required to prevent damage. Soil structure degradation has been found even on the soils more resistant to change with increased cloddiness correlated to lower crop yields on Dermosols and Ferrosols. The more soils are cropped, the more likely it is that timing of operations will be compromised, due to constraints of the weather, finances and contractual obligations. Consequently, there is a greater potential for soil degradation to occur in the future.

Chapter 6 – Effects of intensive agriculture on soil chemical properties in Tasmania

6.1 Chapter outline

Chapter six presents information on the soil chemical properties of sites studied on five soil orders in Tasmania. Amendments of fertilisers and lime added over previous years to the sites investigated are shown to have had a measurable impact on the soil chemical properties. This chapter discusses these dynamic aspects of soil chemical properties. Associated research on the rates of fertiliser applied in intensive agriculture is discussed. Soil analyses from a study on hump and hollow drained land under intensive dairying in north west Tasmania is presented together with results on off-site nutrient losses. Links between soil chemical properties and crop yield are also presented.

6.2 Dynamic soil chemistry

Most of the chemical differences found are probably due to additions of lime and fertilisers (P, K, S, and N) associated with normal agricultural practice. Many agricultural systems are very acidifying to the soil (Slattery *et al.* 1999). However, adequate application of agricultural lime does result in increases in native soil pH in some farming systems. Induced acidification (as distinct from natural acidification) involves changes to the nitrogen and carbon cycles, and the accumulation, depletion and transport of base (Ca, Mg, Na and K) and acid (Al & H) cations (Helyar & Porter 1989). Induced soil acidification in soils can arise from leaching of soil nitrate and associated base cations, application of ammonium fertilisers with associated nitrification, removal of crop and livestock products, and transfer of excreta to localised stock camps leaving surrounding land more acidic. Approximately 50% of agricultural land in Australia (approximately 50 million hectares) have surface pH values less than or equal to 5.5 (in calcium chloride which is equivalent to approximately 6.3 in water) (NLWRA 2001). Most farming systems require inputs of lime to maintain soil pH with cropping systems generally more acidifying than pasture based systems, although continuous legumes with pastures cut for hay have very high acidification rates.

Topsoil pH values for agricultural lands in Tasmania (Table 9) show no sign of increased acidity associated with more intensive use (Cotching *et al*. 2001; 2002a;

2002b; 2002d; Sparrow *et al.* 1999). Soil pH was found to be greater under cropping systems compared to pasture, which is likely to be due to the application of lime or dolomite. Lime and dolomite are readily available in Tasmania and distances from quarry to paddock are not great, which keeps transport costs down. In 1998/99 150,000 tonnes of lime or dolomite were used in Tasmania (NLWRA 2001). A comparison of historic data for Ferrosols on the Department of Primary Industries, Water and Environment soils database found no generalised indication of decreased pH compared to different sites sampled over 40 years later (Table 9).

Extractable phosphorus was greater under cropping compared to long-term pasture on all soil orders in Tasmania, particularly after potatoes (Table 10). An adjunct to the research linking crop yield to soil properties was the collection of phosphorus and potassium soil and fertiliser rate data for a number of commercial crops of potato (*Solanum tuberosum* L.) and oilseed poppy (*Papaver somniferum*) grown on Tasmania's main cropping soils. The data were examined in relation to existing knowledge about the response of potato and poppy to P and K on Tasmanian soils and to crop P and K removal rates (Sparrow *et al.* 2003). An example of the results is that K fertiliser rates on potatoes were mostly at, or close to, maintenance K rates (Figure 23). Large amounts of K are applied to potato crops but potatoes remove much of this (Chapman *et al*. 1992). There was little evidence either of excess K application, or that growers were under fertilising with K, although one grower on a Tenosol with only 100 mg Colwell K/kg may have applied too little K (Maier *et al*. 1986). Few growers depleted soil K reserves even though many, especially on Ferrosols, had soils with K concentrations well above critical levels (Figure 23). Potatoes are a high value crop, and growers are loath to risk yield loss for the sake of a relatively small extra outlay on fertiliser. The uncertainty in critical soil P concentrations on Ferrosols (Moody 1994), combined with the widespread knowledge of their P fixation capacity, means that the generally high P rates applied regardless of soil P status is not surprising. However, on lighter textured Sodosols and Tenosols, there appears to be considerable scope for P fertiliser rates to be safely decreased. This has important environmental implications as cadmium contamination of phosphatic fertilisers has only relatively recently been realised with changes to fertilisers with lower cadmium levels now being recommended (Sparrow *et al.* 1993ab).

Table 9. pH_{water} in Tasmanian soils used for agriculture

Within rows, values followed by the same letter are not significantly different at *P* = 0.05.

	Depth mm	Long term pasture	Cropping with shallow tillage	Cropping (including potatoes) with more rigorous and deeper tillage
Tenosols (n = 15)	*0-75*	5.7	5.6	6.1
(Panshanger sand)	*75–150*	5.6	5.4	5.6
Dermosols (n = 15)	*0-75*	5.6	5.6	6.0
(Cressy shaley loam)	*75-150*	5.5	5.7	5.8
Sodosols (n = 25)	*0 -150*	5.4	5.5	5.5
(Brumby sandy loam)				
		Long term pasture	**Rain fed cropping**	**Irrigated cropping**
Vertosols south east (n = 9)	*0-75*	6.4	6.0	6.5
(Churchill clay)	*75–150*	6.2	6.2	6.6
Vertosols Midlands (n = 12)	*0-75*	5.6	5.5	5.8
(Canola clay)	*75–150*	5.7	5.4	5.8

		CSIRO Sites*	Low input pasture	High input pasture	Intermittent cropping	Continuous cropping
Ferrosols (n = 24) (Burnie clay loam)	0-150	5.7	5.7ab	5.6a	6.1b	6.5c

***** Data are means of CSIRO sites analysed in 1950's and stored on DPIWE soils database

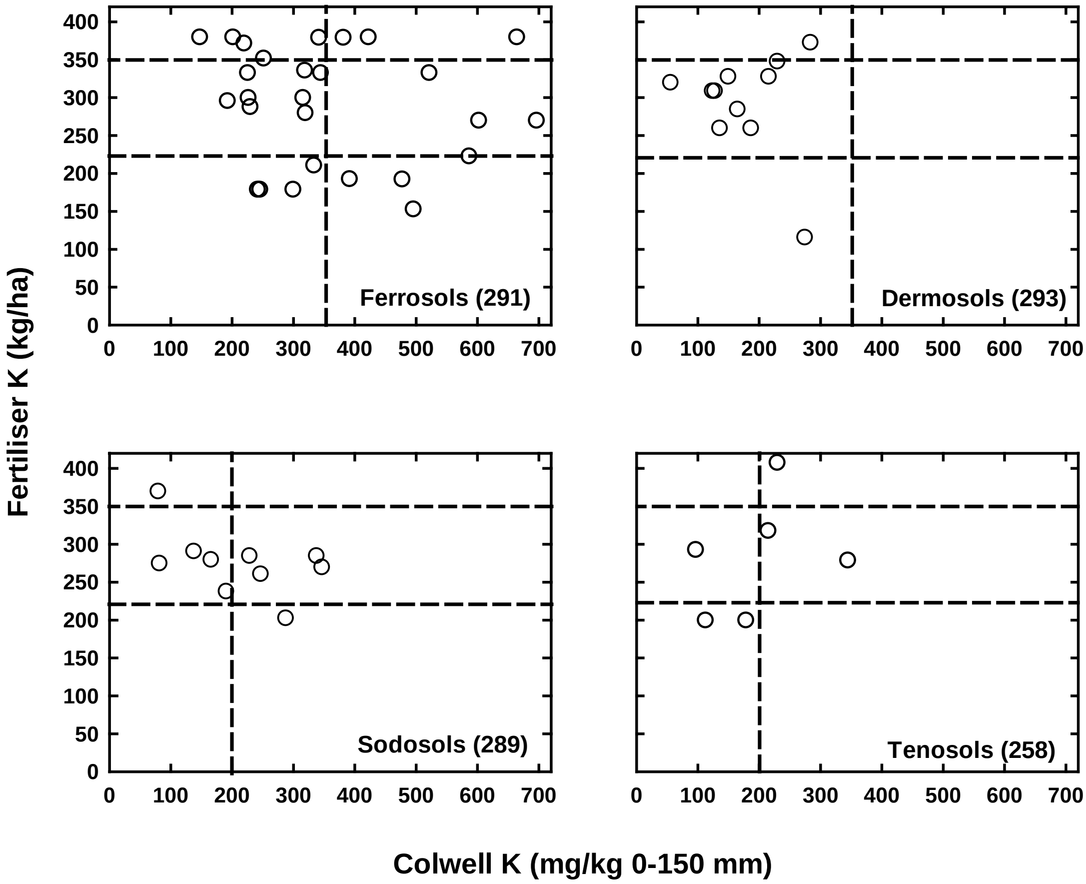


Figure 4. Fertiliser K rates versus soil Colwell K concentrations for potato sites (mean rates given after soil type names. Vertical lines show critical soil K, horizontal lines show range of K removal).

