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THE EFFECTS OF TILLAGE PRACTICES ON SOIL MICROBIAL BIOMASS AND CO_2 EMISSION

A THESIS

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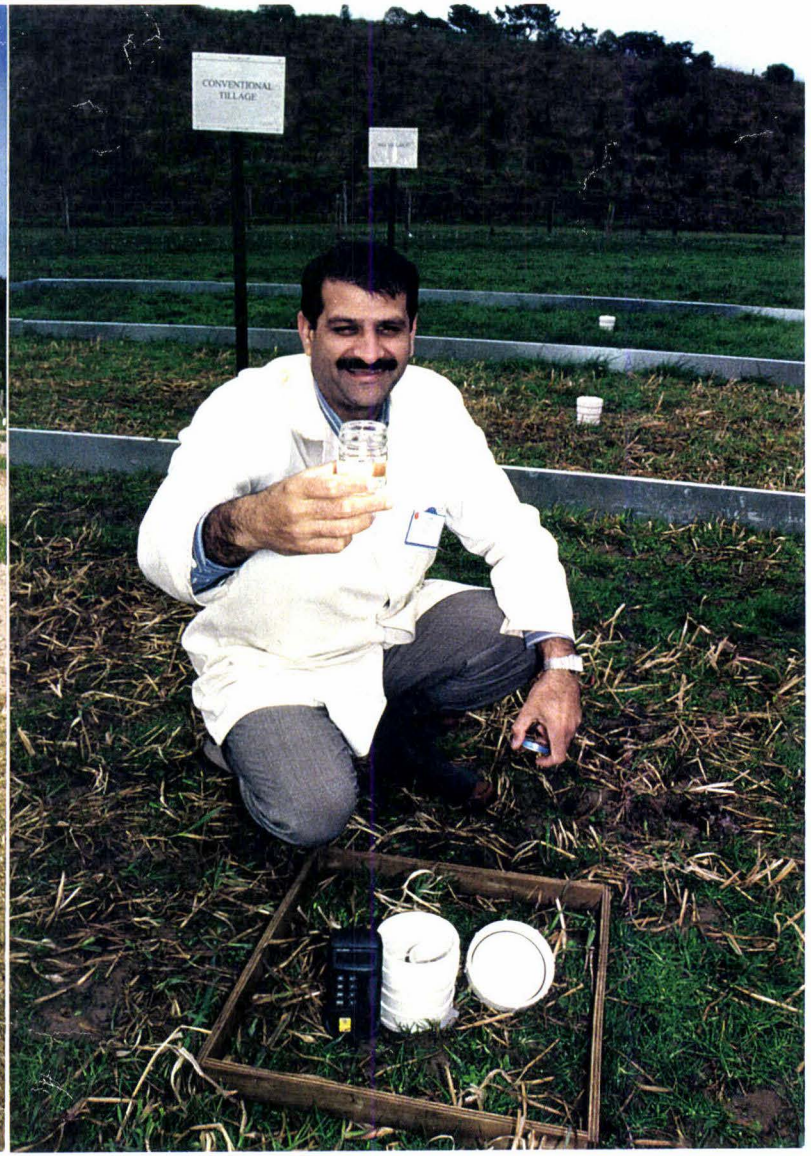
CONVENTIONAL
TILLAGE

ABSTRACT

Conversion of permanent pasture land to forage crop rotation by conventional tillage and reversion to pasture, for recovery of nutrients is a common practice in New Zealand. Because of their effects on soil physical, chemical and biological degradation, and the extent to which these soil management practices are sustainable is not fully known.

To evaluate short- and long-term impact of tillage induced changes in soil physical, chemical and biological properties, a quad replicated field experiment was established at Massey University, Turitea campus in 1995. Permanent pasture land was converted to a double crop rotation using conventional (CT) and no-tillage (NT) practices on the Ohakea silt loam soil. The overall aim of this research programme is to develop a sustainable land use management for pasture-based arable cropping to suit local farming conditions.

The present study investigated the effects of CT and NT practices on soil biological status and CO_2 emission. The test crops were summer fodder maize (*Zea mays L.*) and winter oats (*Avena sativa*). An adjacent permanent pasture (PP) was used as a control.

Soil samples were collected at 0-100 mm in summer, 0-50 and 50-100 mm depths in autumn and winter before or after crop harvest. The 'fresh' field moist, sieved samples were used for the measurement of microbial biomass carbon (MBC), nitrogen (MBN), phosphorus (MBP) and basal soil respiration. Earthworm population and biomass were extrusion with formaldehyde. Field CO_2 emission was measured at 3-4 weeks interval for one year.

After two years of continuous cropping, overall nutrients status (organic C, total N and total P) in NT remained similar to that in PP. In CT the nutrient

levels were significantly lower. Earthworm population and live mass were also significantly lower in CT as compared to PP and NT treatments. However, there was no differences in plant establishment, crop dry matter yield, soil temperature and soil pH (0-100 mm depth) between the two tillage (NT and CT) systems.

Higher levels of MBC, MBN and MBP were found in NT as compared with CT at 0-100 mm depth throughout the three seasons studied. When samples were analysed separately from two depths i.e. 0-50 and 50-100 mm, the microbial biomass contents were higher in surface soil (0-50 mm depth) as compared with 50-100 mm depth. Microbial biomass contents at 50-100 mm layer did not differ significantly among the three treatments. At 0-100 mm depth, MBC declined by 29%, MBN by 32% and MBP by 33% with two years (4 crops) of CT. Such a decline in microbial biomass is an early indication of future decline in soil organic matter. Soil organic matter (total C) had also declined by 22% (from 35,316 to 27,608 kg ha^{-1}) with CT. No such decline occurred either in MBC, MBN and MBP or organic matter with NT.

