EFFECT OF ORGANIC CROP ROTATION

ON SOIL FERTILITY

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ABSTRACT

Studies of soil nutrient fertility status of the organic and conventional plots at the Flock House cropping and organic units, Bulls, were undertaken to investigate the effects of organic crop rotation system on soil chemical fertility. Soil samples (0-75 mm, 75-150 mm, 150-300 mm depths) were collected from two organic plots lying adjacent to conventional plots of identical soil type (Manawatu silt loam) in Autumn and Spring. The crop rotation plots were established in 1988. Soil samples were analysed for total C, total N, mineralizable N, extractable P (Olsen), exchangeable K, CEC and pH. Earthworm surface casts collected from the surface of these plots were also analysed for exchangeable K and CEC.

Results of this study showed that after seven years of conversion to organic management, there were significant quantitative increases in the soil nutrient levels at topsoil depth 0-75 mm. Organic plot number 3 (OP3), now under clover based pasture showed higher percent of organic C and N than the organic plot under continuous cultivation (OP5) and conventional plot (CP8). Mineralizable N was significantly higher in the soil of OP3 and the mean topsoil (0-75 mm) value increased from 104 to 139 $\mu g\ g^{-1}$ (67%) from Autumn to Spring collected soils. Crop rotation under continuous cultivation resulted in decrease of mineralizable N from 90 to 30 $\mu g\ g^{-1}$ (150%) from Spring to Autumn collected soils at depth 0-75 mm. Extractable soil P (Olsen) remained significantly high in CP8 in both Autumn and Spring seasons.

Soil Ca and Mg were significantly higher in the organic plots during Autumn but there was no significant difference observed in Spring collected soils. Exchangeable K levels were similar under both organic and conventional management system and generally showed higher amounts at topsoil (0-75 mm) as a result of mixing with earthworm surface casts which contained appreciably high amounts of K, Ca and Mg. Soil CEC was generally higher in organic plots.

Surface casting by earthworm was significantly higher (> 1000 casts m^{-2}) in OP3 as compared to 380 casts m^{-2} and 300 casts m^{-2} in OP5 and CP8 respectively. This coincided with greater a cation nutrient status observed in the Spring collected soil samples.

Organic management under different crop rotation system resulted in significantly variable levels of soil nutrient fertility. Seven years of crop rotation under the organic system was sufficient to maintain sustainable levels of soil nutrient fertility.

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TABLE OF CONTENTS

CHAPTER 3

CHAPTER 4

CHAPTER 5

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Introduction

World-wide environmental concern at the use of fertilizers and agricultural chemicals, and the growing attraction of higher premiums paid for organically grown agricultural products, are encouraging many conventional farmers to convert to organic methods of farming. Sound rotation, rational use of organic and green manures, appropriate cultivation techniques and exclusion of harmful agro-chemicals form the basic characteristics of organic system. The current move in organic husbandry has rekindled an interest in the role of soil in transforming organic into plant available inorganic nutrients. Thus balancing the key nutrients through organic sources has become the key issue in maintaining sustainable organic agro-ecosystems. The conversion from conventional to organic production must therefore be carefully planned to result in viable and sustainable levels of soil nutrient fertility.

The organic method takes a holistic approach to maintaining plant nutrition and soil fertility rather than applying a specific chemical fertilizer, fungicide or pesticide. The primary aim of the organic production system is to achieve maximum nutrient cycling with minimum losses. Crop rotations which include legumes, green manures and cash crops are basic to cycling of plant available nutrient and hence the principle method for managing soil fertility and controlling weeds, pests and diseases. Development of a sound crop rotation system is also an important practice in arable organic farming system. Mechanical cultivation and regular input of composted organic waste and farm yard manure (FYM) are often a feature of the management of soil fertility and nutrient dynamics under organic farming system.

Major qualitative and quantitative differences have been observed in soil fertility levels in organic and conventional methods of farming. However, the differences in the effect of organic manures and inorganic fertilizers on soil fertility and crop nutrient balances are still something of a mystery. Much emphasis is laid on the cyclical flow of nutrients when designing organic arable farming system. However no system is 100% efficient and some form of external input must be supplemented for both systems of farming in order to compensate for the losses from the system.

In terms of nutrient dynamics within the organic system, the cycling of the macro-nutrients, nitrogen (N), phosphorus (P) and potassium (K), is considered important in maintaining economically sustainable production levels. The macro-nutrients N,P,K are usually the critical elements in terms of limitation of crop yield. Organic farmers rely upon crop rotation, organic manures, mechanical cultivation, mineral based rocks and aspects of biological controls to maintain soil fertility in contrast to the chemical fertilization practices in conventional systems (Arden-clarke and Hodges, 1988). Thus the difference between the plant nutrient supplying media used in these two types of farming systems result in widely contrasting effects on the physical, chemical and biological components of the soil environment. Nutrient cycling is therefore an integral part of soil fertility.

Fertilization practices under organic system tend to raise or maintain soil organic matter levels while conventional farming system tend to lower them (Haysted, 1983; Alvarez et al., 1993; Oberson et al., 1993; Reganold et al., 1993; Wander et al., 1994). The amount of total N and mineralizable N depends on the level of soil organic matter and subsequent microbial activity. The difference in N availability and rates of release from the organic manures and inorganic fertilizers have implications on both sustainable agriculture and the environment.

The claim of organic growers that anything grown organically is better and more healthier has yet to be supported by scientific research. In fact, soil parent material, cultivar characteristics, management practices and environmental factors may have a far greater influence on the nutrient status of the soils under organic cropping system. Since soil fertility levels are often site specific, spatial variation within plots due to variations in topsoil depth, management practices and climatic variations may have far serious implication than utilization of actual ethics of organic farming. Where organic farming is practiced there is inevitably a requirement for an input of available nutrients into the system if yield levels are to be maintained. The only major nutrient that is theoretically possible to maintain without inorganic fertilizer application is N. Organic fertilizers depend on environmental factors for the release of N to plant available forms. Thus seasonal variation of N level may affect yield.

It is well established fact now that excessive use of agricultural chemicals can have detrimental effects on the environment (Heijndermans, 1991; Ball, 1994). However, the promotion of organic agriculture as an ecologically sound and socially acceptable methods of farming will much depend on its economic sustainability.

Organic farming, often perceived by conventional agriculturist as archaic, inefficient or downright silly, is slowly gathering steam in New Zealand. A study by Reganold et al. (1993) on selected biodynamic and conventional farms in North Island has shown that soil chemical fertility under organic management system was significantly higher than in conventional systems. At MAF's Flock House AgResearch area near Bulls, 44 ha of conventional farm was converted to an organic crop rotation system in 1988. Seasonal monitoring of the organic plots (12 organic plots with different history of crop rotations) by the AgResearch at Flock House have indicated that yield levels between the organic plots and adjacent conventional plots were comparably similar and the general trends of the selected chemical parameters were generally higher for organic plots over the seven year period (Appendix 5). A preliminary result of research at Flock House by Springett (1993, pers. comm.) has shown that although cultivation techniques reduced weed problem except for dock weed, soil biological and selected chemical properties of the soil under organic and conventional system were not significantly different.

Cropping history, management practice and environmental factors will undoubtedly affect the qualitative and quantitative yields in organic agro-ecosystem. Such effects on yields will depend on the efficiency of the organic system in cycling the plant available nutrients. Thus soils under plots with repeated organic crop rotations will soon be depleted of essential plant nutrients (unless replenished) whereas plots under permanent organic pasture may become sustainable after several years of organic conversion. It is essential that nutrient dynamics in soils under different cropping history be kept at healthy levels in order to attain sustainability. A study of soil nutrient status will thus enable one to monitor the soil chemical fertility of the organic farming system.

1.2 Objective

The objective of this study was to determine whether there were any quantitative changes to soil chemical fertility after seven years of crop rotation under organic management practices. Measurements of seasonal variations in total C, total N, mineralizable N, P, K, CEC, pH and level of earthworm activities in soils under organic and conventional farming system would indicate whether there was any significant changes in soil nutrient fertility levels during conversion to an organic farming system.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Heavy use of chemical fertilizers, pesticides and other agrochemicals under conventional farming methods and subsequent build-up of toxic levels of metals in soils, and pollution of surface water and groundwater are the major environmental concern worldwide. Although conventional farming systems have greatly increased crop production and labour efficiency, concern over their environmental impact has led to an increasing interest in organic farming systems because they have the potential to reduce some of the negative effects on conventional agriculture (Reganold and Palmer, 1990). Over the years, conventional farming systems have had detrimental effects on soil physical, chemical and biological properties and thus adversely affecting the soil ecosystem (Lampkin, 1990). The ever-increasing prices of fertilizers, agricultural chemicals and global awareness of environmental issues, have brought renewed interests in alternative methods of agriculture generally referred as "organic farming". This has been especially so in New Zealand where organic farming is fast becoming established amidst predominantly conventional farming systems. This review attempts to inter-relate and compare the differing impacts of organic farming and conventional system upon soil chemical fertility.

2.2 Management practices in organic farming

An organic farming system excludes the use of synthetically compounded fertilizers, pesticides, plant and animal growth regulators, livestock feed additives and animal remedies. It is designed to ensure that soil fertility, the soil fauna and the microorganisms on which fertility depends are maintained to provide a sustainable agroecosytem (Stickland, 1994). To maintain sustainable agriculture, organic farmers use compost, green and animal manures to improve soil fertility, control weeds and pests naturally by crop rotation (Reganold et al., 1993). In so called 'biodynamic farming' which is closely similar to organic farming, specific preparations made from cow manure, silica, and various plants are used to enhance soil quality and plant life (Reganold and Palmer, 1990).

The fundamental requirement of organic farming is to establish nutrient dynamics that supply nutrients at the right time according to plant needs (Oberson et al., 1993). The input of organic materials to increase soil organic matter which plays an important role as source of plant nutrients is the key to maintaining sustainability in organic farming system. Soil organic materials creates a favourable medium for biological reactions and life support in the soil environment (Wallace, 1994c). In essence, organic farming relies on nature's way for agricultural productivity.

How does one then maintain nutrient balance in organic farming system? Organic farming systems rely on one or more of the following practices in order to achieve a balanced dynamic agroecosystem.

2.2.1 Crop rotation

Crop rotations involve the sequential growing of cereals after legumes to reduce N fertilizer needs and increase crop yields. This "rotation effect" can be attributed to a number of factors, including a reduction in disease and pests, more efficient weed control, efficient use of water and nutrients, and improved soil physical properties (Reeves, 1994). Planting shallow-rooted crops followed by deep-rooted crops helps to bring up water and plant nutrients from lower soil depths and prevent formation of plough layers and improve soil biological properties (Fyson and Oaks, 1990; Wani et al., 1991). Crop rotations result in significantly higher levels of microbial biomass (McGill et al., 1986) and soil enzyme activity (Khan, 1970; Dick, 1984) than cropping sequences that are either continuously monocultured or have limited crop rotation. Yield increases were the earliest recognized advantage of crop rotation (Reeves, 1994). Under crop rotation system productive yield may be 10-40 % more than in monoculture even when adequate N was supplied (Hesterman et al., 1986). A long-term trial by Wani et al. (1994) showed that there was 16-19% higher yield of barley and a significant increase in plant available nitrogen (N) - phosphorus (P)-potassium (K) and cation exchange capacity (CEC) in soils under crop rotation than in continuous grain.

Crop rotation is one of the principle methods for avoiding major weed, pest and disease problems and for managing soil fertility under organic farming system. Organic farming relies increasingly on renewable resources, for example legumes for nitrogen fixation. Well designed crop rotations are the most essential component of organic farming in maintaining soil fertility by ensuring that sufficient nutrients are available for plant uptake.

Legume crops and barnyard manure which maintain or increase the organic matter and nitrogen content of soils is a natural concomitant of good crop rotation practice in organic farming management (Dubetz and Hill, 1964). Including a legume in crop rotations usually reduces the C:N ratio of crop residues added to the soil by increasing the amount of total soil N (Campbell et al., 1991; Wani et al., 1994). Study by Martyniuk and Wagner (1978) showed that microbial counts were higher with crop rotation. This was attributed to the inclusion of red clover crop in the crop rotation treatment. Another advantage of legumes are their effectiveness in controlling soil erosion, not only by providing surface cover for the soil but also by improving soil physical conditions. Legume-based cropping systems often provide more ground cover and thus reduce surface temperature and potential evaporation rates of soil (Power, 1990).

Crop species vary considerably in their ability to modify soil physical and chemical properties. Plant root morphology and distribution, as well as rhizosphere activity affect uptake of nutrients (Reeves, 1994). For example, fibrous rooted grass species are generally more effective than tap-rooted species in extracting P (Mays et al., 1980). Conversely, some tap-rooted crops, like white (*Lupinus albus* L.) and blue lupin, can secrete large amounts of organic acids that result in increased availability of P (Tadano and Sakai, 1991). Increased soil C, whether from increased surface residues as a result of tillage reductions or from rotation with grasses and legumes, result in greater soil aggregation and infiltration. The end result of these processes is greater soil water storage (Reeves ,1994).

The inclusion of pasture in crop rotation is associated with an accumulation of soil organic matter (Russell and Williams, 1982). The grass/clover ley acts as the major source of fertility within the rotation whereas ruminant livestock are the central point around which the rotation operates (Lampkin, 1990). A Study by Arden-Clarke and Hodges (1987) showed that reducing the proportion of grass in crop rotation invariably reduced soil organic matter levels. Pasture crops serve not only to maintain organic matter levels, but also provide greater protection for the soil surface from raindrop impact, than do arable crops (Russell, 1973). The integration of legume-based pasture into a crop rotation is an effective means of maintaining an adequate supply of soil nitrogen under organic farming system (Johnston et al., 1994). Clover not only provides high-quality feed for livestock but also is an important source of nitrogen for plant growth. Research by Evans et al. (1992) showed that yield of barley obtained after clover/and rye-grass mixtures was 50% greater than barley harvested after rye-grass monoculture.

Significant increases in soil organic C and total N levels have been reported in a range of soils for wheat rotations which have included 2-4 years of pasture (Whitehouse and Littler, 1984). Johnston et al. (1994) found that increasing rye grass/clover leys age up to five years increased total soil C by a maximum of 0.17% although this figure was not considered significant in terms of variabilities between replicates. However, this small increase in soil organic matter provided up to 230 kg/ha mineral N in the first Autumn after ploughing. The fertilizer N needed declined from 174 kg/ha after the one year ley to 48 kg/ha after the six year ley. Another study by Stickland (1994) showed that in white clover-based pasture, an increase in organic matter levels was evident only after three years of pasture establishment. A similar result has been reported for many of the crop rotations used in the Canterbury plain region of New Zealand where 2-5 years of crop rotation periods are considered too short for a substantial build-up and breakdown in soil organic matter to occur (Haynes and Francis, 1990).

In the short-term, influence of crop rotations is likely to be more related to changes in specific organic contents such as microbial biomass C than to changes in total soil organic matter (Baldock et al., 1987; Angers and Mehuys, 1989; Haynes and Swift, 1990). During the short-term pasture phase of the rotation the development of a dense ramified pasture root system, and the associated large microbial biomass, result in the production of large amounts of active carbohydrate binding agents in the surface soil which are known to be closely involved in soil aggregation. When the field is returned to arable cultivation, the dense pasture system is replaced by a more sparse and deeper-rooting crop root system. Consequently, the density of roots, size of the microbial biomass and production of binding agents in the plough layer is reduced and there is decline in soil carbohydrates and aggregate stability (Haynes et al.,1991). When the soil is then put back under pasture there is a rapid increase in root proliferation, and a more rapid recovery in microbial C than total C. However, a study by Sparling et al. (1992) showed that even after 4 years of pasture, the levels of microbial and total C were still much below to that found under permanent pasture (greater than 25 years).

Soil amendments such as animal and green manures, and crop rotations may be more important in maintaining soil microbial activity than conservation tillage in monoculture systems. There is increasing evidence that crop rotation promotes crop productivity by suppressing deleterious microorganisms that flourish under monoculture (Sivapalan et al., 1993).

2.2.2 Crop residue and green manure

Crop residues which include all above ground plant materials left after harvesting or grazing and subsurface rooting system, and organic wastes are important in providing organic matter build-up and as plant nutrient sources. Shallow tillage is commonly used in organic farming system so that crop residues are left on or near the surface and thereby improve the soil N status by building up the soil organic N pools and by reducing N loss by erosion. Presence of crop residues on the soil surface also reduces evaporation rates, increase water storage and subsequent plant growth, and reduces wind and water erosion (Black, 1973; Barnhardt et al., 1978; Cochran et al., 1980). Unger (1978) has shown that application of crop residues (in this case wheat straw) at rates of 12 t/ha/yr can raise available soil water to levels about twice those of the same soil receiving no crop residues. By incorporating residues with ploughing or disking, decomposition and nutrient cycling are more rapid (Power, 1994).

When crop residues with the narrow C:N ratio such as pea residues, are incorporated into a warm, moist soil, the narrow C:N ratio of these material enhances rapid mineralization of the N in these residues, so temporary accumulations of soil nitrate are not common under these conditions. Consequently, NO_3^- may leach from such soils. For example, in New Zealand reported 90 Kg N/ha leached after returning pea residues to the soil (Muller, 1987). On the other hand, Varvel and Peterson (1990a) reported that rotating a seed legume such as soybean (*Glycine max* (L.) Merr.) with a cereal grain such as corn (*Zea mays* L.) usually results in greater cereal yields and greater N uptake and removal in the combined seed harvests of the two crops than would occur with a monoculture. Such a rotation results in more N being returned in crop residues, and only half as much fertilizer N is used as with a corn monoculture (Power, 1994). Varvel and Peterson (1990b) showed that such a crop rotation often reduces residual soil nitrates after harvest, thereby reducing potential for nitrate leaching.

The return of crop residues, including cereal straw, pea and bean haulms, roots and ground level residues, is a logical step in the recycling of nutrients and serves to remedy the inevitable reduction in soil organic matter due to intensive cultivation and cropping. Rice, the major crop in South and South-east Asia produces abundant amounts of crop residues eg. stubble, straw, and rice hull. In a long-term experiment of rice production in Thailand, it was found that rice hull at 6.25 t/ha/yr plus chemical fertilizer N-P- K (16-20-0) at 188 kg/ha produced higher yield than the chemical fertilizer alone (Tawonmas and Hansakdi, 1994). Another study by Tawonmas and Hansakdi (1994) showed that rice receiving rice straw compost at 12.5 t/ha/yr produced higher yield than did chemical fertilizer. The contents of organic matter and available phosphorus in the soil were also increased. The incorporation of these fresh crop residues as a method of building up soil organic matter or nitrogen must be done with caution. The C:N ratio of crop residues is often used as a guide to their composition and suitability for incorporation (Lampkin, 1990). Crop residues vary widely in C:N ratio, with higher values for residues from grain crops and generally lower values from legumes. If the C:N ratio is greater than about 30, little or no net mineralization will occur. Consequently, large crop yield reductions may result from net immobilization occurs.

The presence of leguminous crop residues, as well as absence of tillage, enhances earthworm populations (Power,1990).Crop residues are partially decomposed by microorganisms and the resulting by-products are humus (well-decomposed plant or animal material), dead microbial cells, and nutrients not used by the microorganisms (King, 1990). Earthworms, as well as soil microorganisms are involved in the decomposition of crop residues and subsequent effects upon increasing aggregation of soil (Mackay and Kladivko, 1985).