The differences in the level of total bases (TEB) (Table 10) are likely to be related to the amount of clay and organic matter in different soil orders as well as previous fertiliser history, as correlations were found between TEB or cation exchange capacity and organic carbon on Sodosols, Tenosols and Vertosols (Table 5). The Tenosols and Sodosols have the lowest amounts of clay (Table 6) and organic matter (Figure 5) and the Vertosols have the greatest amounts. However, direct correlation between TEB and sand or clay content is weak (r = 0.2).

The differences in ECEC between sites on Ferrosols (Table 10) were not related to the differences in organic C (*Fprob* of linear regression = 0.276, R^2adj. = 0.01) (Sparrow *et al.* 1999). This contrasts with results comparing developed (cropped or pastured) and undeveloped (forest) Ferrosols from various parts of Australia reported by Moody (1994) where developed sites had lower mean ECEC and organic C. The explanation for this may lie in the fact that the cropped Tasmanian Ferrosol sites had higher soil pH than did pasture sites (Table 9), whereas the soil pH of Moody's developed sites was not different from the pH of his undeveloped sites (Moody

1994). Linear regression of soil pH against ECEC showed that soil pH explained 40% of the variation in ECEC (ECEC = -10.46 + 4.19 pH_w, P<0.001). Adding organic C to pH in a multiple regression explained only 4% more of the variation. It was concluded that the effect on ECEC of the lower organic C concentration in cropped soils was compensated for by a higher pH due to liming. The importance of organic C as the dominant source of cation exchange capacity has often been emphasised in Ferrosols, where the clay fraction is dominated by sesquioxides and 1:1 minerals of low charge density (Isbell *et al*. 1976; Moody 1994; Moody *et al*. 1997). However, the capacity for lime to compensate for loss of organic C by increasing the ECEC of the remaining C is less recognised and seldom promoted as a way to maintain this component of chemical soil quality (Moody 1994).

Table 10. Average chemical properties of topsoils used for agriculture in Tasmania

Soil order	Soil property	Depth mm	Long term pasture	Cropping with shallow tillage	Cropping (including potatoes)	Crop + wet potato harvest
Sodosol	Colwell extractable P (mg/kg)	*0-150*	24a	52b	73bc	75c
(n = 25)	Colwell extractable K (mg/kg)	*0-150*	160	160	172	174
	Cation exchange capacity (cmol/kg)	*0-150*	11.6	10.6	10.5	13.5
Dermosol	Colwell extractable P (mg/kg)	*0-75*	38	53	84	
(n = 15)		*75-150*	27	46	82	
	Colwell extractable K (mg/kg)	*0-75*	367	196	350	
		75-150	183	126	286	
	Total bases (cmol/kg)	*0-75*	12.1	10.3	12.7	
Tenosol	Colwell extractable P (mg/kg)	*0-75*	31a	37a	74b	
(n = 15)		*75–150*	17a	27a	62b	
	Colwell extractable K (mg/kg)	*0-75*	305	297	226	
		75–150	158	195	157	
	Total bases (cmol/kg)	*0-75*	7.8	5.8	5.6	
			LTP	Rainfed crop	Irrigated crop	
Vertosol	Colwell extractable P (mg/kg)	*0-75*	41	84	68	
(n = 21)		*75–150*	21a	55ab	49ab	
	Colwell extractable K (mg/kg)	*0-75*	233	292	270	
		75–150	114a	178a	221b	
	Total bases (cmol/kg)	*0-75*	25.9	18.4	25.2	
			LTP	Intermittent crop	Continuous crop	
Ferrosol	Colwell extractable P (mg/kg)	*0-150*	78b	106b	163c	
(n = 24)	Colwell extractable K (mg/kg)	*0-150*	-	-	-	
	ECEC (cmol/kg)	*0-150*	12.3	16.1	15.5	

Intensive dairy production

A study was conducted in north west Tasmania on hump and hollow drained land on a Hydrosol under dairy pastures (Cotching 2000). Hump and hollow drainage is an artificial drainage system where the land surface is shaped into ridges and swales with construction machinery in order to promote lateral surface drainage and rapid surface runoff.

Soil analyses showed differences in nutrient concentrations on different parts of the paddock (Table 11). The side slopes of the ridges had lower extractable P levels (a measure of plant available phosphorus) than either the top or bottom components of the ridges and swales. Extractable K levels increased progressively from the top of the ridges to the bottom of the swales. These results may have been due to more fertiliser being applied to the tops of ridges than side slopes in addition to movement of K down slope with runoff. Levels of K in samples from the crest and sides of ridges were deficient for high producing pasture (Gourley 1999). Extractable P was more than adequate for pasture production on this sandy loam textured Hydrosol (Roberts 1989). It may be possible to lower P levels applied in fertiliser without adversely affecting production on many paddocks, which may also result in less P being lost in runoff. Lower levels of P fertiliser application would also help to increase farm profitability. Applying P fertiliser between November and March, when rainfall is recharging soil water storages rather than in winter and spring when run off dominates, would result in less P being lost from farms.

Table 11. Soil analysis results on hump and hollow drained land (Hydrosol) at Togari, north west Tasmania

Location on hump & hollow	Month sampled	Colwell extractable P (mg/kg)	Colwell extractable K (mg/kg)
Crest	March	175	42
	July	87	39
	September	160	53
Side	March	92	54
	July	71	49
	September	115	60
Swale	March	125	105
	July	86	91
	September	130	145

Analyses of runoff water showed that levels of dissolved reactive phosphorus (DRP) and total P were 10 - 100 times greater than those recorded in other parts of the Montagu River catchment, providing evidence that paddock runoff is a major contributor to nutrient levels in local waterways. The proportion of DRP was highest on 26 July (82%) and relatively high on 15 September (44%) indicating that recent application of fertiliser had impacted on runoff of soluble P. This is in agreement with Nash *et al.* (1998) who found that P concentration in runoff was controlled by the time between fertiliser application and runoff, with phosphorus fertilisers having a half life of approximately 10 days with respect to fertiliser loss.

Although total amounts of P leaving the paddock in runoff were not determined in this study, they are considered to be important because the hump and hollow drainage system is designed to optimise runoff. Losses in runoff were estimated at between 6.7 and 23.1 kg/ha/year, which has been confirmed by subsequent research (G. Holz *pers. comm.*).

This investigation of nutrient levels in soil and water under an intensive dairy production system has shown that fertiliser practices aimed at maintaining high productivity may not always be appropriately targeted and could be having significant off-site effects. Alternative management practices may be able to improve both the cost effectiveness of applied fertiliser and minimise effects off site.

6.3 Linking crop yield to soil chemistry

A change in soil condition can greatly affect crop growth and economic return to farmers (Charman 2000). Most of the experimental evidence of these effects in Tasmanian cropping systems relates to effects of soil chemical condition (eg. Chapman *et al*. 1992, Temple-Smith *et al*. 1983).

Research was conducted on the correlation of readily measured soil properties at paddock scale with commercial potato (*Solanum tuberosum* L.) and poppy (*Papaver somniferum*) crop yields growing on four soil orders used for cropping in Tasmania (Cotching *et al.* 2004). The soil properties and paddock variables significantly correlated with crop yield and assay varied depending on crop and soil type. Only two soil chemical properties on one soil order (Ferrosols) were correlated to crop yield but amounts of applied fertilisers were correlated to crop yield on several soils.

On Ferrosols, exchangeable Al^{3+} was significantly correlated with poppy yield (r = 0.63). Exchangeable Ca^{2+} correlated positively (r = 0.54) while applied N correlated negatively (r = -0.49) with poppy alkaloid assay. Poppy assay is an important determinant of overall poppy yield. On Dermosols, fertiliser P rate was negatively correlated with potato yield (r = -0.67). On Sodosols, fertiliser K (r = -0.41 and r = 0.55) and N rates (r = -0.45 and 0.42) were negatively correlated with poppy yield but positively correlated with poppy assay. This indicated that fertiliser application to increase the amount of active ingredient or assay, is commonly made at the expense of gross yield. Fertiliser P was found to be positively correlated with potato yield on Tenosols.

Research at small plot scale within paddocks on eroded slopes of Red Ferrosols (Cotching *et al*. 2002c) found that only one soil chemical property, that being Total Exchangeable Bases (TEB) in the 0-150 mm depth, was positively correlated to crop yield. A simple linear regression model was developed:

$$\text{\% maximum paddock plot yield} = 26 + 2.327 \text{ TEB}_{(0\text{-}150\text{mm})}$$

TEB could be a surrogate measure of other crop yield determining soil properties. However, subsequent research into the links between soil properties and crop yields at the paddock scale found no correlation between paddock yield and TEB (Cotching *et al*. 2004). The lack of clear relationships between single soil attributes and yield is perhaps not surprising because other factors such as soil physical properties may be confounding the result. Also, farmer management of water, fertiliser, pests and diseases may be having a significant influence. Trials with more control over site variables would allow for greater testing of the single factors with most influence on yield.