Green manures can be grown with Autumn sown cereals , or as a cover crop for the Winter, to reduce losses of soluble nutrients especially mineralized-N by taking them up before they are leached (Lampkin, 1990; Atallah and Lopez-Real, 1991). Leguminous crops such as peas, clovers and some vetches are commonly used for green manuring because of their ability to increase soil nitrogen through symbiosis with nitrogen-fixing bacteria. These crops will normally only make adequate growth and fix enough nitrogen to make their cultivation worthwhile if the soil contains adequate supplies of C, P and K (Lampkin, 1990). However, green manure must undergo decomposition and mineralization before its N becomes available to the succeeding crop (Singh et al., 1992).

Green manures play a significant role in crop production, especially in tropical and subtropical soils with low organic matter content. The green manures not only add organic matter and nitrogen to the soil but also improve the availability of other soil nutrients by recycling them from subsoil to topsoil and by converting them to easily available forms (Sharma and Sharma, 1990).

Ratanaprateep (1988) reported that cowpea and sunn hemp used as green manure for corn and cassava in Thailand produced higher yield than control, while *Sesbania rostrata* as green manure for rice also increased rice yield equal to the chemical fertilizer N-P-K (16-16-8) at 156 kg/ha. Similar studies in the Philippines showed that *Sesbania rostrata* pre-rice green manure crop accumulated more above-ground dry biomass more than 6 t/ha. It improved the grain yield of the subsequent rainfed lowland rice crop equal to that of the 60 kg N/ ha treatment (Manguiat et al., 1992). Meelu et al. (1992b) reported that *Sesbania cannabina* accumulated mean maximum N as much as 84-199 kg / ha. In addition, Meelu et al. (1992 a) found that soil organic C and total N after wet season rice in the second year of experiment were higher when sesbania or farmyard manure preceded rice. Green manure not only increased N, but also increased P and K. According to the fixed yield concept (the optimum yield given by the poorest treatment), Sharma and Sharma (1990) reported that green manures of crotalaria and sesbania for tuber production, were equivalent to 65 and 27 kg P/ha of fertilizer respectively; and green manures of crotalaria, sesbania, pearl millet and green gram were equivalent to 158, 176, 54 and 89 kg K/ha of fertilizer, respectively. Addition of a green manure crop to wheat-based systems in the highly productive Palouse region of eastern Washington over a 30 year period caused a significant increase in urease, phosphatase, and dehydrogenase activities, N flush and in microbial biomass (Bolton et al., 1985).

2.2.3 Organic manuring

The potential for recycling of nutrients through the application of manure is high. Both nutrients gathered from a large area during grazing and nutrients from conserved and purchased feeds are concentrated in dung and urine and so become available for redistribution. Grazing animals retain only 5-10 % of the nitrogen they eat in herbage. The remaining 90% is recycled through urine and dung. Dairy cows, for example, can excrete up to 250 g N per day (Lampkin, 1990).

Organic manuring aims to improve the physical, biological and chemical properties of the soil. It is an important source of energy and nutrients for the soil ecosystem. The effectiveness of organic manuring in improving soil structure and yield is dependent on a number of variables such as soil type and climate. Significant increase in crop yield is attributed to structural improvements due to organic manuring (Cooke, 1967). Organic manuring is more effective than inorganic fertilizations in vertical distributions of nutrients in the soil profile. As inorganic fertilizers are simply broadcasted over the soil surface, so less soluble plant nutrients tend to be concentrated in the top few centimetres of soils. In contrast, regular annual applications of organic manures tend to raise nutrient levels throughout the soil profile (Webber, 1975).

Aweto and Ayuba (1993) compared the chemical properties of soil under continuous cultivation farming based on the use of organic manure with a similar soil under a natural savanna forest reserve. Their results showed that the application of animal manure on an annual basis had beneficial effects on soil nutrient status. Schjønning et al. (1994) found that application of farm yard manure (about 400-600 kg N/ha/yr, 80-120 kg/ha/yr and 160-320 kg/ha/yr) for 90 years to sandy loam soil, increased the soil organic carbon content and CEC by 23 and 17% from unfertilized soil respectively. Organic manures help to modify the physical condition of soils, by improving water holding capacity, aeration, drainage and friability. The darker colour of organic matter means that soils warm up faster in temperate climates. Organic manures provide the energy needed for increasing microbiological activity and also help to protect crops from temporary gross excess of mineral salts and toxic substances and from rapid fluctuations in soil reaction by means of their high absorption capacity exerting a " buffering" action (Lampkin, 1990).

Organic matter levels in many soils appear to be an important factor in determining available water capacity. Salter and Williams (1963) showed that large applications (50 t/ha/yr) of farm yard manure for 8 years to a sandy loam increased available water capacity in the top 15 cm of soil by up to 70%, and that this effect persisted throughout most of the field life of the crop.

Fauci and Dick (1994) studied the relative importance of long-term versus short-term organic residue or inorganic N management practices to soil biological dynamics during transition period by using soils that have been managed with either organic or inorganic N source since 1931. The result showed that long-term organic soil amendments increased biological activity in proportion to the amount of total C inputs. Recent organic inputs, regardless of long-term management, had a large effect on soil biological response, which was controlled by residue composition (lignin content) and supported 80 to 400% greater microbial biomass C than the control.

Another effective use of organic inputs is to buffer soil acidification. Research conducted in Thailand indicates the potential value of organic inputs on acid soils, for example using biogas slurry as organic fertilizer. It was found that on an acid sulphate soil, rice receiving biogas slurry at 12.5 t/ha/yr together with chemical fertilizer at 125 kg/ha/yr produced significantly higher yield than with the recommended N-P-K (16-20-0) fertilizer at 219 kg/ha/yr (Tawonmas and Hansakdi, 1994).

2.2.4 Microbial biomass

The microbial biomass of a soil is a comparatively labile pool of soil organic matter, with a high nutrient content, rapid rate of turnover

(VanVeen et al., 1985), is an active participant in nutrient cycling (McGill et al., 1986) and represents a substantial pool of soil nutrients (Sparling et al., 1992). It has an important role in nutrient transformation (Carter and Kunilius, 1986; Doran, 1987), thus influencing the fertility status of the soil (Sparling et al., 1992). Consequently, loss of organic matter during cultivation and, especially, loss of the soil microbial component, can adversely affect both the physical, biological and nutrient status of soils (Carter, 1986; Carter and White, 1986).

Microbial biomass dynamics play a critical role in mediating residue decomposition, nutrient cycling, and organic matter turnover. Soils managed with organic amendments generally have larger and more active microbial populations than those managed with mineral fertilizers (Bolton et al., 1985; McGill et al., 1986; Alef et al., 1988; Dick et al., 1988). The result of studies from Flock House AgResearch Centre (Springett, 1993 pers. comm.) showed that potential soil oxygen uptake in microbial respiration studied in the laboratory was more active at depth in organically managed properties than conventional properties. Whereas evolution of CO_2 from the soil surface studied in the field was not significantly difference between the organic and conventional paddocks.

Soil microbial activity influences nutrient availability both directly and indirectly. A direct effect is the breakdown of organic matter and subsequent release of nutrients not used in cell building and maintenance processes. These nutrients are also available to plants. Also, since the microbial biomass itself is a relatively labile fraction of the soil organic matter, nutrients in biomass form become available as dead microbial cells are attacked by other microbes (King, 1990). The organic residues from plants are broken down by soil microorganisms to release both energy and nutrients in the form of inorganic ions which can then be taken up by plants (Lampkin, 1990).

Organic farming systems have a significant reliance on the activities of key soil biota to supply adequate levels of major plant nutrients. An example is symbiotic nitrogen fixation by legumes (Macgregor, 1994). Soil microbial activity plays a key role in the transformation and transfer of nutrients in the soil plant system (Oberson et al., 1993; Richardson, 1994). A major aim of soil biotic management is to manipulate the processes of residue decomposition, nutrient immobilization, and mineralization so that nutrient release is synchronized with plant growth (Sanchez et al., 1989; Sparling et al., 1992). The objective is to match the availability of nutrients with plant demand, thereby increasing nutrient use efficiency and reducing loss of nutrients through leaching.

2.2.5 Grazing management

Large quantities of nutrients are cycled within the agroecosystem through the actions of the grazing animals. Grazing animals have a dominant effect on the movement of nutrients through the soil-plant-animal system and thus on the fertility of pasture soils (Wilkinson and Lowery, 1973; Mott,1974). This is because a large percentage of nutrients (60-99%) ingested by the grazing animals is returned to the pasture in the form of dung and urine. By ingesting herbage, animal grazing encourages pasture plants to grow and therefore take up more nutrients from the soil. The proportion of above-ground herbage that is consumed by the animals is dependent on stocking rate and can commonly reach 85% of that produced. Urine and dung patches are therefore the areas where nutrients are recycled from excreta to soil and back to pasture plants. Although excretal patches may cover only 30-40% of the pasture surface annually, the high nutrient input stimulates herbage growth that may represent 70% of the annual pasture production. Thus, nutrient transformations in the excretal patch areas are of central importance to the fertility and productivity of grazed pastures. As well as being responsible for the cycling of nutrients within the system (Haynes and Williams, 1993).

Nutrients are partitioned differently between dung and urine. Some of the nutrients (K) are excreted predominantly in urine whereas others (P, Ca, Mg, Cu, Zn, Fe and Mn) are excreted mainly in faeces. Other nutrients, such as N, Na, Cl, and S, are excreted in significant proportions in both faeces and urine (Haynes and Williams, 1993). Nutrients return in excreta can be in inorganic and organic forms, depending on the particular nutrient being considered. Over 60% of excreted N is usually in the form of urine and 70-90% of this is in the readily available organic urea form. This is very rapidly hydrolyzed to NH_4^+ in the urine patch and subsequent nitrification will be followed (Lampkin, 1990). For sheep grazing grass/clover pastures in New Zealand, 70-75% of the excreted N occurred in the urine (Haynes and Williams, 1993).

Faecal P represents the predominant pathway for annual returns of P to grazed pasture. Floate and Torrance (1970) showed that faeces contained 80% inorganic P, which are present in less soluble forms. Whereas, K is mostly excreted as urine, with only 10-30% being excreted in faeces (Barrow, 1987). The K in urine and dung is in ionic form and is therefore readily plant available. Potassium commonly represents 60-70% of the equivalent cation content of urine (Haynes and Williams, 1993).

Therefore, returned nutrients may either be in readily plant-available forms or in forms that require mineralization before they are available for plant uptake. Nutrients (mainly N, S, and P) may be released from organic form through the microbial process of mineralization, but at the same time available nutrients may be immobilized in organic form by the soil microbial biomass. Available nutrients (P, K and most micronutrients) may also be converted into chemically fixed forms by adsorption reactions, but may be released from fixed forms via processes such as weathering, solubilization, and desorption (Haynes and Williams, 1993).

However, small amounts of nutrients can be lost from the system by being removed in the form of animal products (e.g. milk, wool, or live animals). The animals also give rise to nutrient losses through transfer of nutrients to camp sites and unproductive parts of the farm such as races and stock yards. Once nutrients are returned to the soil, losses can occur through leaching, gaseous emissions, runoff and erosion. Leaching and gaseous losses occur preferentially from excretal patch areas because of the aggregation of nutrients in these areas of the pasture. Because of the losses of nutrients during cycling, fertilizer inputs are required to maintain soil fertility. Additional inputs of nutrients can occur via irrigation water, rainfall, and dry deposition. In grass/legume pastures a significant input of N occurs through biological N fixation (Haynes and Williams, 1993).

Under grazed pasture the overall biological activity of the soil is generally greater. Associated with the high content of soil organic matter and dense mass of pasture roots is a large microbial biomass representing a reasonably large labile pool of nutrients (e.g. commonly 150-225 kg N/ha). The biomass N contains 11 times more N than the mineral N component of the soil, 3 times more than the standing crop, and 5 times more than excretal returns, respectively (Haynes and Williams, 1993).

2.3 Nutrient dynamics in organic farming

The major objective of organic farming is to create a more sustainable agricultural system by relying on a closed system for crop and livestock nutrition. This proceeds by minimising the use of nutrient inputs from outside as well as losses from within the system. The successful operation of an organic farming therefore requires an understanding of all aspects of nutrient cycling within the agroecosystem. This involves knowing which crops input/remove most nutrients, how to minimise losses and maximise returns, how to make the best use of the soil's recycling abilities and understanding the long-term effect of cultivations and rotations. Therefore, organic farming is about feeding the soil ecosystem and making full use of the natural resources which exist within the farm (Lampkin, 1990). A generalized nutrient (N-P-K) cycling within the closed system is shown in Figure 2.1.

Organic farming system has to rely on internal cycling of nutrients within the system. The key to sustainable agriculture under organic system is on how efficiently the nutrients are cycled through the system shown in

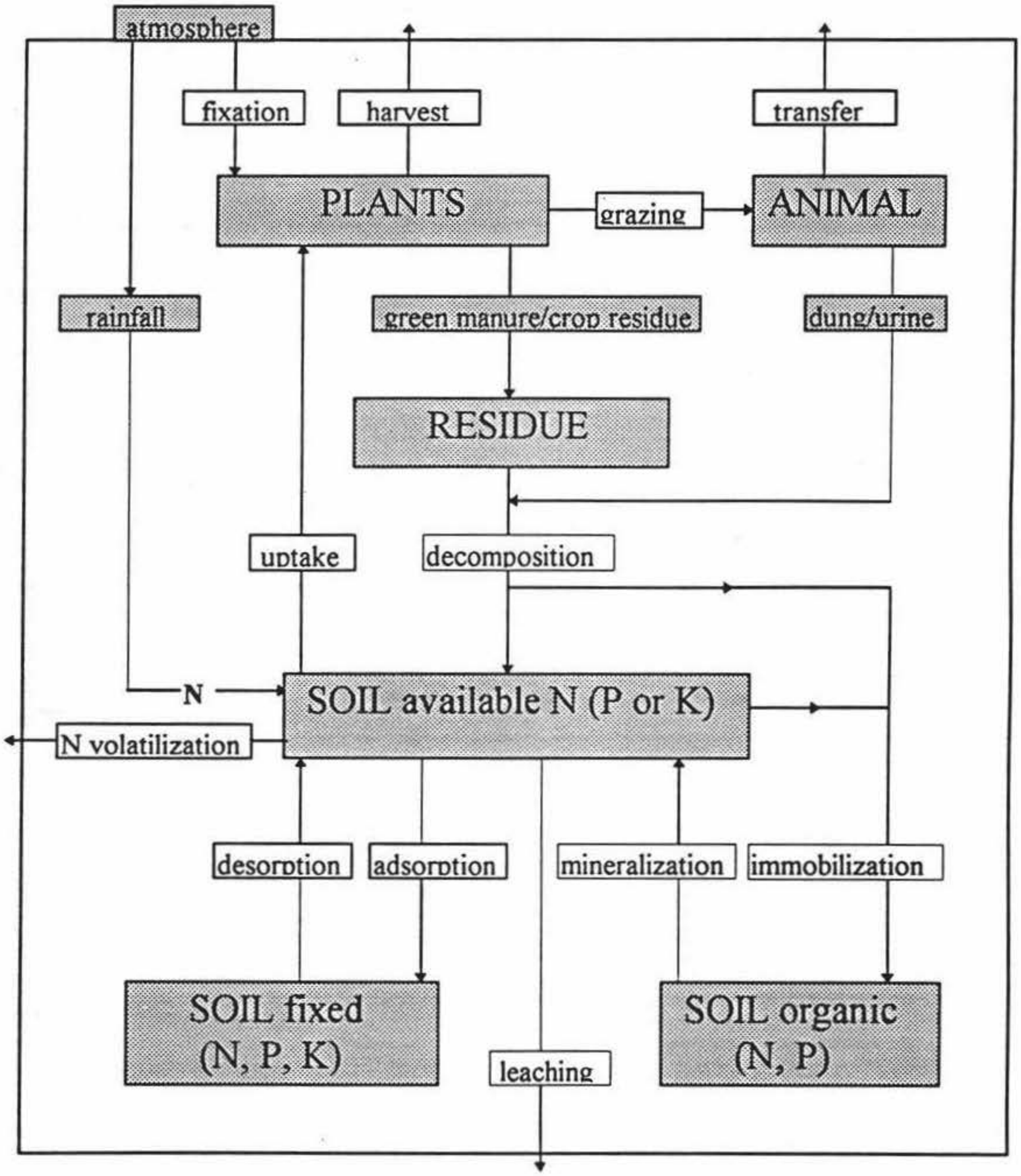


Figure 2.1 Simplified N-P-K nutrient cycling in organic crop rotation system. Arrows indicate direction of flow of nutrients. Shaded areas are sources of nutrient pool while unshaded boxes represent nutrient cycling processes with the system. Diagram adapted from López-Hernández et al.(1993).

Figure 2.1. Managing the cycle to minimise losses and to supply necessary inputs is the key to fertility management in sustainable agricultural systems (King, 1990). The source of plant nutrients on organic farms is a combination of organic materials (crop residues, animal manures and off-farm wastes), relatively insoluble inorganic materials (mineral-bearing rocks such as reactive phosphate rock (RPR)) and green manures.

The major macro-nutrients required by plants for sustainable growth are N, P and K. Thus sustainable agriculture under organic management is effectively the management of these nutrients within the agroecosystem as described in Figure 2.1. An understanding of the pathways of these macronutrients is important in maintaining an efficient organic system.

2.3.1 Nitrogen (N)

Nitrogen transformations in the soil are an integral part of the overall cycle of nutrients on the farm and efficiency is greatly affected by management practices (Lampkin, 1990). Figure 2.1 shows N cycle in organic farming system. N release in soil depends on the content of soil organic matter, characterized by total carbon and total nitrogen content. The amounts of nitrogen, which are linked in organic form in the soil, range from 2 t/ha to more than 10 t/ha in the top 150 mm soil. However, for N release the total N content is not decisive, only the mineralizable part is. This part is mainly influenced by the management (crop rotation, fertilization) while the inert part of soil organic matter is mostly unconcerned with mineralization and strongly correlated to the particle size distribution of soil (Körschens, 1994).

The key feature of the soil nitrogen cycle is the turnover of nitrogen by mineralization and immobilization. Mineralization of N is the transformation of N from the organic state into the inorganic forms of N that are available for plant uptake (Jansson and Persson, 1982). Nitrification processes convert the inorganic forms of N (NH_4^+) to nitrites (NO_2^-) and nitrates (NO_3^-) in the presence of nitrifying bacteria (Lampkin, 1990 ; McLaren and Cameron, 1993 ; Power, 1994). The free nitrate thus formed is either immobilized, assimilated by plants, volatilization or leached through the soil profile (Lampkin, 1990). Immobilization occurs when inorganic ions are assimilated by soil microbes and once again bound organically. The processes of mineralization and immobilization occur simultaneously as a continual process. It is the net movement in one direction which determines if more or less inorganic nitrogen results and this is highly dependent on the availability of organic matter (Lampkin, 1990).

Mineralization and subsequent nitrification or immobilization by soil microorganisms are also affected by factors such as pH, form and concentration of N, soil aeration, moisture and soil temperature. The rate of mineralization is considerably more rapid as neutrality is approached. Acid conditions cause the retention of ammonia in the soil and so slow nitrification (McLaren, and Cameron, 1993). Mineralization speeds up with increased temperatures in the Spring or in mild, wet conditions in the Autumn (Lampkin, 1990). In cool and wet regions mineralization is a strongly retarded and a large amount of organic matter will be accumulated. Conversely in warm and moist regions the conditions for mineralization are much more favourable and a lower amount of organic matter will be retained. The N release can amount from 50 to 250 kg / ha annually depending on soil content of mineralizable soil organic matter (Körschens, 1994). The rates of N mineralization and immobilization may vary from 3 to 5 fold over the range of moisture contents that ordinarily occur in soils. The processes occur much more rapidly at high than at low soil temperature, and cease when the soil is frozen. Little or no nitrification takes place in dry or extremely wet soils (Goring and Laskowski, 1982). Whereas the optimal pH for nitrification takes place is in the range from 4.5 to 7.5 (McLaren and Cameron, 1993).