6.4 Summary

Many of the chemical differences found are likely to be due to additions of lime and fertiliser associated with normal agricultural practice. The differences in the level of exchangeable bases between soil orders are likely to be related to the contents of clay and organic matter and not just to fertiliser and lime additions. Topsoil pH in soils used for agriculture in Tasmania shows no sign of increased acidity associated with more intensive use. Amounts of phosphorus leaving the paddock in runoff from hump and hollow drainage systems under intensive dairy systems are high. Very few soil chemical properties were found to be correlated to crop yield however amounts of applied fertiliser were correlated to yield.

Chapter 7 – Erosion on Ferrosols in north west Tasmania

7.1 Chapter outline

Chapter seven presents information on soil erosion rates in Tasmania, particularly on Red Ferrosols in north west Tasmania. The effects of soil erosion on soil properties have been presented in previous chapters but the off site impacts on water quality are considered in this chapter. Links between soil erosion and land use are presented and the long term nature of the issue of soil erosion is discussed.

7.2 Introduction

The north west coast of Tasmania is dominated by Red Ferrosols formed on basalt lava flows erupted during the mid Tertiary period 25–60 million years ago. Landscape development has resulted in a dissected topography with these soils commonly found on undulating to steep slopes at the margins of flat-topped plateaux. The inherent physical properties of Ferrosols make them versatile soils, suitable for a variety of land uses.

Soil loss by accelerated soil erosion is one of three major challenges identified by Cotching (1995) for the sustainable management of Ferrosols. The other two major challenges are: structural decline, due to compaction; decreased aggregate stability and increased cloddiness; and declining organic matter content, due to reduced carbon inputs, topsoil erosion and oxidation.

7.3 Rates of soil erosion on Ferrosols

The Ferrosols are vulnerable to severe sheet and rill erosion as a result of their occurrence on slopes, frequent intense rainfall events, the fine seedbeds produced and the lack of vegetative cover during fallow periods and the early stages of crop growth. Soil erosion can result in direct loss of soil fertility (nutrients), loss of soil organic matter, deterioration of soil structure by incorporation of subsoil, and decreased capacity to supply water for plant growth. Once lost, these soils are irreplaceable on a human time scale due to the slow process of soil formation. Current estimates of soil loss at 10 to 142 Mg/ha/rainfall event (Cotching 1995) with a recurrence interval of less than 2 years over 1 hour, 12 hours and 72 hours periods greatly exceed rates of soil formation. Soil formation rates are poorly defined but have been found to be less than 0.5 Mg/ha/year from consolidated bedrock material (Pillans 1997; Edwards and Zierholz 2000) such as basalt. Soil formation rates of Ferrosols under eucalyptus forest in Victoria, Australia, were calculated at 0.39 and 0.68 Mg/ha/year (Feller 1981). A study on erosion rates Australia wide (Richley *et al*. 1997) found that permanently vegetated pasture sites have significantly lower rates of erosion than annual cropping ground (Table 12). Rates of erosion per hectare were found to be less in Tasmania than in other States under both grazing and cropping. In Tasmania, soil erosion occurs at rates greater than soil formation (> 0.3 T/ha/yr) on land used for cropping as frequently as in NSW, and more frequently than in Queensland. These results need to be interpreted carefully as the sites were not randomly selected and were selected to provide a cross section rather than full geographic coverage.

Table 12. Net soil loss (Mg/ha/yr) as measured using Caesium-137

Grazing or forestry / unused				
State	**No. of sites sampled**	**Range**	**mean**	**% of sites < 0.3 t/ha/yr**
Queensland	8	0 – 4.1	1.1	53
New South Wales	17	0 – 7.3	0.8	50
Western Australia Rangelands	10 9	0 – 3.8 1.9 – 25.4	0.9 13.5	40 0
Tasmania	16	0 – 3.5	0.6	53
Cropping + Cropping/grazing rotations				
State	**No. of sites sampled**	**Range**	**mean**	**% of sites < 0.3 t/ha/yr**
Queensland	6	1.3 – 14.7	6.3	17
New South Wales	12	0 – 41.2	7.3	8
Western Australia	4	0.1 – 46.0	7.9	< 1
Tasmania	8	0 – 8.2	3.0	13

Several strategies are recommended to prevent soil erosion on Ferrosols including (Cotching 1995):

- Prevention of runoff from upslope paddocks, roads and tracks coming onto cultivated ground with diversion (cut-off) drains
- Protection and stabilisation of natural drainage lines using grassed waterways.
- Shortening the length of slope on paddocks
- Disposal of water into vegetated natural watercourses, or grassed waterways
- Vegetating risk areas when using irrigation equipment, i.e. grassed irrigator runs
- Establishment of grassed buffer strips between cropped areas and waterways or dams.

7.4 Effects of soil erosion on Ferrosols

Soil erosion usually leads to degradation of soil properties at the site of loss but the effect of soil deposition is less clear. The 'on-the-paddock' effects of erosion on Red Ferrosols have been described in Chapters 4 (organic matter), 5 (physical properties) and 6 (chemical properties) with evidence of associated yield decline also presented (Cotching *et al.* 2002c). Crop yield was found to decline with increasing slope. The amount of erosion that had occurred on slopes up to 18% slope had not been so great as to significantly impact on crop yield. Continued erosion at current rates on this less steep land is anticipated to inevitably reduce crop yields.

7.5 Soil erosion and water turbidity

The Red Ferrosols are vulnerable to severe sheet and rill erosion for a number of reasons. These include their landscape position, rainfall events with a recurrence interval of less than 2 years, preparation of fine seedbeds produced for cropping, and the lack of vegetative cover during the early stages of crop growth. The erosion of farmland results in off-site water quality problems such as high water turbidity and total suspended solids in most of the streams in the north west of Tasmania. The effects of particulate matter can be detrimental to aquatic life, while also causing the water to be unsuitable for irrigation and consumption by humans and livestock.

Water turbidity and calculated volumes of water borne sediment (total suspended solids -TSS) reveal that erosion is an active process at both catchment and paddock scales on the north west coast of Tasmania during frequent storm events (Sims and Cotching 2000). Turbidity readings of more than 20 NTUs (nephelometric turbidity units) recorded during storm events show that suspended sediment concentrations were high and water quality was poor in all catchments except for two small catchments (Kindred 1 and Kindred 2) with permanent vegetative cover. Samples taken during flood flow periods indicate that turbidity levels in all sampled streams exceed the interim trigger levels (ANZECC 1998) for assessing risk of adverse effects on different ecosystem types. The data indicated that turbidity levels remain elevated for at least 14 days following the flood event.

At a catchment scale, eroded sediment may be derived from stream bank or stream bed erosion, sheet and rill erosion from paddocks, and roadsides or forestry operations. In the monitored catchments there was little evidence of stream bank erosion, and forestry was only a minor land use in some catchments. The very high turbidities recorded in water from farm paddocks, and previous measurements of in-paddock soil erosion rates, leads to the conclusion that soil erosion from cropping paddocks is the major contributor to sediment load in streams in north-west Tasmania.

It is likely that a large portion of bed load sediment is retained in dams that broach streams, although this will vary depending on the trap efficiency of the dam and the ratio of suspended to bed load. This may account for the lower turbidities recorded in the lower reaches of the heavily dammed streams of Claytons Rivulet and Buttons Creek. It is also likely that a large portion of eroded sediment is stored along channels during recessions in flood flows.

Turbidity readings and associated total suspended solids are plotted in figure 24. The correlation ($r^2 = 0.87$) shows a close relationship between turbidity and suspended sediment loads in streams flowing from catchments in northwest Tasmania. The establishment of a reasonable relationship between these two parameters means that turbidimeters can be used to estimate stream suspended sediment loads. Turbidity is an easier measurement to make, and together with flow data can give a good indication of the suspended sediment loads resulting from soil erosion and aggregate dispersion. However, the instrument does not measure bed load, which may represent a considerable part of the eroded soil as the well agggregated Ferrosols are likely to remain in larger particle sizes that settle out rapidly.

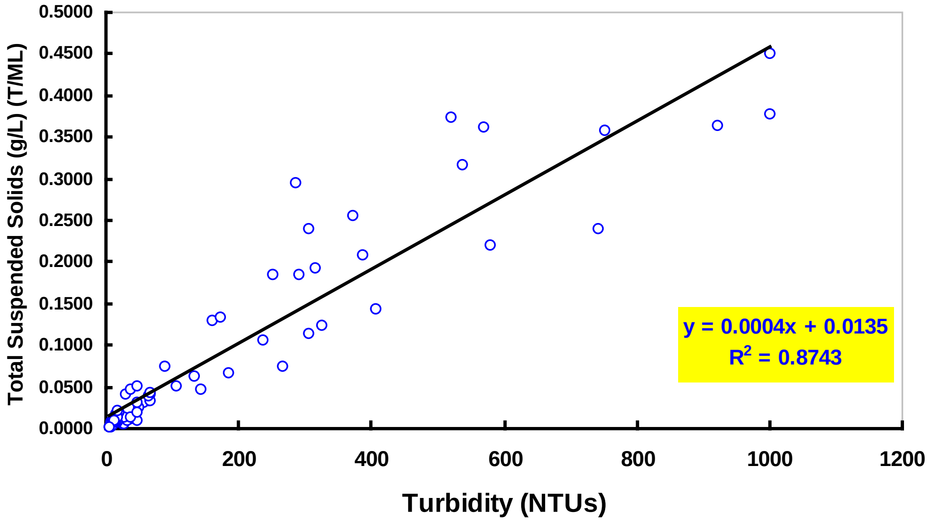


Figure 24. Relationship between turbidity and suspended sediment concentration in streams of northwest Tasmania

The highest turbidity and TSS readings were recorded in runoff from fallowed paddocks. A high TSS was also recorded from a newly sown oat crop where the sparse amount of vegetative cover did little to prevent erosion.

The process of erosion is a natural part of landscape formation and development. Sims and Cotching (2000) confirmed that in intensively cropped catchments on the northwest coast of Tasmania erosion is being accelerated by unsustainable farming practices. The effect of this erosion is not only an on-site soil degradation issue but also results in off-site environmental degradation in the form of high stream turbidity and suspended sediment loads, which impact on stream flora and fauna. This study showed that in areas with annual cropping rotations, which have fallowed ground in spring, soil erosion is active and results in degraded water quality. The protection of soil by vegetative cover is therefore critical in preventing the on and off-site effects of soil erosion. This means that paddock rotations need to be planned in advance with careful consideration of erosion control measures, soil cultivation practices, harvest times and crop suitability.

The erosion of the highly productive Red Ferrosols has implications for long-term land use as well as for short and long-term off-site environmental effects. Current environmental regulations allow for control of off-site effects and need to be fully implemented to ensure good water quality. Some land holders are pursuing best management practice by installing appropriate soil conservation measures but others use their land beyond its capability with long crop rotations, poor soil management practices, and poor riparian zone management with consequent environmental degradation.

7.6 Linking land use and water quality

Jolly *et al.* (1996) indicate that one of the key determinants of stream turbidity is land use. To investigate how water quality is affected by land-use in north west Tasmania, the Buttons Creek catchment was monitored from April to October 2002 for turbidity, orthophosphate, nitrate, macroinvertebrates and landuse. Buttons Creek catchment is considered representative of other small catchments in the north west of Tasmania because of its intensive land-use, and small area (1820 ha). Four sub-catchments were monitored that have streams with steep gradients (1%), flow over short linear distances (2–5 km), and are highly modified by farm dams. The land is used for cropping and livestock production. Soils are predominantly Red Ferrosols with minor inclusions of sandier Brown Dermosols. The majority of the cultivated areas have slopes of 5–18%.

At the Buttons Creek gauging station in the lower reaches of the catchment, average turbidity was above the trigger level of 29 NTU’s. Increased stream flow caused by heavy and extended rainfall caused turbidity levels to increase to 430 NTU's, and readings of over 1000 NTU's have been recorded in previous years. It is these extreme events which are likely to have the most ecosystem impact.

All of the stream soluble nitrate N values were less than 1.0 mg/L which is well below the World Health Organisation safe limit for potable water of 10 mg/L. The nitrate may be derived from leaching of fertilisers, mineralization of organic matter or from nitrogen fixation by legumes.

Low concentrations of phosphorus in water samples were measured in all of the sub-catchments in this study with all values below 0.015 mg/L. Superphosphate is a widely applied fertiliser and the Red Ferrosols have the ability to ‘fix’ large amounts of fertiliser phosphorus in a form unavailable to plants due to the presence of active iron and aluminium oxides. This phosphorus fixation appears to be preventing soluble phosphorus from entering the aquatic system. However, phosphorus fixed to soil particles is reaching the waterways.

Average turbidity was found to be correlated to the percentage of land cropped or fallow in each subcatchment (Figure 25).

The second most intensively cultivated sub-catchment (32–37% of area cultivated in spring and autumn respectively) had the lowest average turbidity, P and N values. However, this sub-catchment had the highest percentage of its area under native bush (26%) suggesting that native bushland has a mitigating effect on stream turbidity.

It would appear that a significant proportion of eroded sediment is deposited in farm dams that broach streams but sediment collected from the lower end of the catchment had a total P concentration of 1500 mg/Kg, indicating deposition of topsoil in the lower reaches of the catchment.

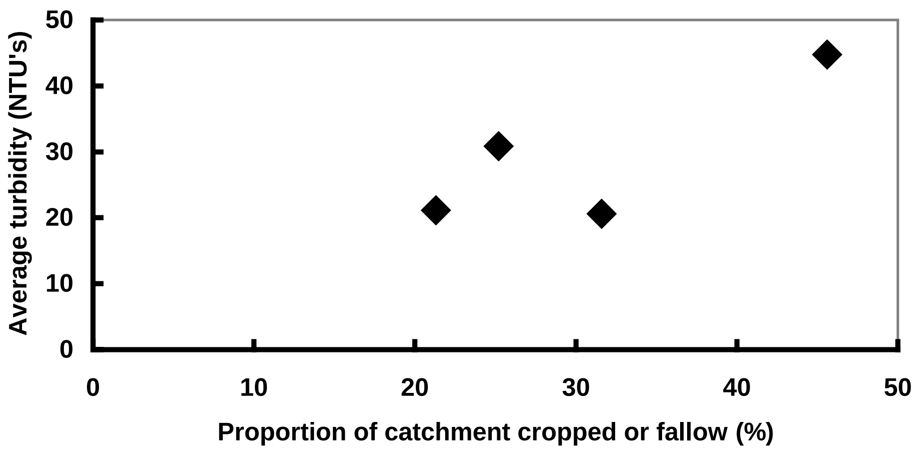


Figure 25. Relationship between stream turbidity and area of land cropped or fallow in each subcatchment

Snapshot measurements of stream flow also indicated that land use was having an impact on runoff during high flow events (Figure 26). A sub-catchment dominated by perennial pasture cover had greater flow rates during low winter flow conditions, but during intense rainfall events the a sub-catchment dominated by annual cropping ground yielded the highest flow rate indicating that run-off is greatest when ground cover is reduced. The high runoff and turbidity during a high rainfall event indicate that run-off and soil erosion are closely linked.

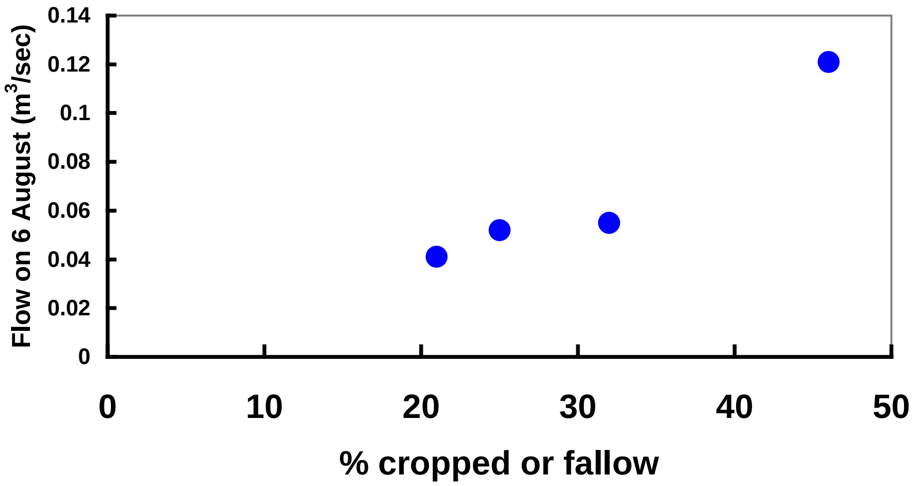


Figure 26. Relationship between runoff and area of land cropped or fallow in each subcatchment

The results from macro invertebrate surveys suggest that high summer temperatures and low summer flow have a greater impact on macro invertebrate populations than elevated winter turbidity. Population numbers more than doubled over the sampling period suggesting that conditions are more favourable during the winter period in comparison to low population numbers following summer. It is possible that winter turbidity has little impact on macro invertebrate populations as flowing stream water in this catchment is not turbid for extended periods. The deposition of suspended particulate matter is more likely to affect the habitat and population size of macro invertebrates.

7.7 Soil erosion - A long term problem

Soil erosion mostly happens over brief periods, is often confined to only a few paddocks on a farm at any one time, and many visible signs are lost from view by subsequent cultivation. In one farmer’s lifetime on the land, the effects of erosion may be progressive but masked by improved plant cultivars, greater fertiliser and irrigation inputs and larger machinery. Declining yields may not occur over entire paddocks or may be attributed to seasonal differences. Soil formation happens so slowly that even in 1000 years only 20 mm of new soil will be formed according to optimistic estimates (Pillans 1997; Edwards and Zierholz 2000). Consequently, the cumulative effects of erosion will only become obvious after many generations. Measurements of soil erosion in Tasmania shown in Table 12, indicate that average soil loss over 1000 years under continuous cropping could range from 0–300mm, which far exceeds soil formation.

A small proportion of cropping farmers in north west Tasmania have taken this problem seriously by installing soil conservation measures to prevent erosion. Soil conservation to prevent erosion can be likened to taking out insurance against potential soil loss. Potential soil erosion events may not occur every year but the soil conservation measures need to be installed in case they do.