Under organic management system, nitrate leaching losses may occur mainly from sudden rapid nitrification of inorganic nitrogen, following cultivation when mineralization will be enhanced. Autumn cultivations are likely to cause the largest losses especially if following a fertility-building ley. Crop rotation design needs to consider how the large losses of nitrogen following the ploughing in of the glass/clover ley can be minimized (Lampkin, 1990).

In conventional farming system, N fertilizers are applied to meet the N requirement of the growing crop. The crop, however is able to utilize only a part of this N. Fertilizer N used by upland crops seldom exceeds 50%. Before the crop can utilize the applied fertilizer N, part of it is immobilized in the soil or permanently lost from the soil system. Major loss of N occurs shortly after application and increases with the rate of application. The lost N follows different paths depending upon its chemical state after transformation. Loss of N by surface run-offs, leaching, and volatilization are major pathways (Heijndermans, 1991). Sustainable forms of agriculture aim to reduce external inputs and to utilize management practices that enhance soil ecological process important to internal recycling of nutrient resources. In the absence of chemical fertilizers, organic inputs and soil microbial and faunal activities become major determinants of nutrient cycling and plant growth (Doran, 1990).

The inclusion of legumes in a cropping system adds N to the soil and improves N availability through the N-fixation process. The biological fixation of atmospheric nitrogen which is the most important to the organic farmer are the symbiotic rhizobia bacteria associated with leguminous plants (Fowler et al., 1993). These bacteria form nodules on the roots of leguminous plants and use carbon compounds produced by the plant as an energy source to fix atmospheric nitrogen. This nitrogen is used by the plant and later released from decomposed material to become available to other plants. The usual range of estimates of nitrogen fixed by grass/clover leys is between 60 and 200 kg N/ha/yr(Lampkin, 1990). The N-fixation from the atmosphere is essentially driven by photosynthesis. Temperature and water availability may affect biological N-fixation (Power, 1990).

In New Zealand, crop rotations involve pasture containing a legume component which are usually clovers (*Trifolium spp)*. Biological nitrogen fixation in New Zealand pastures has been calculated in the range 100-

200 kg N/ ha/yr (Haynes and Francis, 1991). Another report by Hoglund et al. (1979), the annual average N-fixation in New Zealand pasture was 184 kg/ha (range 107-392 kg N/ha). Whereas grain legumes such as peas and field beans take up more soil nitrogen and fix less atmospheric nitrogen than forage legumes. The proportion of the total N accumulated by grain legumes that is obtained via biological N-fixation commonly range from 40 to 70% (La Rue and Patterson, 1981). However, 60-90% of the N accumulated by grain legumes is normally removed in harvested grain (Haynes, et al., 1993).

The N demands of the plants under crop rotation system is primarily met from biological nitrogen fixation both by rhizobia in symbiosis with legumes and by non-symbiotic free living organisms in the soil and from recycling of organic material. The organic farmer relies on the rhizobia bacteria in symbiotic association with legumes to make nitrogen available for plant nutrition.

2.3.2 Phosphorus (P)

Phosphates exist principally as inorganic phosphates in the soil, either as P compounds or P held on the surface of organic particles. The soil solution contains small amounts of organic as well as inorganic P ions. Plants take up phosphorus almost exclusively as inorganic phosphate ions ($H_2PO_4^-$) (Lampkin, 1990). Soluble P occurs at intermediate pH range 6-7. Below this pH range, P occurs as insoluble Fe and Al phosphates whereas above this range, it forms insoluble Ca phosphates compounds (Lampkin, 1990; McLaren and Cameron, 1993).

Phosphate compounds also exist in soil organic matter, although this is unlikely to be directly available to the plant. However, soil micro-organisms can directly increase P supply to plants through the processes of solubilization and mineralization of soil P. In addition, the microbial biomass itself contains a large pool of P that is potentially available to plants. The role of soil microorganisms is important in increasing plant available P (Richardson, 1994).

Increase in soil phosphorus can be achieved through long-term applications of animal manures. Also, in situation of phosphorus deficiency in the whole farm system, particularly in organic farming system, mineral fertilizers (such as rock phosphate and basic slag where still available) and recycled organic material can be used as a supplement to nutrient recycling on the farm.

2.3.3 Potassium (K)

The immediate source of K for crops is that of the soil solution. The uptake of K by the crop depends on the ability of the roots to exploit the soil, the concentration of K at the root surface and the rate at which K ions can diffuse from exchange sites to the root surface. The exchangeable and water-soluble K form a pool of readily available K which is maintained in equilibrium at around 90% exchangeable and 10% in solution. The pool is strongly buffered, so local depletion of the soil solution is replenished by release of exchangeable K. It is these readily available fractions which are the usual forms of K analysed (Lampkin, 1990). The return of excreta ensures the return of K removed in herbage.

Earthworm activity increases the exchangeable K content of the soil by making them more available by shifting the equilibrium between exchangeable K and non exchangeable K pool (Basker et al., 1992).

2.3.4 Cation exchange capacity (CEC)

The CEC of a soil determines the retention and availability of the various cationic macro-nutrients necessary for the production of healthy crops and maximum yields. The macro-nutrient cations supplied by soils are Ca^{2+}, K^+, Mg^{2+}, NH_4^+ and Na^+. Organic farming practices raise soil organic matter levels and hence increase the CEC of the soil, unless that soil has a large mineral fraction with a high CEC. The benefit of high CEC are that the soil becomes a good "sink" for cations, consequently holding large reserves and suffering less loss by leaching of these ions (Cooke, 1967). Cations bound in this way are held with varying tenacities and are subject to replacement by other cations and removal by crop roots. It has been estimated that the organic matter content of mineral soils contributes to 30-65% of the total exchange capacity of the soil (Allison, 1973), while Dijk (1971) reported that this proportion may rise to up to 90%.

2.3.5 C:N ratio

The C:N ratio of the soil has a marked effect on the availability of N for crop uptake, and its vulnerability to leaching and volatilization. The wider the C:N ratio, the greater the potential for biological immobilization of N. The ease with which a nutrient element is taken up by a plant or lost from the soil reservoir is governed by its chemical form. This in turn is affected by the antagonistic and largely microbially-mediated processes of mineralization and immobilization (Alexander, 1971).

In soils where organic matter levels are low, N applied in inorganic form that is not taken up by the crop will be rapidly lost, though a proportion will be retained by microbial elements in the soil, which are usually more N limiting than C. Incorporating an organic manure immobilizes a proportion of the mineral N in the soil, the proportion immobilized and the duration of immobilization depending on the C:N ratio (Arden-Clarke and Hodges, 1988). In a study by Herbert (1977) showed that there was no drop in soil mineral N when the C:N ratio of the incorporated organic matter is below 13.

2.3.6 Soil pH

Under improved pasture there is a tendency for soil pH to decline over time (Batten et al., 1979; Williams, 1980). An increase in the soil organic matter content in the surface soil results in an increase in CEC and H^+ saturation of the exchange complex (Williams, 1980). Excretion of H^+ in the pasture rhizosphere due to excess cation uptake by the N_2-fixing clover (Haynes, 1983; Jarvis and Hatch, 1985) and nitrification of NH_4^+ in the urine patch and subsequent nitrate leaching (Helyar, 1976) are also likely to be major contributors to such acidification. In New Zealand pastures it has long been recognized that regular lime applications (at 2-4 yearly intervals) are required to maintain soil pH at a suitable value (5.6 to 6.2) for optimum pasture production (During, 1984).

Parfitt et al. (1994) reported that there was considerable spatial variability of soil pH for samples collected from the pasture grazed by beef cattle, with pH values ranging from 5.6 to 7.1 for the 0-10 cm samples. The pH values of those samples were higher than for the 10-20 and 20-30 cm. samples, although no lime had been applied for the last five years. The soil pH values were lowest at the 10-20 cm depth, and this may be the zone where acidification is most likely to occur.

Application of inorganic fertilizers is likely to cause wider fluctuations in soil pH than so by organic manures. This is a consequence of both the more chemically reactive nature of inorganic fertilizers, and the lowering of organic matter levels which often accompanies inorganic fertilizer practice in conventional agriculture. Inorganic N fertilizer without a metallic cation deplete reserves of base elements in the soil, thus making it more acid. All ammonium fertilizers have this effect, causing a displacement of exchangeable calcium from soil colloids. The more mobile the anion, the greater will be the losses of calcium and the lowering of pH. When the calcium or other leached bases are not replaced (by liming, for example), a hydrogen ion takes their place and the soil becomes more acid (Cooke, 1967).

Fixation of atmospheric nitrogen and the subsequent leaching of NO_3^- formed from the mineralization of fixed-N_2 result in the acidification of soils. The addition of reactive phosphate rocks (RPR) is likely to reduce the rate of soil acidification from availability of free $CaCO_3$ and dissolution of phosphate mineral component (apatite) which consumes acid (Bolan and Currie, 1994).

2.4 The role of organic matter in soil fertility

Soil organic matter influences soil fertility in several ways. The main contribution of soil organic matter towards fertility is its influence on the physical, chemical and biological properties of the soil (Vaughan and Malcolm, 1985). Soil organic matter is a heterogeneous mix of living, dead and decomposing organic compounds derived from plant, animal and microbial tissue (Smith and Elliott, 1990). It plays an important role in soil chemical fertility and is a ready source of C and energy for micro-organisms. It is a highly complex mixture of carbon compounds that also contain N, S and P (Pierzynski et al., 1994). Therefore, it is a source of nutrients, usually slow release, as it is decomposed by soil microoganisms (Wallace, 1994a). Soil organic matter is the component of mineral soils that makes it possible for successful growth of most plants. It adds structural stability and plays an important role in relation to aggregate stability because of its binding and cementing actions (Tisdall and Oades, 1982; Oades, 1984). Soil organic matter is the precursor to sustainable agriculture.

Organic matter in the form of animal manures, crop residues, green manures and composts have long been known to improve soil and improve crop production (Lumsden et al., 1983). In addition, organic materials added to soil can increase microbial activity to effectively suppress a wide range of other microorganisms including plant pathogens (Cook and Baker, 1983). A major goal of organic farming practices is thus to increase soil organic matter levels. The release of N from soil organic matter is directly related to agricultural management practices that influence soil aeration, residue placement, and the amount of water retained in soil (Power and Doran, 1984).

Organic matter is the major indigenous source of soil N (McLaren and Cameron, 1993). It contains as much as 65% of the total soil P, and provides significant amounts of S and other nutrients essential for plant growth (Bauer and Black, 1994). Soil organic matter is the major contributor to CEC of the soil. The process of chelation, by which organic matter can hold and buffer trace elements, is also important. Organic matter can act as a " scrubber" to avoid toxic levels of trace elements and can detoxify toxic levels of pesticides/herbicides accumulated in the soils. This reduces the possibility of pesticide carryover effects, prevents contamination of the environment, and enhances both biological and non-biological degradation of certain pesticides and organic chemicals (Pierzynski et al., 1994).

Although there are many benefits of soil organic matter, there are also detrimental effects that occur under certain situations. Soils with high organic matter contents may require higher pesticide application rates for effective control. Water contamination is then a concern if these pesticides are leached or transported by wind or water erosion (McInnes and Fillery, 1989).

Soil organic matter influences soil productivity through its effect on physical and chemical properties. Organic matter stabilized soil aggregates and thus affects physical properties such as moisture storage capacity, aeration, infiltration, erosion, and the power required for tillage operations (King, 1990). Study by Springett (1993 pers. comm.) showed that root distribution down the soil profile with better at depth on the organically managed farms than conventionally managed farms. Chemical properties affected by organic matter include CEC and storage of nutrients in organic forms (King, 1990).

Soil organic matter acts as a reservoir for plant nutrients and prevents leaching of elements which are vital to plant growth (Simpson, 1983). An estimated 20 to 70% of the CEC of many soils is attributable directly to the soil organic matter alone (Stevenson, 1982) and Kamprath and Welch (1962) have shown that there is a direct relationship between organic matter content and CEC. Organic matter is negatively charged and thus retain the movement of major cations through soil. The higher this net negative charge (CEC) the greater the retention of cations (King, 1990).

The capacity of soil organic matter to buffer soils against rapid changes in pH is well known. This property arises largely from the interaction of humic substances and clays producing colloidal complexes which have negative surface charges and hold cations such as H^+, Al^{3+}, Fe^{3+} etc. Thus the resistance to pH changes is high in soils which have a substantial CEC (Vaughan and Malcolm, 1985).

The influence of soil organic matter on soil fertility is perhaps as critical as it is on the general ecology of the soil. Organic farming practices increase soil organic matter whereas conventional farming systems reduce soil organic matter, which affect soil fertility. The amount of organic matter present in soil and the rate of soil organic matter turnover are influenced by agricultural management practices (Cambardella and Elliot, 1994).

2.5 Effects of cultivation on soil fertility

Cultivation results in substantial losses of soil organic matter and N. Because soil organic matter is composed of a series of fractions, management practices will also influence the distribution of organic C and N among soil organic matter pools (Cambardella and Elliott, 1994). The distribution of organic C and N among labile and stable pools is affected by many factors including crop rotation, type and length of tillage (Tiessen and Stewart, 1983; Dalal and Mayer, 1987; Balesdent et al., 1988; Cambardella and Elliott, 1992), and fertilizer applications (Stanford and Smith, 1972; Christensen, 1988). Most soil degradation occurred within the first 4 years of cultivation (Mapfumo et al., 1994). The most labile fractions of soil nutrients decline with repeated cultivation (Cambardella and Elliott, 1994).

Lal et al.(1990) have shown that continuous cultivation for 12 consecutive years on clay soil which had high inherent fertility, had no effect on soil organic matter content but the available P content declined significantly. On the other hand, Aweto and Ayuba (1993) reported that the levels of exchangeable Mg, K, available P and CEC were similar in cultivated (over thirty years) and uncultivated soil in the 0-10 and 10-30 cm layers of both soils. However, soil organic C, total N, exchangeable Ca and pH were less in the soil under continuous cultivation, thus indicating a decline in soil fertility.

A study by Doran (1990) has shown that conventional tillage resulted in the inversion and mixing of soil and thus distributing crop residues and organic matter to a greater depth. In contrast reduced tillage resulted in the stratification of organic nutrient reserves. Thus type of tillage is extremely important in determining the status of soil organic matter. Full tillage maximized the mineralization of stable soil organic matter and released plant available nutrients (Wallace, 1994 b).

Cultivation usually results in a marked decline in the organic carbon content of soils compared with soils under permanent pastures (Gupta and Germida, 1988; Havlin et al., 1990; Richter et al., 1990). Study by Blevins et al. (1977) showed that extended period of cultivation of cropped and grassland soils invariably led to a lowering of their total organic matter content. Prolonged cultivation in Australian surface soils has resulted up to 60% loss in soil organic matter (Russell and Williams, 1982). In New Zealand, losses in soil organic C of 10-49% were found in soils cultivated for 6-14 years (Sparling et al., 1992). They have shown that continuous cultivation with maize on the Kairanga silty clay loam for up to 11 years decreased the total C content in the top 20 cm of soil by 21% and microbial C by 49% compared to levels under long-term permanent pasture (greater than 25 years). Sivapalan et al. (1993) have reported that microbial populations were higher in the organic cultivation than in the conventional system. Soil in the organic conversion area supported approximately twice the number and a wider range of fungal species than soil in the conventional cultivation.

2.6 The role of earthworm in organic farming

One of the key soil organisms and often an obvious feature of organic farms is the abundance of earthworms (Macgregor, 1994). Earthworms are the most common species of the soil macrofauna. They help soil mixing and increase available plant nutrients content by earthworm casts. A study by Reganold et al. (1993) showed that biodynamically farmed soil had an average of 175 earthworms per square meter compared with 21 earthworms per square meter on the conventionally farmed soil. Another study by Flock House AgResearch Centre (Springett, 1993 pers. comm.) showed that no differences between total numbers on organically managed farms and conventionally managed farms but more species on the organic farms compared with the conventional farms. At Flock House the earthworm numbers were more affected by the position on the crop rotation.

The most important effect of earthworms in agroecosystem is to increase nutrient cycling rates . They influence the supply of plant nutrients in the soil by increasing the rate of mineralization of crop residue and making it available for further mineralization by microorganisms (De Vleeschauwer and Lal, 1981). The burrowing activities of earthworms improve the aeration, porosity and drainage of the soil, all of which are important factors in the development of healthy and extensive crop root systems. The beneficial effects of channel provision for roots may be enhanced by the lining of the earthworm burrow with a higher proportion of available nutrients than in the surrounding soil (Edwards and Lofty, 1980). Study by Flock House AgResearch Centre (Springett, 1993 pers. comm.)

showed that there were significant differences between the distribution of burrows down the soil profile with more burrows at depth on the organic farms than conventional farms, the differences were greater on the dairy farms.

Of the 190 species of earthworms found in New Zealand, the most useful and active topsoil-mixing species is *Aporrectodea caliginosa.* Other useful species are *A. longa,A. Trapezoides, A. Rosea, A. chlorotica* and *Lumbricus terrestris* (MAF, 1984; Martin, 1977; McLaren and Cameron, 1993).

Earthworms consume large amounts of soil organic matter, mineral soil and surface litter, and produce casts deposited below-ground and on the surface up to 270 t/ha/yr (Lee, 1985). Kaushal et al. (1994) reported that total quantity of casts produced by *A.* alexandri was approximately 100 t/ ha/yr in pasture soil as compared with 25-33 t /ha/yr reported for New Zealand pasture (Sharpley and Syers, 1977; Syers et al., 1979). Surface cast production is a good indication of earthworm activity (Edwards and Lofty, 1977 ; Sharpley and Syers, 1977). Nutrient availabilities are considerably higher in the casts of earthworms than in the soil from which they are derived (Syers and Springett, 1984). Watanabe (1975) found that Megascolecid earthworms in Japanese pastures produced up to 61 t/ha/yr of casts and an increase in pH, total C, total N, Ca and Mg. Increased availability of N in earthworm casts compared to the non-ingested soil has been reported by several workers (Scheu, 1987; Tiwari et al., 1989; Hulugalle and Ezumah, 1991). Studies by various authors have also shown that there was an increase in the availability of P in casts compared to the non-ingested soil(Sharpley and Syers, 1976 ; 1977 ; Mansell et al., 1981 ; De Vleeschauwer and Lal, 1981 ; Tiwari et al., 1989).

A study by Basker et al. (1993, 1994) has shown that earthworm activity enhanced nutrient cycling by ingestion of soil and humus and the production of casts. Result of their study also showed that soil ingestion by earthworms increased the exchangeable K content of Raumai soil with high non exchangeable K but decreased the level in Milson soil with low non-exchangeable K. However, no consistent trends emerged for changes in exchangeable Ca, Mg, and Na as a result of soil ingestion by earthworms. Under certain conditions earthworms have also been shown to influence ion transport and increase nutrient cycling rates within the soil ecosystem. A high proportion of nutrients in casts are plant available and casts have a high enzyme activity (Syers and Springett, 1983). The role of earthworms in nutrient cycling is substantial because they ingest large quantities of pasture litter and return nutrients in the form of casts (Suckling, 1975).