Reasons why farmers do not adopt sustainable land use practices include (TBA Planners *et al*. 1998):

- Farmers generally crop intensively to meet short term financial goals
- Low profitability promotes management for the short term
- Conservation techniques cost time and money in the short term
- Some farmers indicate there is insufficient profit for investment in soil conservation
- Farmers need mechanisms to reward sustainable practices
- The financial benefits of sustainable management predominantly accrue in the long term.
- Land tenure is dynamic with farms changing ownership for reasons such as retirement, lifestyle choice, financial pressure or career development.

There are no quick fix solutions to the problem of on-going soil loss. However, preserving the productive capacity and versatility of Tasmania's rich Red Ferrosols is of critical importance to the State's economic and social future. Farmers' livelihoods depend on continuing production and regional centres such as Devonport, Smithton and Ulverstone have a large percentage of their population dependent on agricultural processing and service industries. The challenge for land managers is to value soils as a critical resource and as such it must be conserved for the benefit of future generations while at the same time allowing for today's productivity and cropping for profit. My view is that soil erosion will generally diminish due to adoption of better management practices. However, some paddocks will be seriously degraded with total loss of the A horizon, and these will have to be retired from annual cropping to less productive pastoral use. I do not envisage bare hillsides of basalt rock with no agricultural production. I hope that 1000 years from now our rich red soils are as productive as they are today and those working and understanding the land acknowledge the sustainable practices adopted by today's land managers.

Chapter 8 – Farmer perceptions of soil management

8.1 Chapter outline

Chapter eight presents information from a series of surveys of farmer perceptions that were conducted three times over a ten-year period (Ewers *et al.* 1989; Chilvers and Cotching 1994; Sims and Cotching 1999). The surveys asked questions relating to crop rotations, soil erosion, soil structure and responsibility for management in an attempt to determine changes in soil management practices.

8.2 Surveying perceptions

Australian Commonwealth and State government resources have been directed at changing farmers' attitudes towards soil conservation and to implementing changes in land management practices. This effort has been focused by the Landcare movement, which began in 1988, and by the Commonwealth Government's declaration of the Decade of Landcare in 1990 (Roberts, 1993). Surveys of farmers' attitudes and behavior show that land degradation is primarily a social, rather than a technical problem. Solutions to land degradation are not adopted by farmers for a wide variety of social, economic, cultural, perceptual and situational reasons (Nowak, 1992; Rickson *et al*. 1988; Vanclay, 1992). There has been awareness amongst those working as agents of change in agricultural soil conservation that a range of components have to be included in any program to ensure on-the-ground outcomes. Agricultural extension requires adult education, facilitation of group learning, working with individual farmers on site-specific problems, providing information and generating ideas (May and Mason, 1992).

The success of ten years (1988-1998) of active extension in soil conservation and management by government agencies and the Kindred Landcare Group on the north-west coast of Tasmania (Kindred Landcare Group, 1994) was measured by surveying farmer perceptions three times over a ten-year period (Ewers *et al.* 1989; Chilvers and Cotching 1994; Sims and Cotching 1999). The survey questions remained unchanged over the 10 years except for two additional questions being asked in 1993 and in 1998.

Median farm size increased with the mean area cropped and % farm cropped also increased over the 10-year period. This indicates that farmers are now cropping more of the ground they farm and are cropping ground more intensively. Property management planning is important in the adoption of sustainable land use (Carey 1991) with farmers who had attended a property management planning course more likely to use soil conservation practices on their farm. Those who had attended a course had an average of 40 ha of soil conservation earthworks established, whereas other farmers had only 14 ha of soil conservation.

8.3 Crops and crop rotations

There is a constant change in crop rotations with 56% of 1998 respondents having discontinued growing certain crops in the past two years. This may imply that many farmers plan rotations and required paddock layouts in the short term, which compromises commitment to longer-term paddock layouts necessary for some soil conservation practices. Economics was the main reason given for discontinuing crops. Soil degradation, unavailability of contracts and incompatibility with farming systems were also cited as lesser factors.

There was an increase in the number of farmers with a pasture phase in their rotation over the ten years (54 to 77%) and the reasons given for growing pasture were to rest the paddock, improve soil structure, provide fodder and improve organic matter. Farmers appear to be more aware that pasture is an important soil management tool that is needed in a good rotation.

Growing green manure crops increased in popularity with approximately half of the average area cropped per farm under green manure**.** Annual ryegrass is grown in preference to oats, tickbeans or ryecorn and lupins are grown by 20% of farmers. Farmers indicated that oats make the ground claggy, hard to work, and after incorporation they keep the ground wetter for longer. Farmers also stated that ryegrass has a dense fibrous root system which improves soil structure and organic matter. These changes in awareness of the management effects of the different green manure crops coincides with an active extension campaign on green manure crops by DPIWE staff over the 2 years prior to the 1998 survey. Ninety eight percent of those interviewed in 1998 said they would be growing a green manure crop in the next 12 months indicating farmers' on-going commitment to this soil conservation technique.

8.4 Soil erosion

Most farmers can visually identify soil erosion by the loss or accumulation of soil at fence lines, the washing of soil down slopes leaving ruts and rills, and by red and dirty waterways and dams. These observations are of the more advanced stages of rill and sheet erosion. However, farmers may be underestimating the amount of soil erosion because the first stages of rill and sheet erosion are hard to detect and interpret. Farmers are more willing to admit to problems in their district rather than on their own farms which is an attitude that has also been found in natural resource management issues in other areas of Australia (Dunn and Gray 1992; Barr and Cary 1984). This discrepancy between district and farm may be due to misperception and underestimation of land degradation processes (Rickson *et al.* 1988; Vanclay 1992). Scientists and conservation advisers use scientific methods and sophisticated tools to measure soil loss while farmers predominantly use visual measurements or subjective methods. Consequently farmers perceive only major gullies as erosion, but other forms of erosion, such as sheet and rill erosion, are seen as "a little bit of wash" (Chamala *et al*. 1983).

Most farmers thought that erosion was not getting any worse, which could have been due to an increase in the adoption of soil conservation techniques, less erosive events in the recent past, or an increasing acceptance of erosion as a part of farming. This last explanation is unlikely in light of the increasing focus of environmental and government groups on both the on-site and-off site effects of soil erosion.

There was an increase in the number of farmers claiming to be doing something to reduce soil erosion which indicates that farmers are becoming more aware of soil erosion. The soil conservation earthworks used included contour drains, grassed irrigation runs, growing green manure and deep ripping.

More farmers now grow a cover crop with onions for soil erosion control with some using it to protect onions from weather damage in the early stages of growth. Over half of those interviewed expressed interest in further technical information on cover crops suggesting the need for the development and availability of this information.

8.5 Soil structure

There was a progressive decrease in the perceived extent of soil compaction, surface crusting and cloddiness on farms over the 10 years. This may be because of an increase in awareness of these problems with farmers taking more preventative measures to ameliorate and lessen the effects of structural decline in the soils they crop. Over 90% of farmers interviewed in the 3 surveys stated they had thought about problems associated with soil structure in the last 12 months. They had considered ways of preventing structural decline and ways of improving soil structure including green manure cropping and the way they worked the soil.

Farmers decreased the number of tractor passes taken to prepare their onion seedbeds. Those farmers using five or more passes to prepare their onion seedbed decreased from 43% to 10% or less over the ten years. Using two or three passes means there is less chance of overworking the soil and so less chance of soil structure degradation.

The use of the deep ripper increased and there was a considerable shallowing in the depth to which farmers now rip, with the majority of farmers now ripping to less than 300mm depth. Perhaps farmers now recognise that deep compaction is uncommon on Red Ferrosols (Sparrow *et al.* 1996) and use ripping more as a surface cultivation technique rather than a deep tillage operation.

8.6 Responsibility for soil management

In 1998 farmers were asked about whom they viewed as responsible for soil management and sustainability. Seventy three percent of farmers strongly agreed that farmers should take more responsibility for soil management on their properties but the same percentage also agreed that processing companies should share responsibility for soil sustainability. Many of the farmers felt strongly about this topic, as soil management is seen as an important issue for them.

Production of crops under contract to processing companies is the predominant means of production in north west Tasmania. Consequently, in 1993 and 1998 farmers were asked 'Are processing companies and contractors willing to cooperate with your efforts to conserve soil?' In 1998, 63% agreed compared to 80% in 1993.

This change in farmers' perception highlights an increasing contrast in objectives between farmers, contractors and companies. A focus by companies on maximising returns to shareholders in the short term is unlikely to allow for expenditure on natural resource management issues which have long pay back times but which would ensure long term sustainable production systems. From discussion with farmers the majority of the problem lies in the harvesting and planting of crops in unsuitable conditions as well as unnecessary traffic on cultivated paddocks with designated headlands often not used. Farmers identified positive things that processing companies and contractors could do to assist in reducing soil erosion including avoiding harvesting in wet weather, provide potato storage facilities, encourage the use of soil conservation earthworks, and provide advice on technical issues.

8.7 Discussion

There have been many positive changes in the way cropping farmers on the north west coast of Tasmania perceive soil management and degradation over the decade from 1988 to 1998. Survey responses indicated that there have been increases in the use of a pasture phase in the rotation, growing green manure and cover crops, and the amount of grass grown. The majority of farmers also intended taking action to prevent or ameliorate soil structure problems in the following 12 months.

Cost is one of several barriers to adoption of soil conservation measures (Green and Heffernan, 1987) with farmers facing a continuing cost/price squeeze. Developers of new soil conservation techniques need to keep this in mind but for many farmers financial constraints may only be a perceived, rather than an actual, barrier to adoption of soil conservation practices.

Some recommended soil conservation techniques have associated management difficulties such as maintenance, machinery damage, inconvenience and weed and pest problems. Development of new soil conservation techniques is required, but researchers need to be mindful that farmers will adopt new management practices only if they perceive them to be proven, practical and profitable, and preferably demonstrated on their own farms (May and Mason 1992). This demand has led to the development of the ‘mulched rip lines’ technique (Cotching 2002).

Processing companies have an important role to play in ensuring that good soil management practices are used. They should respond to the farmers’ request for them to share the responsibility for sustainable soil management rather than dictating what soil management practices should be applied without taking responsibility for preventing associated problems of soil compaction, soil erosion and stream turbidity. Farmers need to adopt property management plans that include an environmental audit and a strategy for reconciling present practices with environmental regulations, which would bring the farm enterprise closer to sustainable land management (Geno 1999).

Many of the changes reported in the surveys show a positive change in farmer perceptions and practices on the north west coast of Tasmania over the Decade of Landcare. However, there needs to be a greater sharing of responsibility for ensuring sustainability of soil use between farmers, processing companies, government agencies and the rest of society. To leave farmers' entirely responsible for voluntary adoption of soil conservation measures to achieve long-term public benefits recognises neither social nor economic realities (Rickson *et al.*1988).

Chapter 9 – Management information for sustainable soil use

9.1 Chapter outline

Chapter nine presents information on how relevant management information presented in this body of research was extended to local farmers. This information was provided in brochures which provide information in an easy to read and pictorial format. Some of this information is also available on the Internet (http://www.dpiwe.tas.gov.au). An implement and methodology invented by the author to minimise soil erosion is also described.

9.2 Soil specific cropping management strategies for Tasmania

Expansion of intensive cropping from the north west coastal region of Tasmania into the midlands and southern areas has been occurring since 1990. Soil preparation and management techniques for crop production have been developed on the predominant Red Ferrosols of the north west with contractors and farmers transferring these methods to other areas. However, soils in these other areas are rarely Red Ferrosols but a range of soils including deep sands (Tenosols and Rudosols), duplex soils (Chromosols, Kurosols and Sodosols) and black self-mulching clays (Vertosols). Cotching and Chilvers (1998) found that some of the soil management practices being used were inappropriate for soils of different texture, mineralogy and profile characteristics to the Ferrosols. There was a need to identify fundamental soil differences for farmers and contractors and for them to apply appropriate soil management techniques to each soil type.

An extension project was run which presented information to Tasmanian cropping farmers in order to stimulate greater adoption of best soil management practices. Information on properties, tillage and management of different soil types was brought together and combined with known properties of the range of soils used for cropping in Tasmania. A book describing soil specific cropping management strategies was published (Chilvers 1996) which was used as the basis of an information and extension program to farmers and contractors. Soil specific management guidelines for five soil types were formulated from farmer discussion groups and then used to identify best management practices. The five soil types were Dermosols (Cressy shaley loam), Ferrosols (Burnie clay loam), Sodosols (Brumby sandy loam), Tenosols (Panshanger sand) and Vertosols (Canola and Churchill clays).

A project based two-year extension program on soil specific management was conducted from 1994 to 1996. This project utilised farmer discussion group meetings, public field days, and soil profile examinations, to generate discussion with farmers and agronomists. Presentations to Landcare groups, teaching university and TAFE students, publishing articles in newspapers and journals, and radio interviews were all part of a larger awareness campaign. The positive outcomes of the project are a good example of how soil morphology can be used to influence appropriate soil management practices by farmers. However, the written material is only a basis for discussion with farmers, rather than being the sole product of an extension program. Successful extension resulting in adoption of better management practices, usually requires close interaction with farmers in the paddock, and often working along side them as they try out and use the preferred soil management techniques.

9.3 Reducing soil erosion on slopes used for annual cropping

A new soil erosion control technique was developed for slopes (5–20%) that are used for annual cropping in north west Tasmania. Mulched rip lines are installed in paddocks sown to annual crops using a purpose-built implement. Immediately after sowing, level contour lines are marked across the slope with small brightly coloured flags. A two-tined ripper hitched to a wheeled tractor is used to install rip lines across the slope. At the same time mulched cereal straw is laid on top of the rip lines at a rate of approximately five tonnes per hectare in the rip line. The mulched rip lines are spaced at 25 to 80 m apart, depending on slope.

The mulched rip lines are designed to retain run-off water on the paddock by:

- Slowing water movement downslope with the straw; and
- Getting the water to infiltrate into the soil along the rip lines.

The bulk of the soil moving downslope is also trapped by the straw and so prevented from leaving the paddock. Previous erosion control techniques relied on catching run-off water in sloping contour drains and directing it into grassed drains to remove the water from the paddock. The contour drains and permanent grassed drains were unpopular with farmers because they gave a rough ride when spraying by tractor, spray booms and harvesting equipment suffered breakages, crops had to be hand pulled either side of the drains prior to harvest, and drains had to be filled in before harvest. A colour brochure was produced and sent to over 700 farmers supplying McCains Foods and Simplott in the north west of Tasmania. The new technique, which was designed locally for use in Red Ferrosols, has received a much higher level of acceptance by farmers. The technique was first trialled in 1999/2000, the first implement was built for the 2000/01 season when 100 ha was protected from soil erosion and in 2001/02 over 600 ha were protected. There are now six implements in use in Tasmania and one in Dorrigo, New South Wales. This simple new erosion control technique is a very low cost insurance against likely soil erosion. Further research into an assessment of the benefits of using this technology is needed to quantify the amount that soil erosion is reduced, how long the effect lasts in different soil types, what the optimal spacings are, overall crop yield effects, and optimal depth of ripping on different slopes and soil types.

9.4 Red Ferrosol topsoil structure

A guide for farmers to assess the structure of Ferrosol topsoils and to show better ways to manage their soils, was published as an easy to read brochure with numerous colour plates to illustrate the described information (Cotching 1997). This guide is for farmers and field officers to use in the paddock to help identify soil structural problems which can be readily observed in the paddock and to show ways of managing soils to prevent degradation and actively improve structure.

The brochure presents visual clues to soil structure problems at 3 different scales:

- Paddock appearance with problems of machinery ruts, ponding, patchy crop growth and soil erosion.
- A closer look with indicators of poor soil structure being: hard to dig, many large clods, surface crusting and plant roots along clod faces.
- A close look at the soil aggregates revealing plate like layers, smooth clod faces, sharp angular aggregates and fine powdery seedbeds.

Advice is given on how to improve soil structure by using a pasture phase in the rotation, growing green manure crops, deep ripping and retaining crop residues. The brochure also provides some information on what soil structure is and its functions. It also describes how dynamic soil structure is, how susceptible it is to change, and how long it takes to rejuvenate structure.

9.5 Soil structure scorecard for clay loam textured topsoils

Visual assessment of structure was found to be an easily applied soil test and this was correlated to crop production on heavier textured Dermosols and Ferrosols (Chapter 5.3). The scorecard (Figure 19) presents a scale from 1–10 to visually rate the appearance of the topsoil according to the presence of clods, the size of aggregates and clods, the shape and surface roughness of aggregates and clods, plus the size distribution of aggregates. A score of 6 or less indicates that there are large firm aggregates (clods) and some powdery unaggregated soil present, which is considered to be indicative of soil structure degradation. If soil structure degradation, such as cloddiness, is visible on clay loam topsoils of Dermosols and Ferrosols, then crop yield is probably being limited and this may be having a considerable impact on farmers' returns. The structure scorecard is now being trialled as a practical diagnostic test by farm advisers and agronomists.

9.6 Growing pyrethrum on Red Ferrosols

A guide for farmers growing pyrethrum on Red Ferrosols in northern Tasmania was published (Cotching and Sparrow 2000) which provides information on the best ways to manage the Red Ferrosols for sustainable production and gives results of research into the effects of pyrethrum on soil properties. The brochure is given to farmers by field staff of Botanical Resources Australia, the company controlling the growing of pyrethrum in Tasmania.

The brochure outlines the good properties of Red Ferrosols but also emphasises the degradation currently occurring. Practical guidelines on tillage options and timing of operations are given for the preparation of a paddock for growing pyrethrum. Advice is given on how to avoid the major risks of degradation by cultivating when the soil is friable, avoiding compaction, protecting against erosion, maintaining nutrient levels, and growing green manure crops.

Results of research into the effects of growing pyrethrum on subsequent crops are included (Sparrow and Cotching 2001). The research found no significant differences in crop yield in crops grown after pyrethrum, growing pyrethrum decimates the earthworm population, and topsoils had lower resistance to penetration, which would make them easier to cultivate.