Earthworms are not favoured by tillage. The greater the intensity and frequency of tillage, the lower the population density of earthworms (Barnes and Ellius,1979; Gerard and Hay,1979; Mackay and Kladivko,1985). Incorporation of organic fertilizers to soils is found to greatly increase earthworm populations (Mackay and Kladivko, 1985) but high rates of inorganic fertilizer application can sometimes cause an immediate reduction in earthworm numbers (Fraser, 1994). Another study by Scullion and Ramshaw (1987) indicated that the applications of poultry manure encouraged casting and burrowing to the surface, while applications of inorganic fertilizer discouraged these activities, especially at high application rates. Their results also indicated that inorganic fertilizer led to significantly lower population densities of the two species "primarily" responsible for surface casting (*Lumbricus terrestris* and *Aporrectodea caliginosa*). Fumigants such as methyl bromide and chloropicrin used to sterilise the soil are extremely toxic to earthworms at normal dose rates and can be lethal even for earthworms that live in deep burrows (Edwards and Lofty, 1977).

2.7 Organic farming versus conventional farming system

Comparison of the effects of the range of organic manuring techniques used in organic farming systems and the application of inorganic fertilizers practiced on conventional farm reveals major differences in the transfer of nutrients from soil to plant and the physical, chemical and biological effects (Russell, 1973). A comparative study of biodynamic and conventional farming systems (Reganold et al., 1993) in North Island of New Zealand showed organic matter content, total N, mineralizable N, and the ratio of mineralizable N to organic C (which indicates microbial activity in the soil) were significantly higher on almost all the biodynamically farmed soils. Available P , S and soil pH were commonly higher on the conventional farms whereas amounts of Ca, Mg and K were similar in the two systems (Table 2.1). However results of a study on pineapple cultivation under conventional and organic managements (Alvarez et al., 1993) showed that soil pH, and available Ca and Mg were higher in the organic treatment which used garden waste compost as fertilizer, than in conventional one using N-P-K fertilizers.

A study by Nguyen et al. (1994) on the status of nutrient fertility in soil managed under conventional and organic systems (Canterbury, NZ) showed that the levels of soil organic matter (soil C and N), soil pH and soil enzyme activity under organic farming system were comparable to those under conventional system. Wander et al. (1994) have shown that

Table 2.1. Nutrient status in biodynamic versus conventionally farmed soils at depth 0-100 mm (from Reganold et al. 1993).

Soil properties	Biodynamic farms	Conventional farms
Carbon (%)	4.84*	4.27
Mineralizable N ($\mu g\ g^{-1}$)	140.0*	105.9
Ratio of mineralizable N to C ($mg\ g^{-1}$)	2.99*	2.59
CEC ($cmol(+)kg^{-1}$)	21.5*	19.6
Total N ($\mu g\ g^{-1}$)	4840*	4260
Extractable P ($\mu g\ g^{-1}$)	45.7	66.2*
Extractable Ca ($cmol(+)kg^{-1}$)	12.8	13.5
Extractable Mg ($cmol(+)kg^{-1}$)	1.71	1.68
Extractable K ($cmol(+)kg^{-1}$)	0.97	1.00
pH (1:2.5 w/w soil to water)	6.10	6.29*

* $P < 0.01$

after 10 years of converting from conventional to organic management practices, the net changes in the soil organic matter contents of the soils were small but organic management practices enhance biologically active soil organic matter. Results of a study on P dynamics under conventional versus biodynamic systems by Oberson et al. (1993) have shown that soil microbial biomass (ATP content) and biological activities (the activity of acid phosphatase) were significantly higher in biological farming systems.

Results of a three year study by Nolte and Werner (1994) showed negative balances for P, K, and Mg in biodynamically managed soils. There was a deficit of 2.9 kg P/ ha/yr and 8.4 kg Mg/ha/yr, whereas the K balance had a deficit of 65 kg K/ ha/yr. For N balance was in the range from +16 to -38 kg N/ ha/yr.

A survey of selected New Zealand farms by Haysted (1983) showed that the levels of mineralized N in biodynamic management were significantly higher than the conventionally managed soils. Olsen-P, Ca and soil pH were higher in conventional farm whereas organic farms had higher Mg and lower levels of K. The most important finding was that there was no significant differences in biological activity in the soil or in the size of the microbial biomass. This finding would appear to contradict the belief of the organic and biodynamic farmers that their management strategies stimulate biological activity in the soil.

Another comparison of organic farming and conventional farming in the corn belt of Central USA, Lockeretz et al. (1984) found that after 7 year of organic management, organic farms maintained a high positive N balance and organic carbon than conventional management, but no significant difference existed in the available P and exchangeable K. They also suggested that organic farming may eventually deplete the soils' reserves of total P and K.

2.8 Summary

The foregoing review shows that sustainable productivity can only be achieved with proper management of the organic agroecosystem. Organic farming, is a system aimed at achieving an economically adequate and ecologically balanced level of production, along with the long-term stabilization of the agroecosystem. It is the system that enhances environmental quality and make the most efficient use of renewable resources. The paradigm of organic agriculture is therefore a systems-oriented concept, contrary to conventional farming which is product-oriented. Organic agriculture has to optimize the internal farm productivity and to minimize external inputs in order to develop a sustainable production pattern. Organic farming may not be possible for use on all farms of the world because of some limitations, but it does provide useful insights and directions needed for stable and sustainable agriculture to meet human and environmental needs now and in the future.

CHAPTER 3

MATERIALS AND METHODS

3.1 Site location and management history

Studies of soil nutrient fertility status of the organic and conventional plots were undertaken at the Flock House cropping and organic units situated near Bulls (NZ). The total area of the units is 82.73 ha, of which 44 ha was converted to an organic crop rotation system in 1988. The organic units were divided into 12 plots of varying sizes (Appendix 1) and different management history. Two organic plots (OP3 & OP5) and a conventional plot (CP8) were selected for this study in order to investigate the objective of this study. The management history of the selected plots since conversion to organic units is given in Appendix 2. The Bulls area had moderate annual total rainfall of 780 mm in 1994. Average monthly rainfall in the area (Appendix 3) showed that Spring season was wetter than Autumn.

3.2 Soils on the organic site

The soil was a well drained Manawatu silt loam (Dystric Fluventic Eutrochrept). Parent material was quartzo-feldspathic alluvium. Soil material contained 21% clay and 62% silt in the Ap horizon (0-20 cm), 20% clay in the Bw horizon (20-37 cm), and lower subsoils vary from 5 to 20% clay (Soil Survey Staff, 1990). The soil had friable dark greyish brown (10YR 4/2) silt loam with a moderately developed fine and medium nut structure.

3.3 Soil sampling

Soil samples were taken from the site in Autumn (15 May, 1994) and Spring (27 August 1994) so that seasonal variation of the soil chemical fertility could be studied. Five pits (a spade width x 40 cm deep) at about 100 m spacing were dug in each plots along profile lines shown in Appendix 1. About 2 kg samples of soil were taken from depths 0-75, 75-150 and 150-300 mm respectively. Thus a total of 15 soil samples were taken from each plot as described below:-

OP3	3 depths (0-75, 75-150 and 150-300 mm) x 5 locations = 15
OP5	3 depths (0-75, 75-150 and 150-300 mm) x 5 locations = 15
CP8	3 depths (0-75, 75-150 and 150-300 mm) x 5 locations = 15
	Total number of samples = 45

The soil samples were air dried for 1 week at room temperature and sieved through a 2 mm sieve for selected chemical analysis.

3.4 Surface casts of earthworm

Freshly deposited surface casts of earthworm were counted and collected using an iron quadrat (40 x 40 cm) at each sampling location. Grass within the quadrat was first removed by clipping prior to counting and collecting cast material. About 200 g of freshly deposited earthworm surface cast materials were collected from each sample locations. The surface cast samples were oven dried at 25°C for 48 hours and passed through 2 mm sieve prior chemical analysis.

3.5 Laboratory methods

Soil pH

Soil pH was determined in 1:2.5 w/w soil to water ratio as described by Blackmore et al. (1987). Ten grams of air-dried soil (< 2 mm) was mixed with 25 cm^3 of deionised water in a 50 cm^3 plastic beaker and left overnight after stirring. The pH was measured at 20°C and 98.2% sensitivity using PHM 83 Autocal pH meter. A sample of Manawatu silt loam was included as an internal analytical standard.

Total C

Total C was determined by a combustion method as described by Bremner and Tabatabai (1971). A Leco Gravimetric Carbon Determinator (Model 521-275) was used for the combustion of soil samples. The samples were oven dried at 105°C and finely ground. Approximately 0.2 g of the ground sample was mixed with the combustion catalysts of iron, copper and tin chips in a ceramic cup and combusted for 5 minutes. The amount of CO_2 evolved from combustion was determined by weighing the ascarite trap before and after each oxidation. The total carbon (C%) was obtained from the increase in weight of the CO_2 generated during combustion of organic carbon. Glucose was used as standard for checking percent recovery of the C in the samples. Percentage recovery obtained was in the range 97.5 to 100%.

Total N

The Kjeldahl digestion method described by McKenzie and Wallace (1954) was used for analysis of total N. Air-dried soil (< 2 mm) was finely ground in a ring grinder (to increase digestion rate) and 1 g of the ground sample was mixed with 4 cm^3 of the digest mixture in a 50 cm^3 pyrex test tube. The mixture was left overnight after which it was heated in an aluminium block at 350°C for 7 hours. When cooled, the mixture was diluted with 50 cm^3 of deionized water, stirred in a vortex mixture and left overnight. Total N in the supernatant solution was measured by an autoanalyzer (Technicon, 1976). A sample of Manawatu silt loam (a soil analytical standard) and reagent blank were included in the measurements.

Mineralizable N

Mineralizable nitrogen (i.e. nitrogen that is potentially able to be converted to inorganic-N as NH_4^+ and NO_3^-) was determined by an aerobic incubation method described by Keeney and Bremner (1967). Ten grams of air-dried soil (< 2 mm) was mixed with 30 g of 50-150 mesh acid purified sand and put into a 250 cm^3 erlenmeyer flask. The soil-sand mixture was moistened with 6 cm^3 of distilled water and incubated at 30°C for 14 days.

The incubated sample was mixed with 100 cm^3 of 2M KCl and shaken for 1 hour on an orbital shaker and allowed to stand until a clear supernatant solution was obtained. The supernatant was filtered through Whatman filter paper No. 42 and analyzed for exchangeable NH_4^+ and NO_3^- by an autoanalyzer (Technicon, 1976). The percent recovery was obtained by spiking 2M KCl with ammonium nitrate standard. Percentage analytical recovery of NH_4^+ and NO_3^- was 97.5 and 97.0 respectively.

The difference in inorganic-N content between the incubated and non-incubated samples was identified as the amount of net mineralizable N expressed as μg inorganic N g^{-1} soil.

Olsen-P

Olsen-P, a measure of plant-available P, was determined by the phosphomolybdate method of Murphy and Riley (1962). One gram of air-dried soil (< 2 mm) was weighed into 50 cm^3 polypropylene centrifuge tube and 20 cm^3 of 0.5 M $NaHCO_3$ was added to it. The mixture was shaken in an end-over-end shaker for 30 minutes and filtered through Whatman No.42 filter paper after centrifuging at 8000 rpm for 10 minutes. The extract was transferred into 50 cm^3 test tube and 8 cm^3 of Murphy and Riley reagent was added to it and volumerized to 50 cm^3 with distilled water. The mixture was shaken well and left to stand for 30 minutes for colour development. Absorbance was measured using a Phillips PU 8620 Spectrophotometer at 712 nm using a 1 cm cuvette. P concentration of the soil extract was read directly from the best fit standard curve of P (ppm) versus absorbance. A sample of Manawatu silt loam (a soil analytical standard) was included in the measurements.

Exchangeable K

Exchangeable K was determined by semi-micro leaching method described by Blackmore et al. (1987). One gram of air-dried soil was mixed with 3 g of 50-150 mesh acid-washed silica sand and packed into a semi-micro leaching tube. The soil-sand mixture was leached with neutral (pH 7) 1M NH_4OAc at a 1:50 soil to solution ratio using a CEC pump. Blank samples were used in each batch of leaching. Exchangeable K in the leachate was determined by atomic absorption spectrophotometry (AAS).

Cation exchange capacity (CEC)

The CEC of the soil was determined by semi-micro leaching method described by Blackmore et al. (1987). One gram of air-dried soil was mixed with 3 g of 50-150 mesh acid-washed silica sand and packed into a semi-micro leaching tube. The soil-sand mixture was leached with neutral (pH 7) 1M NH_4OAc at a 1:50 soil to solution ratio using a CEC pump. Blank samples were used in each batch of leaching. The leachate was weighed and its pH measured. The H^+ concentration was obtained from the difference in pH between the sample leachate and the blank. Exchangeable Ca^{2+}, Mg^{2+}, K^+ and Na^+ were determined by atomic absorption spectrophotometry (AAS). The CEC value of the soil was obtained from the summation of the exchangeable cations.

The CEC value of earthworm cast material was also determined by the method described above.

3.6 Statistical analysis of analytical data

The experiment was designed as nested design. A SAS programme for analysis of variance (ANOVA) using test of least significant difference (LSD) at 5% confidence level ($p=0.05$) was used to discriminate parametric differences between the organic and conventional plots. A summary of the statistical analysis is presented in Appendix 6.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Soil chemical fertility

Soil chemical fertility is generally measured in terms of certain key plant available nutrients and level of organic C in the topsoil. During conversion to organic crop rotation system, the nutrient levels are likely to change as a result of significant increase in organic matter. In this study, the aim was to establish parametric differences in nutrient status of organically managed soils as compared to soils under conventional cropping system. Quantitative measurements of changes in soil pH, total C, total N, mineralizable N, Olsen-P, exchangeable K and CEC would thus indicate the effects of organic crop rotation system on soil chemical fertility.

A summary of the chemical analyses of the soils from organic and conventional plots collected during Autumn and Spring (1994) are presented in Table 4.1 and 4.2 respectively. Abundance and chemical properties of the earthworm surface cast is also given in Table 4.3. Analysis of variance (ANOVA) of mean values are included in the tables and in Appendix 6.

Results of the analysis showed that the major soil nutrients N, Ca, Mg and K were generally higher in the organic plots (OP3 and OP5) except for available Olsen-P which was significantly higher in the conventional plot

Table 4.1 Chemical analyses of soils from organic and conventional plots:- Autumn sampling

	OP3			OP5			CP8		
	Soil Depth (mm)			Soil Depth (mm)			Soil Depth (mm)		
Soil parameter	0-75	75-150	150-300	0-75	75-150	150-300	0-75	75-150	150-300
pH(H_2O)	5.8 a	5.8a	5.9 a	5.4 b	5.6 b	5.8 a	5.3 b	5.5 b	6.1 a
Total C, %	3.6 a	3.1 a	2.4 a	2.8 b	2.9 a	2.2 a	3.1 b	2.5 b	1.9 a
Total N, %	0.40 a	0.36 a	0.28 a	0.34 b	0.30 b	0.23 ab	0.33 b	0.28 b	0.18 b
C/N ratio	9	9	9	8	10	10	9	9	11
Mineralizable N, $\mu g\ g^{-1}$	104 a	65 a	53 a	30 b	48 a	50 a	91 a	54 a	32 b
Ratio Min-N/C, $mg\ g^{-1}$	2.9 a	2.2 ab	2.2 a	1.1 b	1.7 a	2.3 a	3.0 a	2.1 a	1.7 b
Olsen-P, $\mu g\ g^{-1}$	13 b	13 b	10 a	15 b	10 b	9 a	29 a	22 a	9 a
K, cmol(+)kg^{-1}	1.20 a	0.75 a	0.55 a	0.83 a	0.62 ab	0.44 ab	0.79 a	0.43 b	0.26 b
Ca, cmol(+)kg^{-1}	8.9 a	8.5 ab	7.8 a	9.4 a	9.7 a	8.2 a	7.3 b	7.5 b	7.2 a
Mg, cmol(+)kg^{-1}	1.79 ab	1.58 a	1.63 a	1.94 a	1.69 a	1.59 a	1.42 b	1.39 a	1.44 a
CEC, cmol(+)kg^{-1}	16.5 b	17.5 a	17.0 a	19.2 a	18.3 a	14.8 a	16.4 b	15.9 a	13.7 a
BS, %	73 a	64 a	60 a	64 b	66 a	70 a	59 b	59 a	65 a

OP3 = Organic plot (pasture)   OP5 = Organic plot (cultivated)   CP8 = Conventional plot (pasture)
Means with the common letter for each depth are not significantly different ($p = 0.05$)
See appendix 2 for history of crop rotation in each plot

Table 4.2 Chemical analyses of soils from organic and conventional plots:- Spring sampling

	OP3			OP5			CP8		
	Soil Depth (mm)			Soil Depth (mm)			Soil Depth (mm)		
Soil parameter	0-75	75-150	150-300	0-75	75-150	150-300	0-75	75-150	150-300
$pH(H_2O)$	6.0 a	5.9 a	6.0 a	6.0 a	5.8 a	5.9 a	5.7 b	5.8 a	6.1 a
Mineralizable N, $\mu g\ g^{-1}$	139 a	86 a	66 a	99 b	80 a	68 a	86 b	66 a	43 a
Ratio Min-N/C^{*}, $mg\ g^{-1}$	4.0 a	2.9 a	2.7 a	3.5 ab	2.8 a	3.6 a	2.8 b	2.6 a	2.2 a
Olsen-P, $\mu g\ g^{-1}$	18 b	15 a	12 a	18 b	13 a	7 a	38 a	23 a	10 a
K, $cmol(+)kg^{-1}$	1.55 a	1.14 a	0.76 a	1.28 a	0.73 ab	0.50 a	1.00 a	0.53 b	0.41 a
Ca, $cmol(+)kg^{-1}$	10.1 a	9.1 a	8.4 a	9.0 a	9.4 a	8.3 a	8.9 a	8.9 a	8.0 a
Mg, $cmol(+)kg^{-1}$	1.49 a	1.02 b	1.08 a	1.38 a	1.39 a	1.28 a	1.54 a	1.36 a	1.39 a
CEC, $cmol(+)kg^{-1}$	20.9 a	19.8 a	17.8 a	17.2 b	16.7 b	14.3 a	19.3 a	17.1 b	13.0 a
BS, %	64 a	58 b	61 b	69 a	70 a	72 a	60 a	65 a	77 a

OP3 = Organic plot (pasture) OP5 = Organic plot (cultivated) CP8 = Conventional plot (pasture)

C^{*} value from Autumn, 1994

Means with the common letter for each depth are not significantly different ($p = 0.05$)

See appendix 2 for history of crop rotation in each plot

(CP8). Nutrient status of the organic plot under cultivated crop rotation (OP5) was closely similar to that of corresponding conventional system and that organic plot under clover based pasture (OP3) for the last three years showed significantly higher levels of soil nutrient fertility. Moreover, the average nutrient levels were higher in Spring in both the organically and conventionally managed soils. Soil pH was variable at surface and both OP5 and CP8 showed indication of acidification. A comparative distribution of the nutrient parameters measured in this study is discussed below.