9.7 Managing wet soils on dairy farms

Most of the research and management information described has related to cultivation of the soil for annual or perennial crop production. Crop production involves the intensive use of machinery and this can have detrimental effects on soils. Intensive livestock production can also have detrimental effects on soils if the livestock and soils are not managed appropriately. This is particularly so when soils are wet as this is when they are most susceptible to degradation. Tasmanian dairy farmers estimate that a wet winter/spring can cost from $20 000 to $50 000 in a season with many of the costs being carried through to the following season. These costs are due to buying in extra feed, lower pasture utilisation, pugging of soils, and cultivation and re-sowing of damaged pastures.

A series of discussion groups was held with groups of dairy farmers in the State to gather relevant information and to make them aware of potential soil management problems and ways to manage them. A full colour brochure was subsequently produced on how to manage wet soils on dairy farms and this was sent to every dairy farmer in Tasmania (Cotching 2000).

The brochure shows the type of soil degradation that can be caused and the consequences and costs for herd management. Management problems on dairy farms that can result from wet soils include:

- Cow lameness,
- Mud in the dairy and on cows udders requiring cleaning
- Farmer discomfort
- Pugging of soils resulting in soil structure degradation
- Pasture damage by treading
- Slow grass growth
- Late start to seasonal growth

- Slow stock movement
- Restricted machinery access
- Low pasture utilisation rate
- Poor shed hygiene (mastitis, high somatic cell counts)
- Surface water ponding.

On-the-paddock soil and pasture management is based on an understanding of the soil types on the farm – their fundamental properties and their behaviour when wet. Wet soil conditions can be created by many factors such as a high regional water table, landscape position resulting in seepage, slow permeability, a perched water table, degraded soil structure, non-wetting behaviour, presence of a surface thatch, or intense rainfall that exceeds drainage capacity.

Twelve low cost solutions are presented giving farmers ideas on what they can do immediately to manage their soils during wet periods. The short-term management options to overcome on-the-paddock problems were:

- On-off grazing to give short grazing times when raining
- Stand the cows off the paddock on a hard surface area when soils are wet
- Graze well drained soils in wet periods
- Feed out on sandy banks
- Over graze or sacrifice particular paddocks due for pasture renovation
- Back fencing of fed pastures to stop cows trampling over grazed areas
- Start the winter with more grass cover
- Give the cows a bigger area for grazing in wet weather
- Feed off areas furthest from the paddock gate first
- Delay calving
- Minimise mastitis infection by removing cows from pugged paddocks
- Use wider gateways
- Don't go and look at the cows more than is necessary.

The higher cost options include agistment of stock (leasing additional land for grazing cows on), building a feed pad, or installing drainage with the type of drainage depending on soil type. Photographs of local farmers were included to give credibility to the advice offered.

Chapter 10 – Summary and conclusions

10.1 Overview

The thesis reviews 23 publications including refereed papers, soil survey reports, soil maps, interpretive brochures and an unpublished technical report. The primary aim of the research has been to provide information required by land managers on inherent and dynamic soil properties for sustainable intensive agriculture.

To achieve this objective, the research has included four main components:

- Soil surveys to assess inherent soil properties, and their interpretations for intensive agricultural use in the Bay of Plenty, New Zealand and north west Tasmania
- Assessment of the effects of intensive agriculture on soil organic matter, soil structure and soil chemical properties
- Assessment of soil erosion and associated off-site effects of intensive agriculture
- Farmer assessment and perceptions of soil health and management, plus relevant soil management information.

10.2 Soil surveys

Soils in the Bay of Plenty, New Zealand, covering an area of 33 300 ha in the Te Puke district were characterised and mapped at a scale of 1:15 000 from 1978–1982 (Cotching 1998). During the survey, 24 soil series were identified and 60 soil map units were defined.

Tephra deposits (unconsolidated volcanic materials) are the predominant parent material of soils occurring in the Te Puke and surrounding districts with the Kaharoa Ash having a dominant role. The soils are characteristically young soils with all but the raw soils having some component or layer of tephra in their profiles.

The differing chemical properties between and within the soils of the Te Puke district result mainly from the layered nature of the parent materials with the nutrient status being related to the low overall nutrient status of the parent rhyolite. Soils developed in volcanic ash are sandy and free draining due to considerable volumes of large pores, they have high to very high available water capacities and they have no barriers to root growth. Soils on low-lying former swamplands and floodplains have restricted rooting depths due to high ground water and contrasting textures and pore-size distributions between horizons which inhibits drainage.

A land use interpretation based on inherent soil properties is presented that was driven by the high value of the crops grown in the Te Puke district. This describes the soil and landscape properties that need to be managed for intensive horticulture, together with the degree of management input required for the various soils.

A catchment management plan of the Pet and Guide River catchments in north west Tasmania included a soil and land capability survey of 3200 ha at a scale of 1:25 000 in 1995 (Grose and Cotching 1996). Six soil series were identified and 14 map units were defined with soils developed on basalt predominating. The Ferrosols are characteristically strongly structured, strongly acid and have high organic carbon contents. Land capability ratings determined how the land could be used without destroying its long term potential for sustainable agricultural production. It gives an indication of the inherent capability of the land for broad scale grazing and agricultural use. It was considered land in the Pet and Guide catchments that was being managed at its optimum class or better at the time of survey. There was little evidence of degradation apart from minor trampling by stock around gateways and water points. There was some concern as to the likely impact of any change of land use to more intensive cropping and the effects of forest clearance as forest areas mature.

10.3 Effects of intensive agriculture on soil properties

A broad survey approach was adopted to assess impacts of agricultural use on the health of a range of soils in Tasmania (Sparrow *et al*. 1999; Cotching *et al*. 2001, 2002a, 2002b, 2002d, Cotching and Dean 2003). This included chemical, physical and biological soil characteristics. The importance of taking a morphological approach to these Tasmanian studies of soil health is illustrated by comparing data for similar histories across the soil orders studied. Organic carbon contents are greater in soils with the most silt and clay (Vertosols) and least in the sandy soils (Tenosols). The differences in physical properties between soil orders are also pronounced. It was shown how important horizons and horizon boundaries are in determining physical behavior of soils, particularly in relation to water storage.

Soil carbon levels were found to be decreasing with increased years of cropping in both Tasmania and New Zealand. Strong correlations were found between soil carbon and a range of soil physical, chemical and biological properties (Sparrow *et al*. 1999; Cotching *et al*. 2001, 2002a, 2002b, 2002d). Interpretation of the organic carbon results and management histories tested has led to an understanding that different management has different effects on the organic carbon content in soils. The knowledge gained about soil carbon values for different soil orders and different management regimes in Tasmania has allowed for suggested target levels for cropping systems to be used as an indicator of sustainability. Total organic carbon appears to be as good a measure of the impact of agriculture as other carbon or microbial fractions that are more expensive to measure.

It is not easy to show a clear link between soil organic carbon concentrations and crop yield and crop quality as many other factors can affect yield and quality to a greater extent. Results show no clear relationship between paddock soil carbon and yield. This is perhaps not surprising because other important factors like soil water, fertiliser rates, pest and disease management also varied from paddock to paddock. Good management of these factors would tend to mask any differences across a paddock in organic matter levels. When yields were measured at a number of points within individual paddocks (Cotching *et al.* 2004), a stronger but still variable effect of carbon content could be seen. Further research into the different pools of soil organic carbon in Tasmanian soils may yield greater insights into the relationships between soil carbon and crop yield.

Morphological differences between soil orders are a useful way of differentiating between form, stability and resistance, the three basic aspects of soil structure. The effects of cropping on soil structure varied depending on inherent differences between the soils studied. Morphological evidence of the effects of intensive agriculture was found on soils with clay loam or clay textured topsoils but not on sandy loam to sand textured topsoils (Sparrow *et al*. 1999; Cotching *et al*. 2001, 2002a, 2002b, 2002d). It is proposed that light textured Sodosols and Tenosols are more at risk of degradation, while the heavier textured Ferrosols are more resistant. However, soil structural degradation has been measured on these robust soils with increased cloddiness correlated to lower crop yields on both Dermosols and Ferrosols (Cotching *et al.* 2004). No correlation was found between the soil properties tested and crop production on sandier textured Sodosols and Tenosols.

In New Zealand the Horotiu soil appeared to be relatively resistant to change and so maize cropping can probably be continued on soils of this type for many years without serious soil structural problems arising (Cotching *et al*. 1979). The Puniu soil was considered to be in a relatively poor physical condition at the sites sampled. Due to its low level of structural resilience, maize cropping should be discontinued on the Puniu soil.

The effect of erosion on the physical properties of Red Ferrosols was found to be relatively small as these soils characteristically have a gradational texture profile and both A and B horizons are strongly structured (Cotching *et al*. 2002c). Thus the incorporation of subsoil material by cultivation to replace that lost by erosion, had little effect on physical soil properties under intensive cropping. However, crop yield declined with increasing slope angle. The amount of erosion that has occurred on slopes up to 18% gradient has not been so great as to significantly impact on crop yield, but continued erosion at current rates on this undulating to rolling land, is anticipated to eventually reduce crop yields as more soil is lost.

10.4 Soil erosion and off-site effects of intensive agriculture

A study under intensive dairy pastures on hump and hollow drained land found that soil nutrient concentrations varied over different parts of the constructed drainage network. Levels of dissolved reactive phosphorus (DRP) and total P in runoff water exceeded values for acceptable water quality. These levels were 10–100 times greater than those recorded in other parts of the Montagu River catchment where hump and hollow drainage with intensive livestock grazing was not the predominant land use, providing evidence that paddock runoff is a major contributor to nutrient levels in local waterways. Although total amounts of P leaving the paddock in runoff were not determined in this study, they are considered to be significant in this case because the hump and hollow drainage system is designed to optimise runoff. Holz (pers comm) has since demonstrated this.

Water turbidity and calculated volumes of water borne sediment (TSS) reveal that erosion is an active process at both catchment and paddock scales on the north west coast of Tasmania during frequent rainstorm events (Sims and Cotching 2000). Turbidity readings of more than 200 NTU's recorded during rainstorm events show that suspended sediment concentrations were high and water quality was poor in all catchments except for two small catchments with permanent vegetative cover (Cotching and Sims 2003). Average turbidity was found to be correlated to the percentage of land cropped or fallow in each subcatchment. The very high turbidities recorded in water from farm paddocks, and previous measurements of in-paddock soil erosion rates, leads to the conclusion that soil erosion from cropping paddocks is the major contributor to sediment load in streams in north west Tasmania.

10.5 Farmer perceptions and soil management information

Changes in farmer perceptions of soil management issues were measured by surveying farmers on the north west of Tasmania three times over a ten-year period (Cotching and Sims 2000). There have been many positive changes in the way cropping farmers on the north west coast of Tasmania perceive soil management and degradation over the decade from 1988 to 1998. Survey responses indicated that there have been increases in the use of a pasture phase in the rotation, growing green manure and cover crops, and the amount of grass grown. The majority of farmers also intended taking action to prevent or ameliorate soil structure problems in the following 12 months.

Despite the improved understanding and awareness of soil management in north west Tasmania, there needs to be a greater sharing of responsibility for ensuring sustainability of soil use between farmers, processing companies, government agencies and the rest of society. To leave farmers entirely responsible for voluntary adoption of soil conservation measures to achieve long-term public benefits recognises neither social nor economic realities.

Soil specific management guidelines for five soil orders were formulated from farmer discussion groups and then used to identify best management practices (Cotching and Chilvers 1998). This was part of an extension project which presented information to Tasmanian cropping farmers to stimulate greater adoption of best soil management practices. Information on tillage and management of different soil types was brought together and combined with known properties of the range of soils used for cropping in Tasmania.

A new soil erosion control technique was developed for steep slopes that are used for annual cropping in north west Tasmania (Ashley and Cotching 2001; Cotching 2002). Mulched rip lines are installed in paddocks newly sown to annual crops using a purpose-built implement. The new technique, which was designed locally for use on Red Ferrosols, has received a high level of farmer acceptance.

Several guides were published for farmers to assess their own soils and to show the best ways to manage their soils for sustainable production (Cotching 1997; Cotching 2000; Cotching and Sparrow 2000; Ashley and Cotching 2001; Cotching 2003). These are easy to read brochures with many colour plates to illustrate the described information.

10.6 Conclusion

The research reviewed in this thesis has produced substantial information on inherent and dynamic soil properties required by farmers for sustainable intensive agriculture. The emphasis has been to make the information produced relevant to farmers needs and to actively extend it to the farming community through easy to read publications plus seminars and field days. Bringing a morphological approach to soil management was found to be relevant and useful in Tasmania for understanding how different soils should be managed in distinctly different ways in order to minimise degradation of dynamic soil properties. The author has found that undertaking an active research program was highly beneficial in conducting extension to farmers. This was because the author had results from new research in the local area to present to farmer groups which made the extension messages about soil management very relevant in a local context. Farmers tend to trust results from their own areas and particularly their own farm more than results from other areas, States or even countries. There is currently an emphasis on ensuring that extension is a component of most research projects funded by industry bodies but sometimes the researchers are not the best people to conduct extension and so the optimum use may not be made of research results in agriculture.

A submission containing much of the work described was awarded the Landcare Tasmania BHP Billiton Landcare Research Award in 2001. The work has been cited in the scientific literature (Table 13) and has played a major role in influencing soil management on farms in both Tasmania and the Bay of Plenty, New Zealand. It will inevitably play a significant part in the understanding of how soil management has impacts, both on and off site, because farmers are increasingly required to report on the environmental impacts of farming to industry, government and the community.

Table 13. Publications cited in the scientific literature as at 20/12/2005

Authors	Title	**Journal**	**Year of publication**	**No. of citations**
Cotching WE, Allbrook RF, Gibbs HS	Influence of maize cropping on the soil structure of two soils in the Waikato district, New Zealand	*N.Z.Journal of Agricultural Research* **22**, 431-438	1979	14
Sparrow, L.A., Cotching. W.E., Cooper, J. and Rowley, W	Attributes of Tasmanian Ferrosols under different agricultural management	Australian Journal of Soil Research **37**, 603-622	1999	12
Cotching WE, Cooper J, Sparrow LA, McCorkell BE, Rowley W	Effects of agricultural management on Sodosols in northern Tasmania	*Australian Journal of Soil Research* **39**, 711-735	2001	5
Cotching WE, Cooper J, Sparrow LA, McCorkell BE, Rowley W	Effects of agricultural management on Dermosols in northern Tasmania	*Australian Journal of Soil Research* **40**, 65-79	2002	2
Cotching WE, Cooper J, Sparrow LA, McCorkell BE, Rowley W	Effects of agricultural management on Tenosols in northern Tasmania	*Australian Journal of Soil Research* **40**, 45-63	2002	3

***** ISI Journal Citation Reports

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References in bold indicate publications submitted for the degree and reproduced in full in volumes 1 and 2. For multi-authored publications, the estimated percentage contribution by the candidate is shown in parentheses at the end of the reference.

1. **Cotching WE, Allbrook RF, Gibbs HS 1979. Influence of maize cropping on the soil structure of two soils in the Waikato district, New Zealand. *New Zealand Journal of Agricultural Research* 22, 431-438 (90%)**

2. **Cotching WE 1995. A review of the challenges for long term management of krasnozems in Australia. *Australian Journal of Soil and Water Conservation* 8(1),18–27**

3. **Grose CJ, Cotching WE 1996. Soil survey and land capability classification of the Pet and Guide catchments, District of Burnie. (Department of Primary Industry and Fisheries: Tasmania) (50%)**

4. **Cotching WE 1997. Krasnozem Topsoil Structure. (Australian Institute of Agricultural Science and Department of Primary Industry and Fisheries: Tasmania)**

5. **Cotching WE 1998. Soil survey of the Te Puke district, Bay of Plenty, New Zealand. 222p & 4 maps (Landcare Research New Zealand Ltd)**

6. **Cotching WE, Chilvers WJC 1998. To dig or not to dig. Soil specific cropping management strategies for Tasmania. *Natural Resource Management* 1(2), 25–27. (50%)**

7. **Sparrow LA, Cotching WE, Cooper J, Rowley W 1999. Attributes of Tasmanian ferrosols under different agricultural management. *Australian Journal of Soil Research* 37, 603–22. (30%)**

8. **Cotching WE 2000. Nutrient runoff from a dairy pasture on a hump and hollow drainage system at Togari, North West Tasmania. *Natural Resource Management* 3(2), 18–24**

9. **Cotching WE, Sims CC 2000. Changes in farmer perceptions towards soil conservation and management in North-West Tasmania. *Rural Society* 10(3), 379–392. (50%)**

10. **Cotching WE 2000. Managing wet soils on dairy farms. (Department of Primary Industries, Water and Environment: Tasmania)**

11. **Cotching WE, Sparrow LA 2000. Growing pyrethrum on red soils. (Department of Primary Industries, Water and Environment, Tasmania and Tasmanian Institute of Agricultural Research). (60%)**

12. Sims CC, Cotching WE 2000. Erosion and water quality: Turbidity and sediment loads from selected catchments in North West Tasmania *Natural Resource Management* 3(1) 8–14. (40%)

13. Cotching WE, Cooper J, Sparrow LA, McCorkell BE, Rowley W 2001. Effects of agricultural management on sodosols in northern Tasmania. *Australian Journal of Soil Research* 39, 711–735. (60%)

14. Ashley R, Cotching WE 2001. Ripper-mulcher stops soil erosion. (Department of Primary Industries, Water and Environment, Tasmania and Five Rivers Waterwatch) (50%)

15. Cotching WE, Cooper J, Sparrow LA, McCorkell BE, Rowley W 2002a. Effects of agricultural management on dermosols in northern Tasmania. *Australian Journal of Soil Research* 40, 65–79. (60%)

16. Cotching WE, Cooper J, Sparrow LA, McCorkell BE, Rowley W 2002b. Effects of agricultural management on tenosols in northern Tasmania. *Australian Journal of Soil Research* 40, 45–63. (60%)

17. Cotching WE, Hawkins K, Sparrow LA, McCorkell BE, Rowley W 2002c. Crop yields and soil properties on eroded slopes of red ferrosols in northwest Tasmania. *Australian Journal of Soil Research* 40, 625–642 (60%)

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