Soil pH

The mean pH for topsoil (0-75 mm) in organic plots OP3 and OP5 was 5.8 and 5.4 respectively in Autumn and 6.0 for both the plots in early Spring. The corresponding value for CP8 was 5.3 and 5.7 in Autumn and Spring respectively (Table 4.1 and 4.2). While OP3 showed constant pH throughout the soil profile depth, 0-300 mm, both OP5 and CP8 had lower topsoil pH in Autumn collected soils (Figure 4.1). The application of urea fertilizer in CP8 and its nitrification and its rapid decomposition of organic matter in OP5 may have caused acidification of the soils during Autumn.

Seasonal distribution and variation between soil depth of pH for each plot are shown in Figure 4.1. The topsoil pH of both OP5 and CP8 were significantly lower than that of OP3 during Autumn (Table 4.1). However, the Spring topsoil pH values were significantly greater than Autumn values (Appendix 6) despite similar amount of rainfall during both the

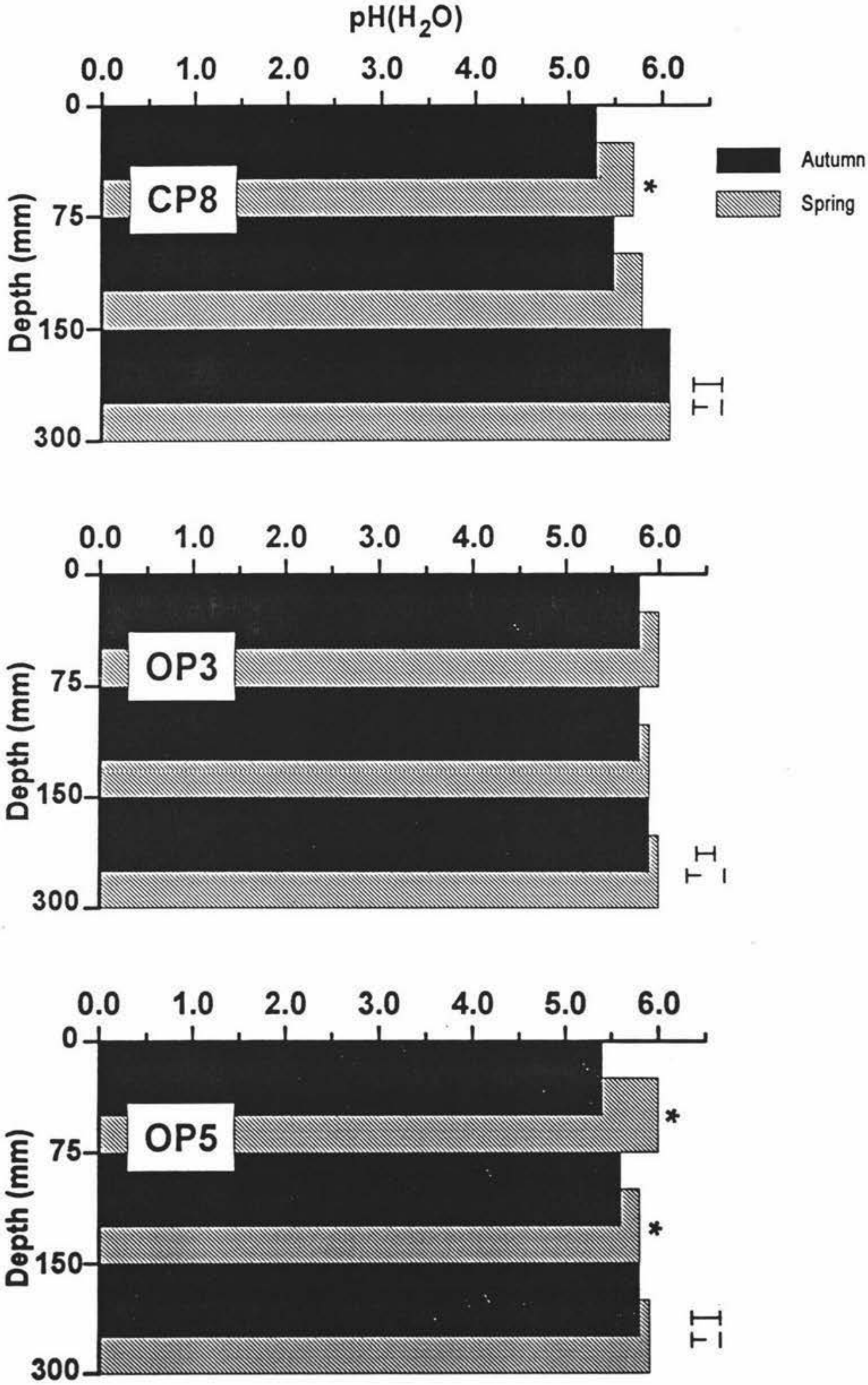


Figure 4.1 Seasonal variation of pH in conventional (CP8) and organic plots (OP3 & OP5). LSD(5%) bars are for mean variation between soil depths in Autumn (——) and Spring (------). Bars marked with asterisk (*) are significant at 5% level between seasons.

seasons (Appendix 3). An application of superphosphate fertilizer to the conventional plot (CP8) and liming effect of reactive phosphate rock (RPR) in the organic plots may have caused higher levels during Spring. The increased stocking rate in Spring may also have caused an increase in surface soil pH due to neutralising effects of $CaCO_3$ and $MgCO_3$ contained in the animal excreta (Barrow, 1987).

Total C and N

Total organic C content of the Autumn collected soils in the organic and conventional plots at all soil depths (0-300 mm) was in the range 1.1%-4.1% and 0.8%-3.2% respectively. The mean variation between soil depths total C in the organic plots (OP3 and OP5) ranged from 3.6% in topsoil (0-75 mm) to 2.2% at depth 150-300 mm (Table 4.1). The corresponding mean value for the conventional plot (CP8) was 3.1% to 1.9%. As expected, soils in OP3 under pasture since 1991 contained significantly higher amount of total C compared to OP5 under continuous crop rotation and the CP8 under pasture. A significantly higher level (3.6% C) of organic C in topsoil layer 0-75 mm under OP3 indicated that there was significant build up of organic matter as compared to CP8 and OP5. Continuous cultivation in OP5 has resulted in lower levels of C at topsoil 0-75 mm but still comparable to CP8. At a soil depth of 150-300 mm, the level of total C was similar in all three plots studied. Crop rotations in organic plot, OP3, included pasture / serradella / wheat / pasture over seven years period (Appendix 2) resulting in substantial input of organic residues and subsequent increase in levels of soil organic matter. In organic plot, OP5, incorporation of green manure crops resulted in significant build-up of soil organic matter distributed evenly in the soil profile by tillage. The effect of cultivation mixed the soil and thus distributing crop residues and organic matter to a greater depth. Such changes in specific organic C contents of the organically managed soils were reported by Reganold et al. (1993) and Johnston et al. (1994).

All soil depths (0-300 mm), the total N content of the organic plots ranged from 0.27% to 0.44% and 0.19% to 0.41% in OP3 and OP5 respectively. While N content of the CP8 was in the range 0.07-0.35%. The mean distribution of total N in CP8, OP3 and OP5 with depth 0-75, 75-150 and 150-300 mm are given in Table 4.1. Total N in the depth range 0-150 mm were significantly higher than at depth 150-300 for all the plots [Appendix 6 (Table A1)]. The variations between plots of total N was similar to the variations of organic C with OP3 containing significantly higher levels. Again management practices in OP3 resulted in the higher turnover of organic N in the topsoil where most of the organic matter accumulate. In addition, incorporation of legumes in crop rotation increased total soil N through symbiosis with nitrogen-fixing bacteria. However, the effect of consecutive cultivation over several years in OP5 caused decline in soil organic matter and thus lowering the total soil N content.

The overall mean values of organic C and N and their statistical significance together with corresponding C:N ratio are presented in Table 4.1. These values showed that over seven years of organic management of the plots at Flock House has resulted in an overall increase in C and N contents of the soil throughout the profile to a depth of 300 mm. Organic plot (OP3) that has been under clover based pasture for the last 3 years contained significantly higher amounts of both C and N while the organic plot (OP5) that has until recently been crop rotated with continuous cultivation contained comparable amounts of both these nutrients with that of conventional plot (CP8).

Thus the effect of pasture in the crop rotation was to raise the level of organic C and N in the soils. This increase in organic C and total N in time provided a stable C:N ratio as shown in Figure 4.2. In general, CP8 provided highest correlation (r^2=0.94, N=15) between C and N while OP3 and OP5 showed lesser correlation of r^2=0.76 (N=15) and r^2=0.63 (N=15) respectively. Organic crop rotation resulted in the increase of both C and N thus keeping the C:N ratio constant. Once again the effect of cultivation on soil organic matter is reflected in the lower correlation of C and N in OP5.

Mineralizable N (Min-N)

The mineralizable N value for Autumn collected soils at all soil depths (0-300 mm) ranged from 17-131 $\mu g\ g^{-1}$ in conventional plot (CP8) to 43-142 $\mu g\ g^{-1}$ and 13-73 $\mu g\ g^{-1}$ in organic plots OP3 and OP5 respectively. The mean net mineralizable N contents of the soils collected in Autumn and Spring are presented in Table 4.1 and 4.2. The topsoil (0-75 mm) mean values of mineralizable N were significantly higher than at depth (75-300 mm) for OP3 and CP8 while OP5 had the reverse trend as shown in Figure 4.3. As expected the Min-N values for OP3 and CP8 were significantly higher than OP5 at surface depth 0-75 mm. Effect of cultivated organic crop rotation has depleted Min-N in OP5 as result of

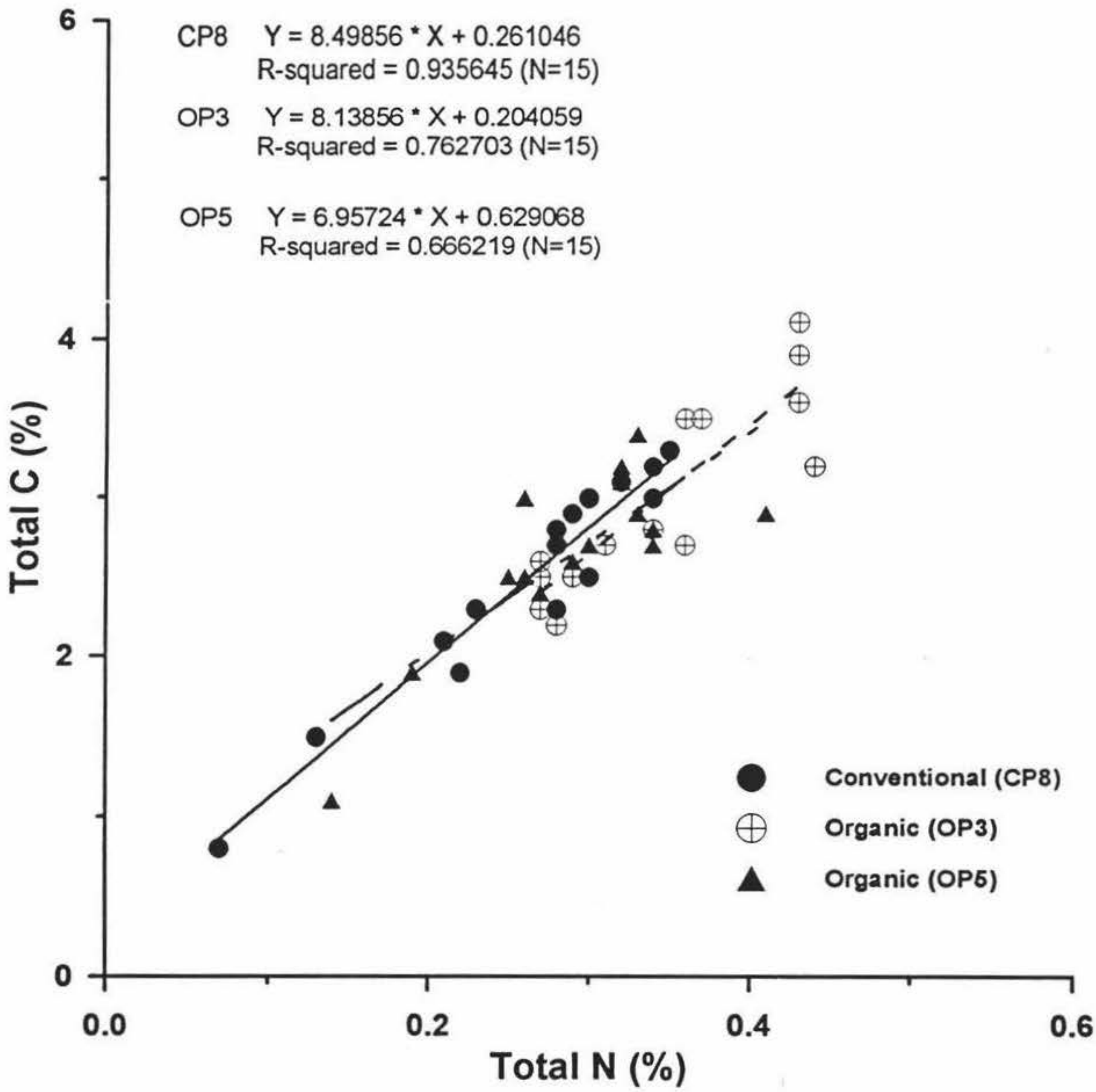


Figure 4.2 Correlation between total C and total N contents of the soil for the organic and conventional plots (0-300 mm depth).

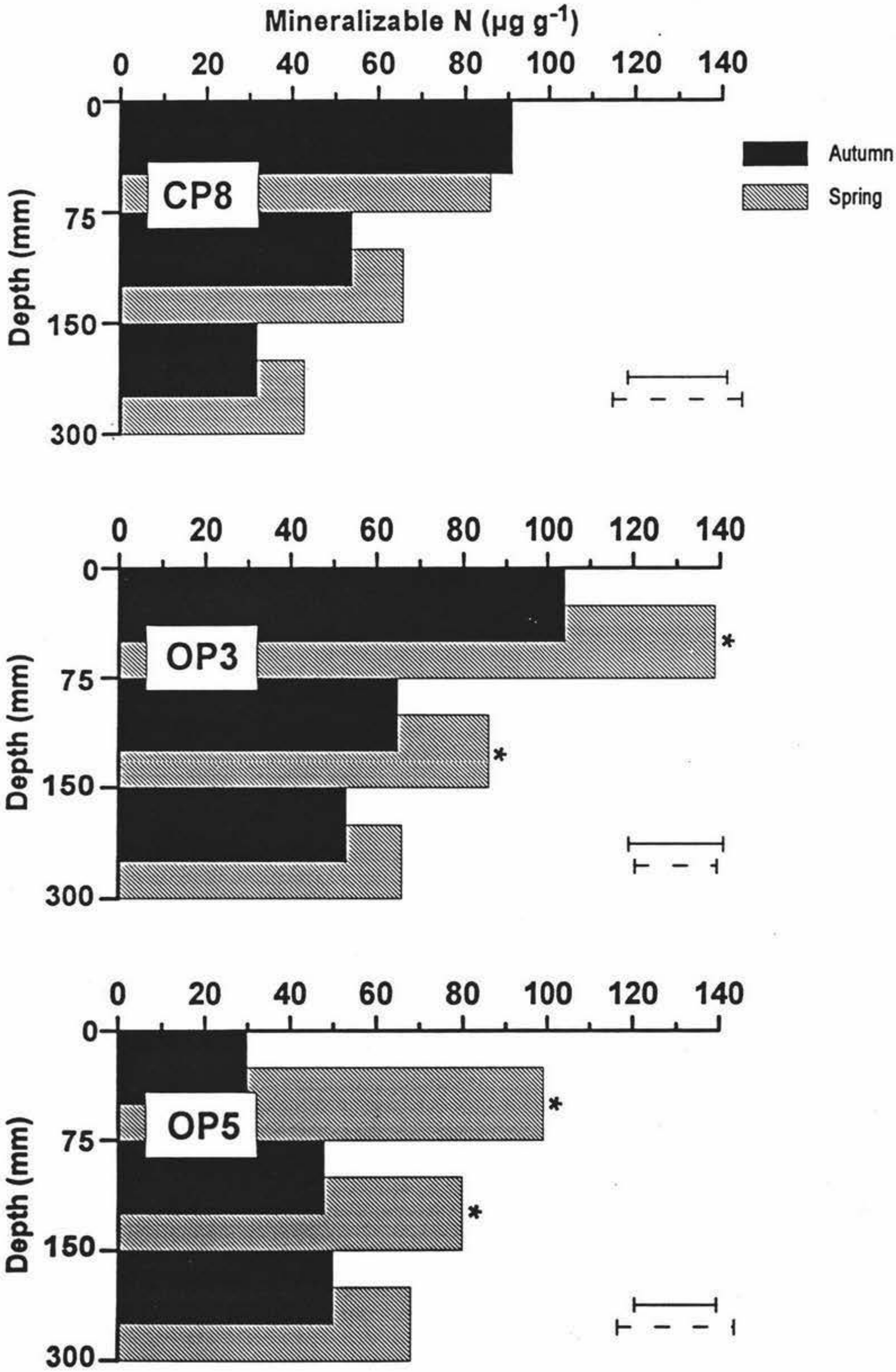


Figure 4.3 Seasonal distribution of mineralizable N in conventional (CP8) and organic plots (OP3 & OP5). LSD(5%) bars are for mean variation between soil depths in Autumn (——) and Spring (------). Bars marked with asterisk (*) are significant at 5% level between seasons.

reduced organic matter content in the topsoil. At depth 75-150 mm, there were no significant difference in Min-N levels between organic and conventional plots (Table 4.1). Inversion and mixing of crop residue by tillage practice reduced microbial activity at surface soil and hence reduced level of Min-N in OP5. In contrast, gradual build up of organic matter under pasture in OP3 and input of nitrogen fertilizer (urea) in CP8 in addition to grazing is reflected in higher amounts of Min-N in these plots. Organic crop rotation under cultivation (OP5) resulted in substantial loss of soil organic matter and hence reduction in Min-N.

Because a lab-incubation test is used to simulate and speed up what happens in the field, the values obtained cannot be extrapolated to the actual soil in the field. Min-N is a measurement that ranks the soil potential to provide plant available N. Min-N is really a measure of biological activity. The variation between soil depths of Min-N in Autumn showed that generally topsoil (0-75 mm) in OP3 and CP8 provided significantly greater amounts of Min-N than at depth 75-300 mm (Figure 4.3). As both OP3 and CP8 were pasture, so plant residues were left on or near the surface and increased the soil N status by building up the pool of soil organic N. The presence of crop residues on or near the soil surface may have helped prolong favourable soil moisture levels, thus creating favourable conditions for microbial activity. In contrast, the amount of Min-N increased with depth in OP5. This is because consecutive cultivation has resulted in a substantial decline of soil organic matter and N in the surface layer. At the time of sampling, soil of OP5 had recently been cultivated and fresh and decomposing plant residues from the surface soil were inverted and mixed to a greater depth in soil. This may have resulted in fewer microorganisms and less microbial activity in the top layer (0-75 mm soil).

The distribution of Min-N in Spring (Table 4.2) showed very similar trend as in Autumn except for OP5. Figure 4.3 shows that Min-N in both OP3 and OP5 were higher than CP8 and that OP5 value had increased significantly to level comparable to CP8. There was a slight decrease in CP8 value but OP3 value was still significantly higher than the other two plots. At depth 75-300 mm, there was no significant difference in Min-N between the organic and conventional plots (Table 4.2).

Soil from the surface layer of OP5 sampled in Spring showed a marked increase in Min-N and this is attributed to the influence of the newly sown pasture only 3 months before. Overall Spring values of Min-N were significantly higher for the organic plots while it remained unchanged in the conventional plot (Figure 4.3).

The results indicated that over a short period, influence of different cropping components (i.e. pasture) can result in increased soil microbiological activity followed by increased rate of N mineralization in the soil. A crop rotation which included a legume based pasture improved organic matter levels in the soil and thus enhanced nutrient cycling in the soil-plant system. A measure of the level of microbial activity in the soil can be shown by the ratio of Min-N to organic C as shown in Figure 4.4. It can be seen mineralization of N were similar in organic and conventional plots. The organic plot, OP5, showed lower level of N mineralization during Autumn because this activity had been reduced

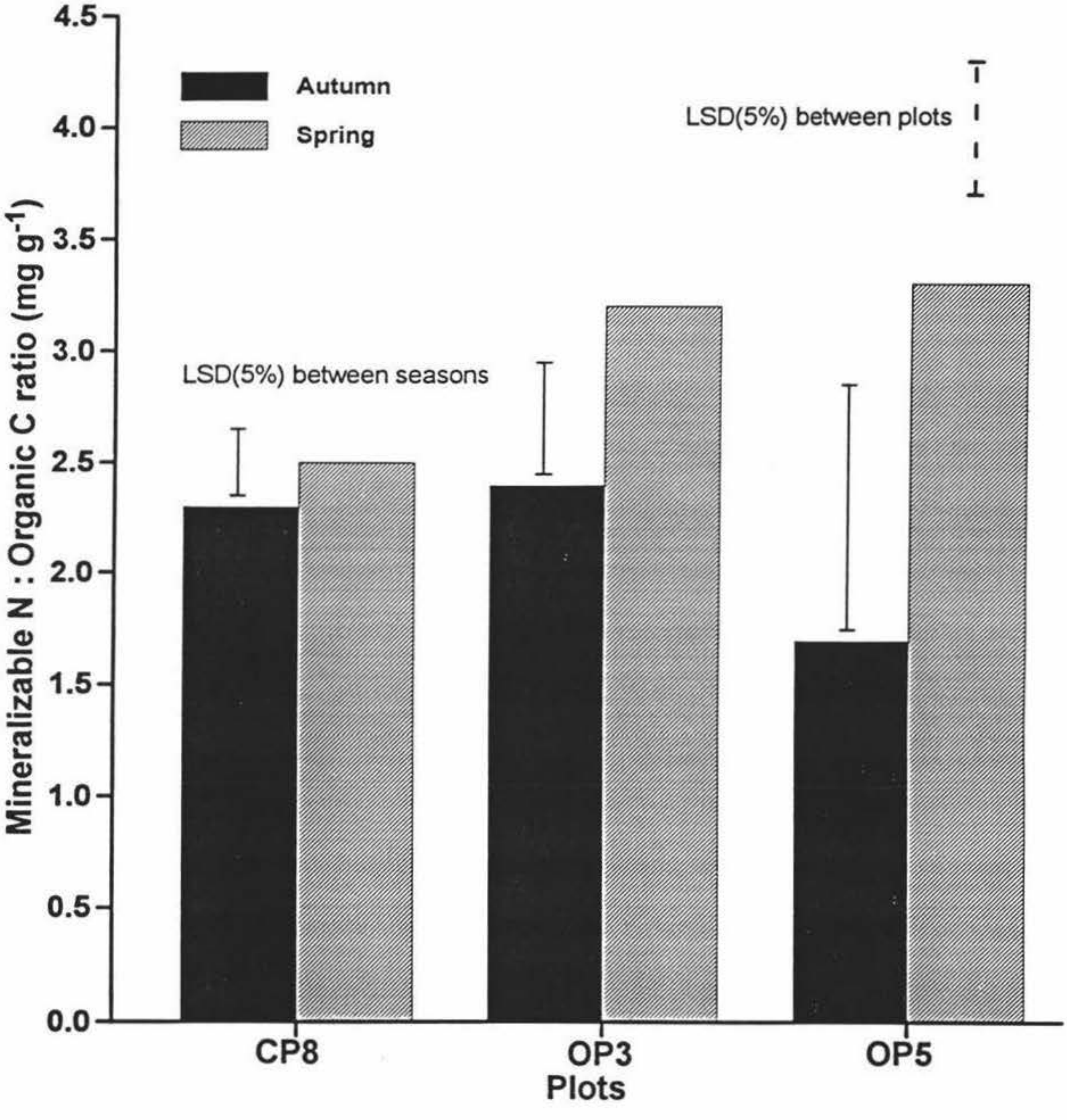


Figure 4.4 Seasonal variation in the ratio of mineralizable N to organic C between organic (OP3 and OP5) and conventional plots at soil depth 0-300 mm.

through cropping, before it was put into pasture. The figure also shows that microbial activity was significantly higher during the warmer Spring in the organic plots but no changes occurred in the conventional plot.

Olsen-P

The soil Olsen-P values for Autumn sampled soils at all soil depths (0-300 mm) was in the range 5-19 $\mu g\ g^{-1}$ and 2-18 $\mu g\ g^{-1}$ in organic plots OP3 and OP5 respectively. The corresponding CP8 value was in the range 5 to 37 $\mu g\ g^{-1}$. The mean Olsen-P values of the soils collected in Autumn and Spring are presented in Table 4.1 and 4.2. The CP8 mean Olsen-P value was generally two-fold higher than the organic plots OP3 and OP5 at soil depth 0-150 mm but it was similar at depth 150-300 mm. There was no significant difference between the Olsen-P values for OP3 and OP5 in the sampled soil depth (0-300 mm). Figure 4.5 shows seasonal distribution and variation between soil depths of Olsen-P in the organic and conventional plots. Olsen-P values remained constant throughout the sampled depth for the organic plots but were significantly higher at depth 0-150 mm for OP5. While the effect of fertilizer application raised the P level in CP8, the slow releasing reactive phosphate rock (RPR) in the organic plots did not affect the soil extractable Olsen-P.

The Olsen-P in Spring collected soil samples at all soil depths (0-300 mm) ranged from 5 to 28 and 8 to 22 $\mu g\ g^{-1}$ in OP3 and OP5 respectively while CP8 value was in the range 4-60 $\mu g\ g^{-1}$.The general trend of the variation between soil depths of Olsen-P for each plot were very similar to that of

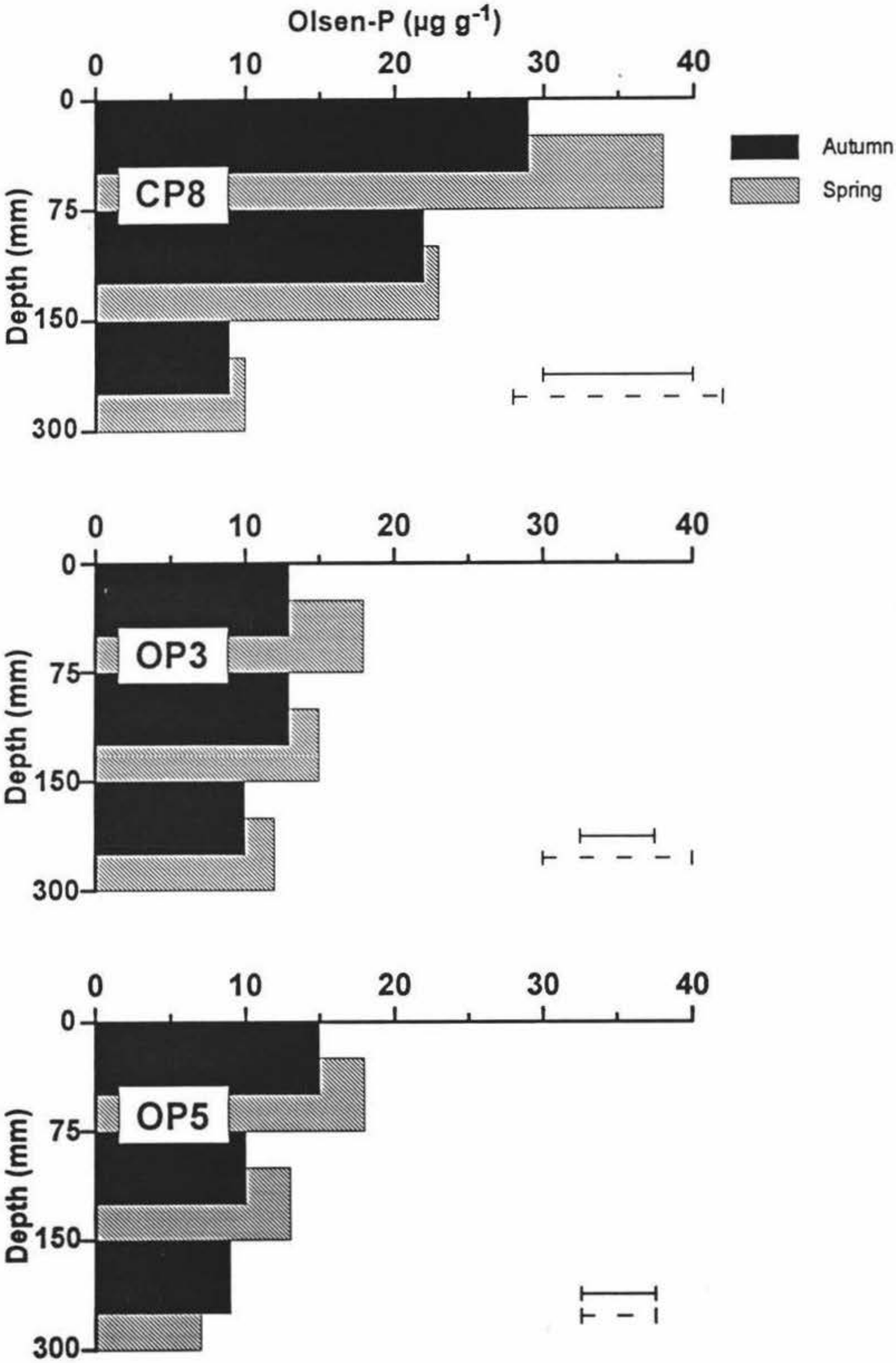


Figure 4.5 Seasonal distribution of Olsen-P in conventional (CP8) and organic plots (OP3 & OP5). LSD(5%) bars are for mean variation between soil depths in Autumn (——) and Spring (------). No significant difference between seasons.

the Autumn collected soils. However, the Spring soils had higher levels of Olsen-P especially in CP8 than the Autumn soil samples (Figure 4.5).

Although there was spatial variations of P within the plot, overall the conventional plot had significantly higher levels of Olsen-P than organic plots in both Autumn and Spring collected soils. Similar trends have been reported by Haysted (1983) in their comparative assessment of the organic and conventional farms, and also Reganold et al. (1993).

Exchangeable K

The seasonal distribution and variation between soil depths of exchangeable K in the organic and conventional plots are shown in Figure 4.6 and the mean values of the K contents is given in Table 4.1 and 4.2 for Autumn and Spring seasons respectively. The exchangeable K content of the organic plots at all soil depths (0-300 mm) was in the range 0.34-2.41 cmol(+)kg^{-1} and 0.31-1.08 cmol(+)kg^{-1} in OP3 and OP5 respectively while CP8 had value in the range 0.19-1.19 cmol(+)kg^{-1} for Autumn collected soil samples. The corresponding value for Spring season was 0.4-1.99 cmol(+)kg^{-1} and 0.35-1.98 cmol(+)kg^{-1} for OP3 and OP5 respectively whereas CP8 had value was in the range 0.15-1.30 cmol(+)kg^{-1} . From Table 4.1 and 4.2, it is evident that there is no significant differences in the exchangeable K between the organic and conventional plots in the top layer 0-75 mm soil. However, the topsoil (0-75 mm) exchangeable K values were significantly higher for all the plots in both Autumn and Spring sampled soils (Figure 4.6). Such surficial increase in exchangeable K content has been attributed to earthworm

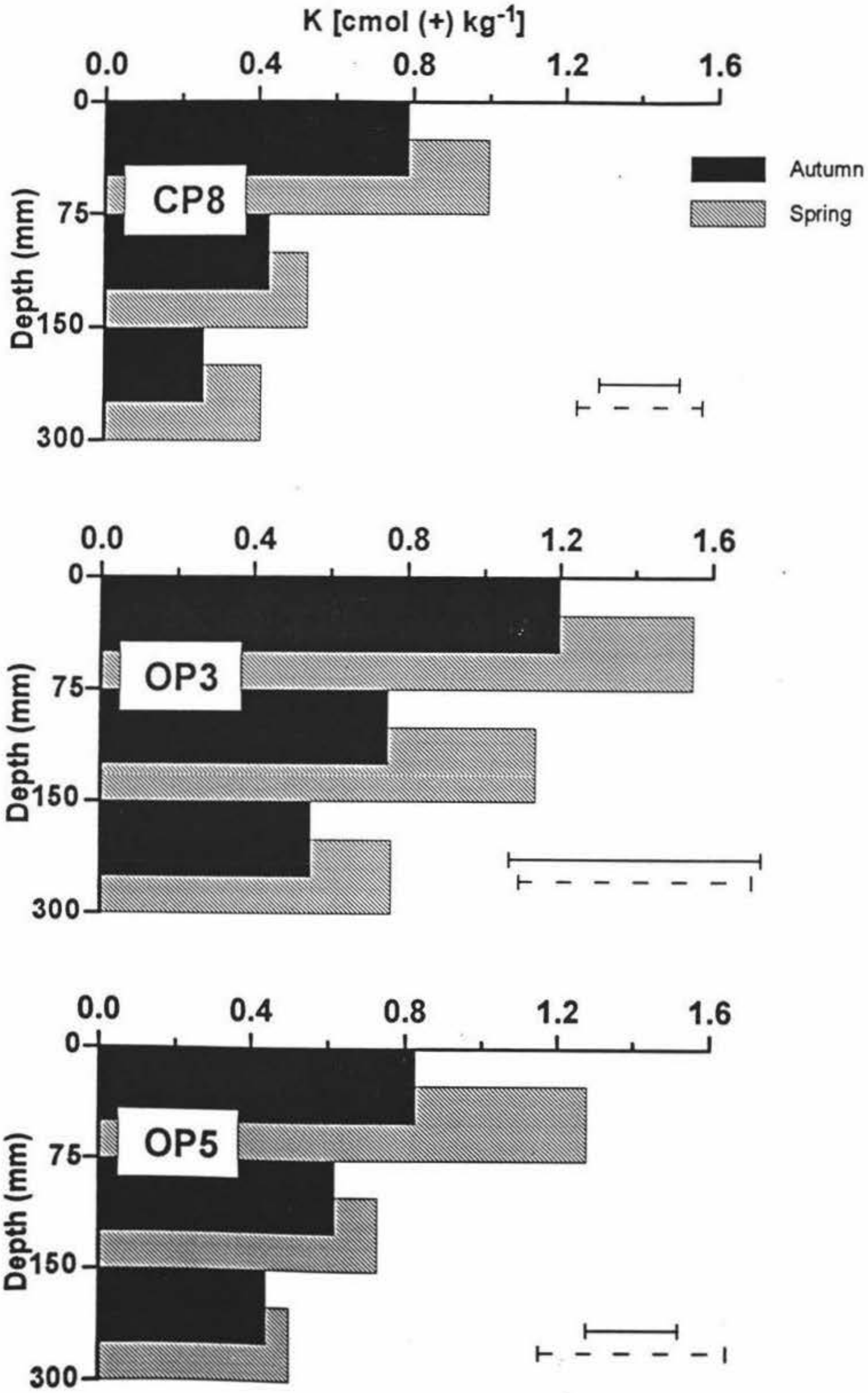


Figure 4.6 Seasonal distribution of exchangeable K in conventional (CP8) and organic plots (OP3 & OP5). LSD(5%) bars are for mean variation between soil depths in Autumn (——) and Spring (------). No significant difference between seasons.

activity (Basker et al, 1992; 1993; 1994). Earthworm ingestion of soil helped increase exchangeable K content of soil with high non-exchangeable K by increasing in the levels of exchangeable K in the casts.

Cation exchange capacity (CEC)

The CEC of the soil determines the retention and availability of the various cationic nutrients (Ca^{2+}, Mg^{2+}, K^{+}, Na^{+} and NH^{+}_{4}) in the soil and is therefore critical in regulating the supply of macronutrients. Organic practices that tend to increase soil organic matter are believed to enhance CEC values of the soil. The Autumn soils had CEC values at all soil depths (0-300 mm) in the range 13.3-21.2 cmol(+)kg^{-1} and 8.6-21.7 cmol(+)kg^{-1} for OP3 and OP5 respectively and 9.1-17.8 cmol(+)kg^{-1} for CP8. The corresponding Spring values were in the range 9.9-22.4 cmol(+)kg^{-1} and 8.6-18 cmol(+)kg^{-1} for OP3 and OP5 and the CP8 value was in the range 7.7-21.0 cmol(+)kg^{-1}. The seasonal distribution and variation between soil depths of the CEC are shown in Figure 4.7 and the mean Autumn and Spring CEC values are presented in Tables 4.1 and 4.2 respectively.

The organic plot, OP5, had significantly higher topsoil (0-75 mm) CEC than OP3 and CP8 in Autumn collected soils (Table 4.1). This trend was reversed in Spring when OP3 and CP8 CEC were higher. The OP3 CEC in Spring two-fold greater than OP5 (Figure 4.7). It is not surprising to find that OP3 had the highest CEC since it had the highest level of % total C. It has been estimated that organic matter content of mineral soils contributes to 30-65% of the total CEC of the soil (Allison, 1973) and

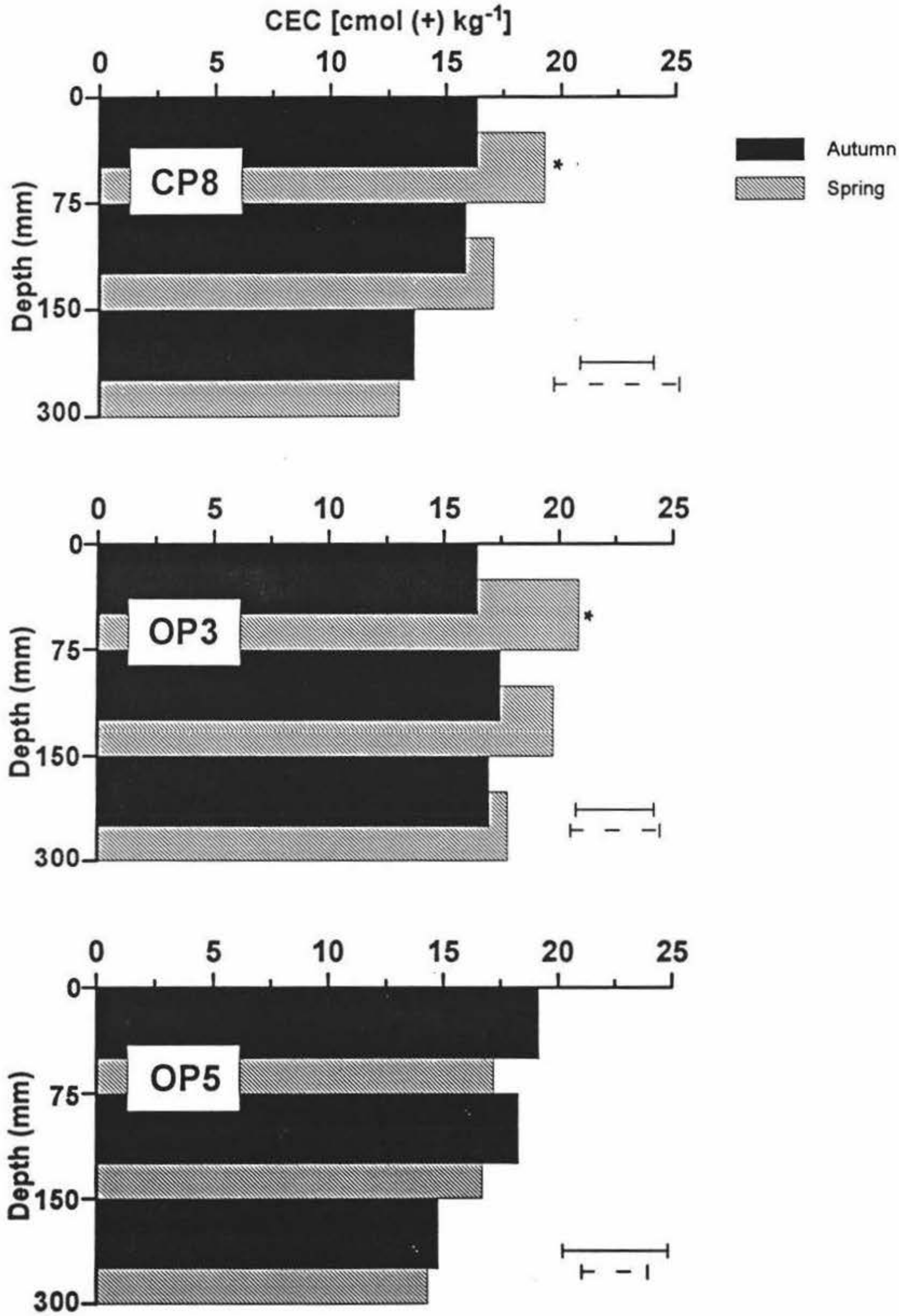


Figure 4.7 Seasonal distribution of CEC in conventional (CP8) and organic plots (OP3 & OP5). LSD(5%) bars are for mean variation between soil depths in Autumn (——) and Spring (------). Bars marked with asterisk (*) are significant at 5% level between seasons.

may rise up to 90% (Dijk, 1971). Organic crop rotation under arable cultivation initially raised CEC in Autumn but decreased with plant uptake during Spring. However, the significant increase in CEC for OP3 and CP8 during Spring may be attributed to decomposition of organic crop residue into the soil.

The levels of exchangeable cationic nutrients, Ca^{2+} and Mg^{2+},were significantly higher in the organic plots (Table 4.1 and 4.2) in Autumn soils but there was no significant difference in Spring values. The cationic macro-nutrients were directly related to the CEC contents of the soils and as such follow similar trends. This is in contrast to a study by Reganold et al. (1993) whose study showed similar levels of Ca and Mg in conventional and biodynamic farm soils.

Surface casts of earthworm

The number of surface casts of earthworms was highly variable. The number of surface casts of earthworms in Autumn ranged from 63 to 188 casts m^{-2} in CP8 while in organic plots OP3 and OP5, they were in the range 575-656 casts m^{-2} and 163-194 casts m^{-2} respectively. This suggested that surface casting were much higher during Spring when grass growth was maximum. The mean number of surface casts of earthworms in Spring were 1088 and 388 casts m^{-2} in OP3 and OP5 respectively (Table 4.3). The corresponding value for CP8 was 300 casts m^{-2} .The quantity of Spring surface casts produced in the organic plots were estimated to be approximately 22 and 8 t ha^{-1} in OP3 and OP5

Table 4.3 Abundance and chemical properties of the earthworm surface cast:- Spring sampling

Parameter measured	OP3	OP5	CP8
No. of cast m^{-2}	1088 a	388 b	300 b
K, cmol(+)kg^{-1}	1.96 a	1.49 b	1.31 c
Ca, cmol(+)kg^{-1}	12.3 a	10.8 b	10.7 b
Mg, cmol(+)kg^{-1}	2.15 a	1.67 c	1.98 b
CEC, cmol(+)kg^{-1}	23.6 a	20.4 b	21.1 b
BS, %	71 a	70 a	68 a

OP3 = Organic plot (pasture) OP5 = Organic plot (cultivated) CP8 = Conventional plot (pasture)

Means with the common letter for each depth are not significantly different (p=0.05)

See appendix 2 for history of crop rotation in each plot

respectively, while in CP8 it was 6 t ha^{-1} taking the average weight of the field moist cast as 2g.

The abundance of Spring surface casts and selected mean chemical properties are given in Table 4.3. The data show that organic plot, OP3, that has been under pasture for a number of years has a significantly higher number of surface casts than either CP8 or OP5. The results of the analysis indicated that earthworm activity was probably higher in pasture under organic management system than that both organic crop rotation under continuous cultivation (OP5) and conventional system (CP8) did favour casting. This result contrasted with preliminary study at Flock House by Springett (1993, pers. comm.) in which no difference was found in earthworm activity between organic and conventional plots.

Chemical analysis of the casts (Table 4.3) showed that Ca, Mg, K and CEC were all significantly high in organic plot under pasture (OP3). The mean values of Ca, Mg and K in the cast were in the 10.7-12.3 cmol(+)kg^{-1}, 1.7-2.2 cmol(+)kg^{-1} and 1.3-2.0 cmol(+)kg^{-1}. There was no difference in the percent base saturation (BS%) between cast materials of the organic and conventional plots. A comparison of the nutrient content of the cast material with that of topsoil (0-75 mm) showed that earthworm ingested soils contained greater amounts than non-ingested soils. The data indicate that earthworm activity enhances nutrient availability in the topsoil by ingestion of soil and organic matter and transporting the nutrient rich soils to the surface as casts. Thus organic management tends to increase earthworm activity (hence surface casting) while inorganic fertilizers reduced it. Such a trend has been observed by Scullion and

Ramshaw (1987). Since the number of earthworm casts is an indirect indication of earthworm numbers, this study showed that organic system with minimum tillage probably supported larger population of earthworm species. Reganold et al. (1993) have reported that biodynamically farmed soil had higher number of earthworm than conventionally farmed soil.

Soil nutrient status

From the foregoing results and discussion, it can be seen that differences in the total organic C, total N , mineralizable N and CEC were among the most obvious features of the nutrient status of the soils under organic management system. The conversion of conventional to organic production system over seven years period has resulted in improved levels of major nutrient forms of N, Ca, Mg and K. Extractable soil Olsen-P can also be maintained at sufficient level with timely applications of reactive phosphate rock. Organic crop rotation with clover based pasture showed higher levels of soil fertility while rotation under repeated cultivation indicated gradual depletion of major nutrients. Nutrient fluxes in the respective plots were greater in Spring than in Autumn. Similar trends of nutrient fluxes were observed by Lockeretz et al. (1984) and Reganold et al. (1993), in organically managed farms.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

1. Organic management and crop rotation resulted in quantitative increase in soil nutrient fertility. This was reflected in the significant increase in total C, total N and CEC levels of the soils under organic crop rotation.

2. Organic crop rotation containing a clover based pasture (OP3) was more effective in soil fertility maintenance than arable crop rotation under continuous cultivation (OP5). Mineralization of N in organic plots was comparable to that of conventional plots. However, there was significant seasonal fluctuation in mineralizable N in organic plots as a result of microbial activity, but it maintained constant in CP8. Mineralizable N in OP5 was significant lower than OP3 due to the effect of cultivation. Whereas extractable soil P (Olsen) was significantly higher in conventional system due to application of fertilizer (superphosphate).

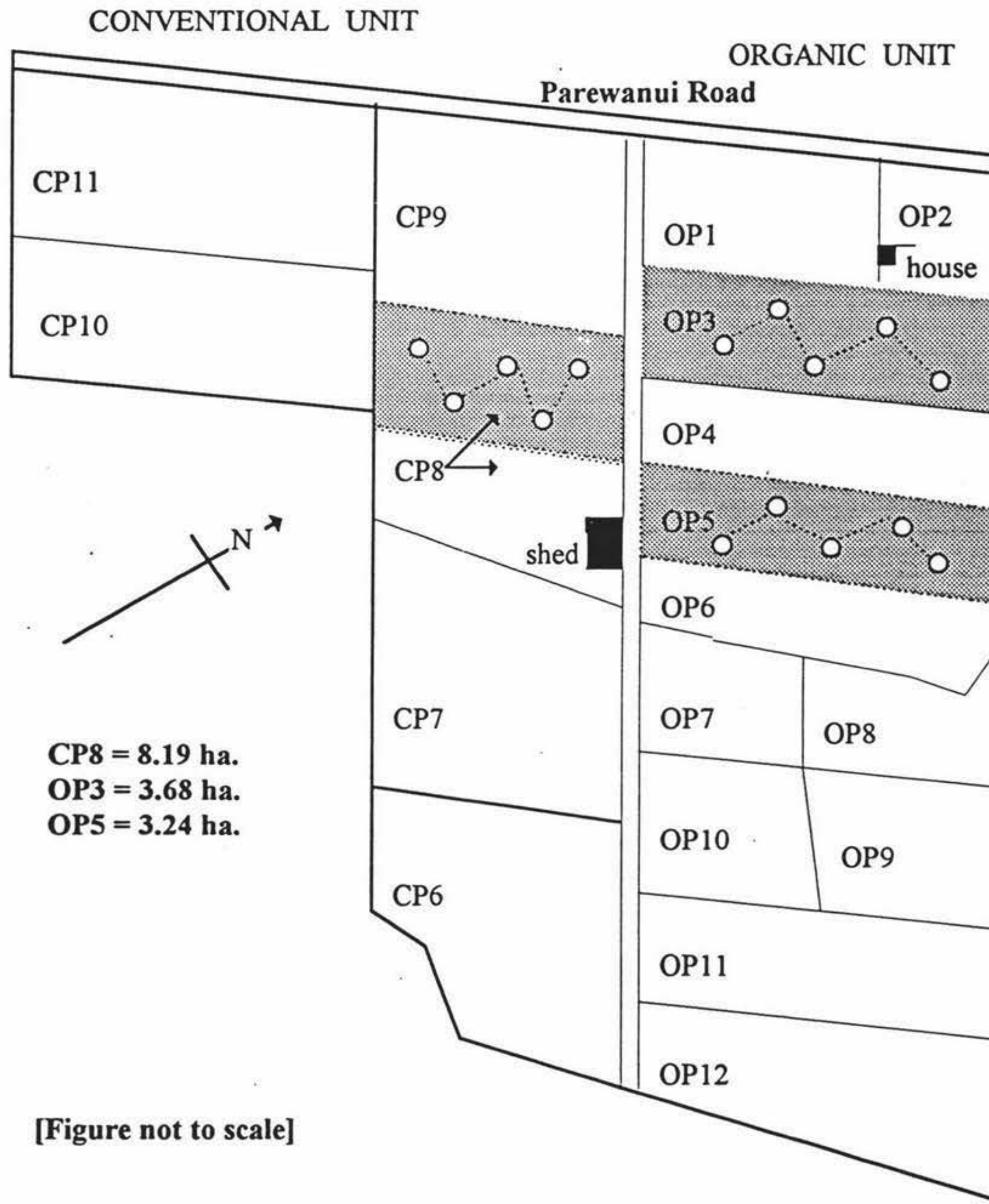
3. Exchangeable K levels were similar in both organic and conventional plots whereas Ca and Mg were significantly higher in organic plots in autumn. However, spring collected soil samples generally contained higher levels of nutrient fertility than the autumn samples.

4. The presence or absence of crop rotations in which sequences of arable crops are alternated with periods laid down to pasture had the most profound influences on the soil fertility levels.

5. Earthworm surface casts were more abundant in organic plot under pasture. Cultivation practices and application of inorganic fertilizers resulted in significantly less surface casting. Ca, Mg, K and CEC in surface cast were generally higher than in the underlying soil.

7. Fertility sustainability under organic system is dependent on soil type, crop rotation, cultivation practices, environmental factors and style of management. While organic farming is economically attractive and is environmentally attractive, there is no simple standard recipe for maintaining sustainable levels of nutrient fertility.

Appendix 1



Flock House cropping and organic units at Bulls, New Zealand. Shaded plots with approximate sample locations were used in this study. OP = Organic plots, CP = Conventional plots, ○ = sample locations, ...= sampling profile.

Appendix 2. Management history of the plots used located at Flock House AgResearch Centre (1988-1994)

Plot	1988	1989	1990	1991	1992	1993	1994
CP8	pasture	pasture	wheat	barley	pasture	pasture	pasture
OP3	pasture	Serradella	wheat	pasture	pasture	pasture	pasture
OP5	wheat	pasture	pasture	wheat /winter greenfeed	barley /winter greenfeed greenmanure	wheat /winter greenfeed	pea /pasture

CP = Conventional plot

300-350 kg Single superphosphate (SSP) per year plus N- P- K (6-6-5) 300 kg per year during cropping.

300 kg SSP per year and 44 kg Urea/ha/yr (100 kg/ha/yr in 1994) during pasture.

4-(4-chloro-2-methyl phenoxy) butyric acid(MCPB) for controlling thistle (1991-1992)

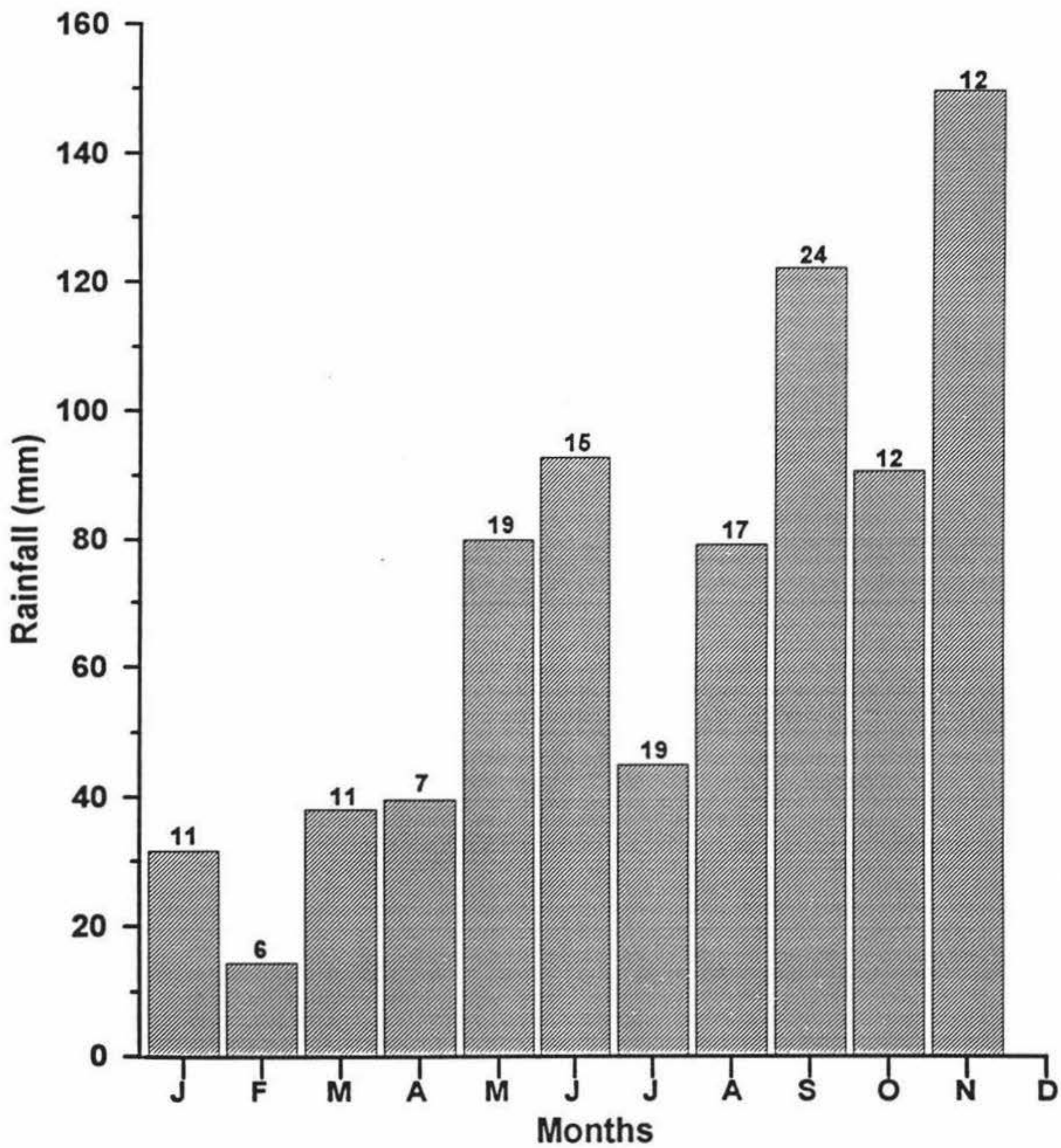
4-methylthio-3,5-xylyl N-methyl carbamate (Mesurol) to control snail and slug (1991-1992).

OP = Organic plot

300 kg RPR + 20 kg elemental sulphur every year in OP5 (only in 1990 on OP3).

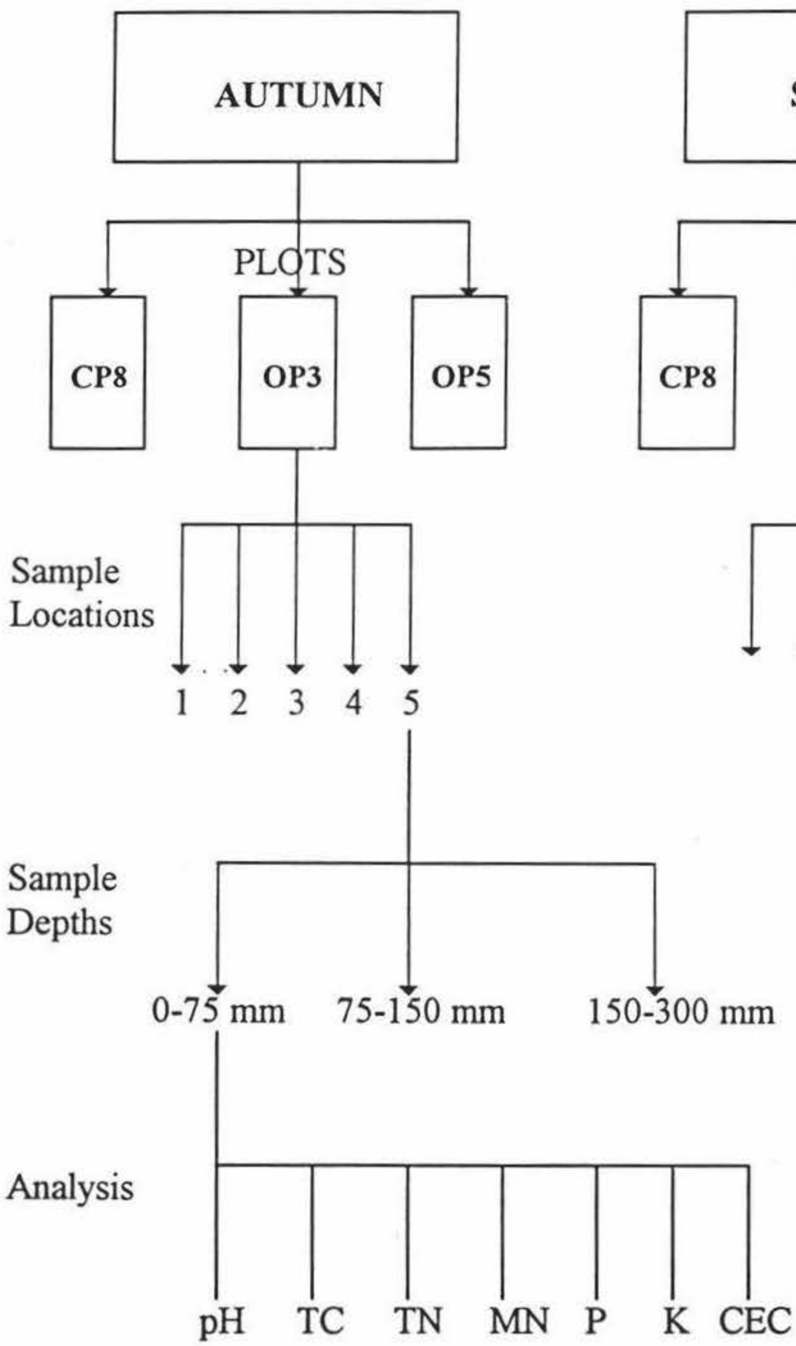
Pasture composition in organic plots - Nui ryegrass, white clover, red clover and chicory.

Appendix 3



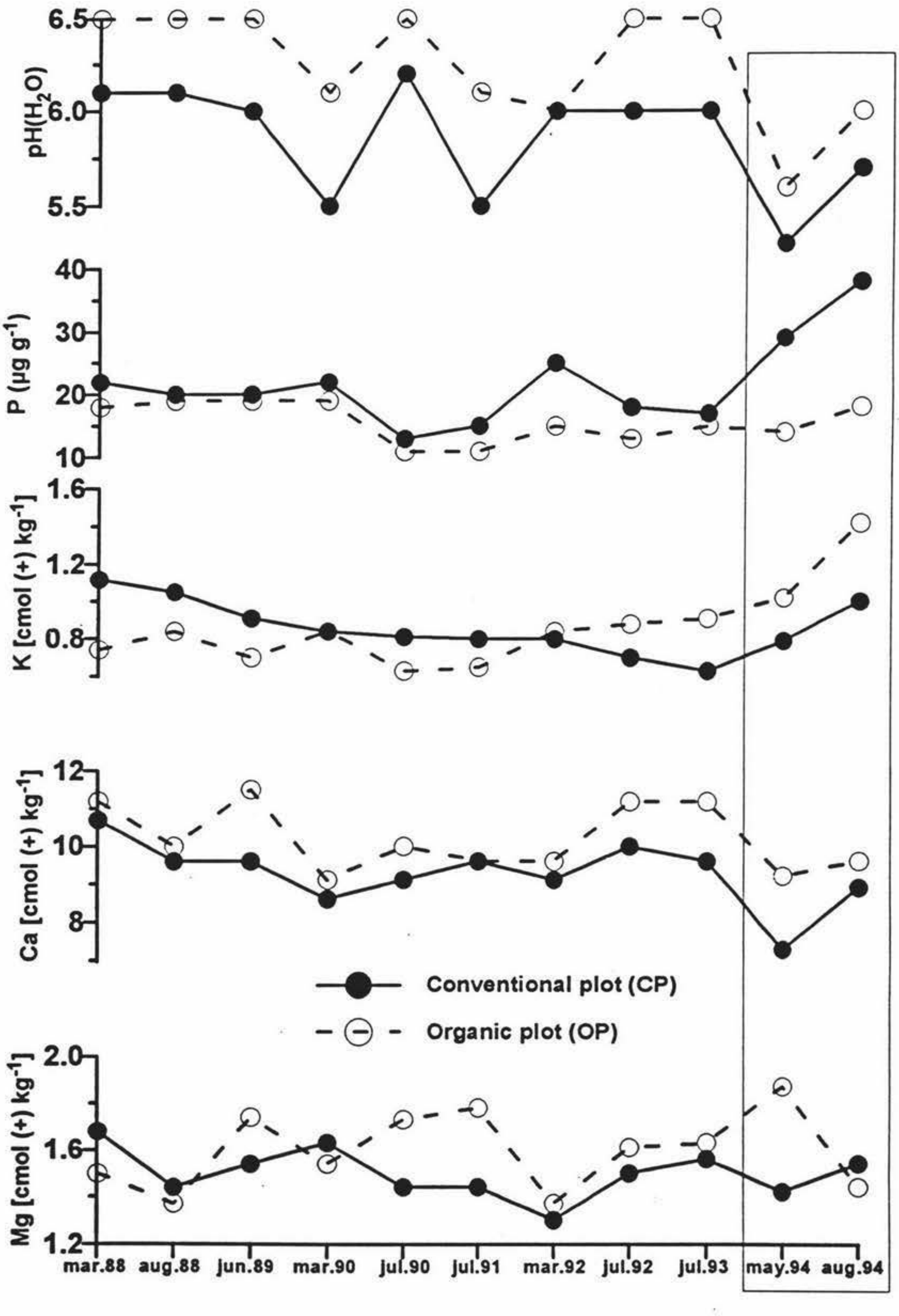
Monthly total rainfall at Flock House area for 1994. Numbers on top of bars refers to number of days of rainfall. Data from AgResearch Centre, Flock House, Bulls, NZ.

Appendix 4



Experimental design to determine soil nutrient fertility under organic cropping system. OP= Organic plot, CP= Conventional plot.

Appendix 5



Comparative trends in selected soil chemical properties of organic versus conventional plots (data from AgResearch, Flock House). Boxed area shows the trends for Autumn and Spring,1994 data analysed in this study.

Appendix 6

Table A1. Summary of ANOVA (SAS) of variation between plot and soil depth in soil chemical properties for Autumn collected soils.

pH

Depth (mm)	CP8	OP3	OP5	LSD (5%)
0-75	5.3 b	5.8 a	5.4 b *	0.2
75-150	5.5 b	5.8 a	5.6 b *#	0.2
150-300	6.1 a *	5.9 a	5.8 a #	0.4
LSD (5%)	0.3	0.2	0.3	

Total C

Depth (mm)	CP8	OP3	OP5	LSD (5%)
0-75	3.1 b *	3.6 a *	2.8 b	0.5
75-150	2.5 a *#	3.1 a #	2.9 a	0.5
150-300	1.9 a #	2.4 a $	2.2 a	0.9
LSD (5%)	0.7	0.5	0.7	

Total N

Depth (mm)	CP8	OP3	OP5	LSD (5%)
0-75	0.33 b	0.40 a	0.34 b *	0.06
75-150	0.28 b	0.36 a	0.30 b *#	0.05
150-300	0.18 b *	0.28 a *	0.23 ab #	0.09
LSD (5%)	0.08	0.05	0.07	

Mineralizable N

Depth (mm)	CP8	OP3	OP5	LSD (5%)
0-75	91 a *	104 a *	30 b *	29
75-150	54 a	65 a	48 a *#	17
150-300	32 b	53 a	50 a #	17
LSD (5%)	23	22	19	

Olsen P

Depth (mm)	CP8	OP3	OP5	LSD (5%)
0-75	29 a	13 b	15 b *	6
75-150	22 a	13 b	10 b *#	7
150-300	9 a *	10 a	9 a #	8
LSD (5%)	10	5	5	

K

Depth (mm)	CP8	OP3	OP5	LSD (5%)
0-75	0.79 a *	1.20 a	0.83 a *	0.62
75-150	0.43 b	0.75 a	0.62 ab *#	0.35
150-300	0.26 b	0.55 a	0.44 ab #	0.23
LSD (5%)	0.21	0.66	0.24	

CEC

Depth (mm)	CP8	OP3	OP5	LSD (5%)
0-75	16.4 b	16.5 b	19.2 a	2:6
75-150	15.9 a	17.5 a	18.3 a	3.5
150-300	13.7 a	17.0 a	14.8 a	5.0
LSD (5%)	3.2	3.4	4.6	

Ca

Depth (mm)	CP8	OP3	OP5	LSD (5%)
0-75	7.3 b	8.9 a *	9.4 a	1.4
75-150	7.5 b	8.5 ab *#	9.6 a	1.7
150-300	7.2 a	7.8 a #	8.2 a	2.8
LSD (5%)	2.4	0.9	2.5	

Mg

Depth (mm)	CP8	OP3	OP5	LSD (5%)
0-75	1.42 b	1.79 ab	1.94 a *	0.62
75-150	1.39 a	1.58 a	1.69 a *#	0.35
150-300	1.44 a	1.63 a	1.59 a #	0.49
LSD (5%)	0.43	0.26	0.51	

Within a row, means with a common letter are not significantly different at 5 % level
Within a column, means with a common symbol are not significantly different at 5 % level
Units for Mineralizable N, Olsen-P = μg/g; Total C, Total N = %; CEC, K, Ca, Mg = [cmol(+)/kg]

Appendix 6 (continued......)

Table A1. Summary of ANOVA (SAS) of variation between plot and soil depth in soil chemical properties for Autumn collected soils.

	BS				Min-N/C			
Depth (mm)	CP8	OP3	OP5	LSD (5%)	CP8	OP3	OP5	LSD (5%)
0-75	59 b	73 a *	64 b	8	3.0 a *	2.9 a	1.1 b *	1.0
75-150	59 a	64 a *#	66 a	9	2.1 a	2.2 ab	1.7 a *#	0.6
150-300	65 a	60 a #	70 a	13	1.7 b	2.2 a	2.3 a #	0.6
LSD (5%)	9	12	9		0.7	0.9	0.7	

Within a row, means with a common letter are not significantly different at 5 % level
Within a column, means with a common symbol are not significantly different at 5 % level
Units for BS = %; Min-N/C = mg/g

Appendix 6 (continued......)

Table A2. Summary of ANOVA (SAS) of variation between plot and soil depth in soil chemical properties for Spring collected soils

pH

Depth (mm)	CP8	OP3	OP5	LSD (5%)
0-75	5.7 b	6.0 a	6.0 a	0.3
75-150	5.8 a	5.9 a	5.8 a	0.3
150- 300	6.1 a *	6.0 a	5.9 a	0.4
LSD (5%)	0.3	0.4	0.3	

Mineralizable N

Depth (mm)	CP8	OP3	OP5	LSD (5%)
0-75	86 b *	139 a *	99 b *	26
75-150	66 a *#	86 a #	80 a *#	23
150- 300	43 a #	66 a $	68 a #	28
LSD (5%)	30	19	27	

Olsen P

Depth (mm)	CP8	OP3	OP5	LSD (5%)
0-75	38 a *	18 b	18 b	12
75-150	23 a	15 a	13 a	10
150- 300	10 a	12 a	7 a *	9
LSD (5%)	14	10	5	

K

Depth (mm)	CP8	OP3	OP5	LSD (5%)
0-75	1.00 a *	1.55 a *	1.28 a *	0.60
75-150	0.53 b	1.14 a *#	0.73 ab	0.43
150- 300	0.41 a	0.76 a #	0.50 a	0.43
LSD (5%)	0.33	0.61	0.49	

CEC

Depth (mm)	CP8	OP3	OP5	LSD (5%)
0-75	19.3 a *	20.9 a	17.2 b *	1.7
75-150	17.1 b *#	19.8 a	16.7 b *#	2.5
150- 300	13.0 a #	17.8 a	14.3 a #	6.4
LSD (5%)	5.5	3.9	2.9	

BS

Depth (mm)	CP8	OP3	OP5	LSD (5%)
0-75	60 a	64 a	69 a	10
75-150	65 a	58 b	70 a	6
150- 300	77 a	61 b	72 a	10
LSD (5%)	68 ab	61 b	70 a	7

Ca

Depth (mm)	CP8	OP3	OP5	LSD (5%)
0-75	8.9 a	10.1 a	9.0 a	2.0
75-150	8.9 a	9.1 a	9.4 a	2.1
150- 300	8.0 a	8.4 a	8.3 a	4.0
LSD (5%)	3.5	2.5	2.4	

Mg

Depth (mm)	CP8	OP3	OP5	LSD (5%)
0-75	1.54 a	1.49 a *	1.38 a	0.37
75-150	1.36 a	1.02 b	1.39 a	0.29
150- 300	1.39 a	1.08 a	1.28 a	0.52
LSD (5%)	0.58	0.25	0.29	

Min-N/C

Depth (mm)	CP8	OP3	OP5	LSD (5%)
0-75	2.8 b	4.0 a *	3.5 ab	1.1
75-150	2.6 a	2.9 a	2.8 a	0.7
150- 300	2.2 a	2.7 a	3.6 a	2.2
LSD (5%)	1.0	0.8	2.2	

Within a row, means with a common letter are not significantly different at 5 % level
Within a column, means with a common symbol are not significantly different at 5 % level
Units for Mineralizable N, Olsen-P = μg/g; BS = %; CEC, K, Ca, Mg = [cmol(+)/kg]; Min-N/C = mg/g

Appendix 6 (continued......)

Table A3. ANOVA (SAS) of seasonal variation with soil depth in soil chemical properties.

OP3	**0-75 mm**	Season	pH	Mineralizable-N	Olsen P	K	CEC	BS	Ca	Mg
		Autumn	5.8 a	104 b	13 a	1.20 a	16.5 b	73 a	8.9 a	1.79 a
		Spring	6.0 a	139 a	18 a	1.55 a	20.9 a	64 a	10.1 a	1.49 b
		LSD (5%)	0.3	32.00	7	0.88	2.3	10	1.8	0.31
	75- 150 mm	Season	pH	Mineralizable-N	Olsen P	K	CEC	BS	Ca	Mg
		Autumn	5.8 a	65 b	13 a	0.75 a	17.5 a	64 a	8.5 a	1.58a
		Spring	5.9 a	86 a	15 a	1.14 a	19.8 a	58a	9.2 a	1.02 b
		LSD (5%)	0.3	15.00	8	0.62	3.1	10	2.0	0.30
	150-300 mm	Season	pH	Mineralizable-N	Olsen P	K	CEC	BS	Ca	Mg
		Autumn	5.9 a	53 a	10 a	0.55 a	17.0 a	60 a	7.8 a	1.63 a
		Spring	6.0 a	66 a	12 a	0.76 a	17.6 a	61 a	8.4 a	1.08 b
		LSD (5%)	0.30	14.00	10	0.46	5.4	16	2.1	0.19
	Overall	Season	pH	Mineralizable-N	Olsen P	K	CEC	BS	Ca	Mg
		Autumn	5.8 a	74 b	12 a	0.83 a	17.0 a	66 a	8.4 a	1.67 a
		Spring	6.0 a	97 a	15 a	1.15 a	19.4 a	61 a	9.2 a	1.20 b
		LSD (5%)	0.2	11	8	0.62	3.0	9	1.7	0.17

Means with the same letter are not significantly different (P=0.05)
Units for Mineralizable N, Olsen-P = µg/g; BS = %; CEC, K, Ca, Mg = [cmol(+)/kg]

Appendix 6 (continued......)

Table A3. ANOVA (SAS) of seasonal variation with soil depth in soil chemical properties.

		Season	pH	Mineralizable-N	Olsen P	K	CEC	BS	Ca	Mg
OP5	**0-75 mm**	Autumn	5.4 b	30 b	15 a	0.83 a	19.2 a	64 a	9.3 a	1.94 a
		Spring	6.0 a	99 a	18 a	1.28 a	17.2 a	69 a	9.0 a	1.38 b
		LSD (5%)	0.2	20	5	0.62	2.6	7	1.8	0.54
	75-150 mm	Season	pH	Mineralizable-N	Olsen P	K	CEC	BS	Ca	Mg
		Autumn	5.6 b	48 b	10 a	0.62 a	18.3 a	66 a	9.7 a	1.69a
		Spring	5.8 a	80 a	13 a	0.73 a	16.7 a	70 a	9.4 a	1.39 a
		LSD (5%)	0.3	25	3	0.23	3.3	7	2.0	0.32
	150-300 mm	Season	pH	Mineralizable-N	Olsen P	K	CEC	BS	Ca	Mg
		Autumn	5.8 a	50 a	7 a	0.44 a	14.8 a	70 a	8.2 a	1.59 a
		Spring	5.9 a	68 a	9 a	0.50 a	14.3 a	72 a	8.3 a	1.28 a
		LSD (5%)	0.4	28	7	0.24	5.6	9	3.6	0.60
	Overall	Season	pH	Mineralizable-N	Olsen P	K	CEC	BS	Ca	Mg
		Autumn	5.6 b	43 b	11 a	0.63 a	17.4 a	67 a	9.1 a	1.74 a
		Spring	5.9 a	82 a	13 a	0.84 a	16.0 a	70 a	8.9 a	1.35 a
		LSD (5%)	0.30	20.00	4	0.33	2.9	5	2.2	0.43

Means with the same letter are not significantly different (P=0.05)
Units for Mineralizable N, Olsen-P = µg/g; BS = %; CEC, K, Ca, Mg = [cmol(+)/kg]

Appendix 6 (continued......)

Table A3. ANOVA (SAS) of seasonal variation with soil depth in soil chemical properties.

CP8	**0-75 mm**	Season	pH	Mineralizable-N	Olsen P	K	CEC	BS	Ca	Mg
		Autumn	5.3 b	91 a	29 a	0.79 a	16.4 b	59 a	7.3 a	1.42 a
		Spring	5.7 a	86 a	38 a	1.00 a	19.3 a	60 a	8.9 a	1.54 a
		LSD (5%)	0.3	34	14	0.33	2.0	11	1.8	0.51
	75-150 mm	Season	pH	Mineralizable-N	Olsen P	K	CEC	BS	Ca	Mg
		Autumn	5.5 a	54 a	22 a	0.43 a	17.1 a	59 a	7.5 a	1.39 a
		Spring	5.8 a	66 a	23 a	0.53 a	15.9 a	65 a	8.9 a	1.36 a
		LSD (5%)	0.2	22.00	13	0.16	3.2	6	2.2	0.39
	150-300 mm	Season	pH	Mineralizable-N	Olsen P	K	CEC	BS	Ca	Mg
		Autumn	6.1 a	32 a	9 a	0.26 a	13.7 a	65 b	7.2 a	1.44 a
		Spring	6.1 a	43 a	10 a	0.41 a	13.0 a	77 a	8.0 a	1.39 a
		LSD (5%)	0.4	28	10	0.36	7.0	11	4.8	0.68
	Overall	Season	pH	Mineralizable-N	Olsen P	K	CEC	BS	Ca	Mg
		Autumn	5.6 a	59 a	20 a	0.49 a	15.3 a	61 a	7.3 a	1.42 a
		Spring	5.9 a	65 a	24 a	0.65 a	16.5 a	68 a	8.6 a	1.43 a
		LSD (5%)	0.24	17.00	12	0.21	3.7	8	2.6	0.45

Means with the same letter are not significantly different (P=0.05)
Units for Mineralizable N, Olsen-P = µg/g; BS = %; CEC, K, Ca, Mg = [cmol(+)/kg]

Appendix 6 (continued......)

Table A4. ANOVA (SAS) of variation of earthworm surface cast and soil chemical properties (Sping sampling)

Plot	No. of cast	CEC	BS	K	Ca	Mg
CP8	300 b	21.1 b	68 a	1.31 c	10.7 b	1.98 b
OP3	1088 a	23.6 a	71 a	1.96 a	12.3 a	2.15 a
OP5	388 b	20.4 b	70 a	1.49 b	10.8 b	1.67 c
LSD(0.05)	43	1.1	4	0.11	0.4	0.11

Means with the same letter are not significantly different (P=0.05)
Units for CEC, K, Ca, Mg = [cmol(+)/kg]; BS = %; No. of cast counts are per square metre

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