Basal soil respiration data indicated that microbial biomass activity in CT was 38% lower than in NT at 0-50 mm depth. However, at 50-100 mm depth, the activity was 25% higher in CT as compared with NT. Metabolic quotient (qCO_2) did not differ among the three treatments at 0-50 and 50-100 mm soil depths.

Field CO_2 emission from PP was significantly higher as compared to NT and CT treatments. The two tillage practices did not influence the CO_2 emission measured both shortly after tillage and during crop growth period. The annual estimated carbon loss through CO_2 emission was 34 t C $ha^{-1}year^{-1}$ in PP, 24 t C $ha^{-1}year^{-1}$ in NT and 21 t C $ha^{-1}year^{-1}$ in CT treatment. Field CO_2 emission was generally higher in summer and autumn as compared to winter and spring.

Overall, this study, which spanned two cropping seasons, clearly showed that 2 years cropping with CT resulted in a decline in soil biological status and organic matter. The decline in soil biological status is likely to affect crop yields in CT over the longer period. Conversely, NT cropping was efficient in sustaining soil biological status and organic matter. NT had similar influence on soil biological status as clover based PP during a short-period. Therefore, it is concluded that NT may be used as an effective tool to enhance soil productivity while promoting agricultural sustainability.

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CHAPTER 1

INTRODUCTION

1.1 General Introduction

Clean air and clean water are necessary for human health. However, our well being is also dependent upon the health of another component of our environment 'the Soil'. Soil supports the growth of our food and fibre, so its productivity is a major factor in the health, economics and environmental stability through its ability to filter, buffer and preserve nutrients. Therefore, we must conserve such a resource and use it in a sustainable manner. Soil sustainability is defined as the process " that maintains the soil productivity, while minimising energy and resource use and optimising rate of turnover and recycling of organic matter and nutrients" (Campbell, 1989). Minimising soil erosion and maintenance of soil organic matter are key components of soil management strategies for sustainable land use, crop production and agriculture as a whole.

Tillage operations usually cut, invert and mix the soil affecting soil structure and storage of organic matter. Soil organic matter (SOM) provides a major soil energy and nutrient reserve, and plays a major role in system stability and sustainability (Lal, 1991; Karlen et al., 1994; Grace et al., 1994; Carter, 1995). SOM is one of the most important soil quality characteristics in relation to tillage because of its influence on soil physical, chemical and biological properties. Recent concerns with global changes in the atmospheric CO_2 emissions balance have also emphasized the possibility of increasing the storage of atmospheric CO_2-C in the soil by changes in land use and soil management practices that increase the synthesis and retention of SOM (Carter and Hall, 1995).

Microbial biomass - an active agent of soil organic matter decomposition, nutrient cycling and reservoir of plant available nutrients - plays an important role in the functioning of the system (Jenkinson and Ladd, 1981; Paul, 1984; Yeates, 1997). It is a labile pool of SOM with a high nutrient content and rapid rate of turnover (Van Veen 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). Microbial biomass has an important role in nutrient transformation (Carter and Kunilius, 1986; Doran, 1980; 1987), thus influencing the fertility status, and is used as an indicator of the biological status of the soil fertility (Swift, 1994). These microbial biomass measurements are further used as sensitive indicators of management induced changes in soil biological properties, such as tillage practices, incorporation of crop residues, N fertilization, crop rotation sequence and changes in soil moisture regimes (Pankhurst, 1994).

New Zealand agriculture is generally based on animal production farming system. To meet the requirements for animal feed, more than 40% (10.6 million ha) area is under permanent pastures (Newsome, 1987) and only 9% is considered as potentially arable (Choudhary and Baker, 1994). The occasional dry summers in Manawatu and elsewhere in New Zealand have emphasized the shortcoming of pasture production as it involves hard grazing with bare ground in summer and little herbage in winter. To overcome this problem, there has been an increase in the use of forage crops such as maize, sorghum, lucerne, oats and barley in rotation with pasture using cultivation. The research on alternative tillage and crop rotation suggests maize and oat crop rotation as most suitable to multiple cropping for Manawatu region (Hughes, 1985).

The application of tillage practices for crop production is although rapidly expanding throughout the world (Cannell and Hawes, 1994), it is now known that excessive cultivation is the major cause of soil degradation, organic matter loss and non point source pollution internationally, as well as in New

Zealand (Lal, 1991; Mahboubi et al., 1993; Francis and Knight, 1993; Karlen et al., 1994). In New Zealand, there is a growing acceptance of no-tillage for establishing cereal as well as forage crops (Hughes et al., 1992; Choudhary and Baker, 1994). No-tillage system allows farmers to improve their cropping flexibility, to save time and labour and to adopt profitability and sustainable cropping system. In addition, no-tillage enhances soil moisture conservation (Lal, 1991), earthworms population (Fraser et al., 1992), organic matter (Sparling et al., 1992; Horne et al., 1992), and soil structure (Haynes et al., 1991; Bruce et al., 1990). Lal (1995) emphasized that the impact of land use and soil management practices on agricultural sustainability and environmental quality can only be assessed by obtaining data from well-planned and properly conducted long-term soil management experiments.

To evaluate short and long-term impacts of tillage induced changes in soil physical, chemical, and biological properties, tillage experiments were initiated at Massey University Research farm in 1995. The overall aim of these experiments is to develop a sustainable land use management guidelines for pasture-based arable cropping for local farming system. These experiments are expected to provide insights into issues such as:

- Soil sustainability in conventional tillage vs no-tillage.
- Whether a good crop rotation is a substitute for permanent pasture.
- Impact of conventional and no-tillage systems on soil physical, chemical and biological degradation.
- Impact of conventional and no-tillage systems on wider environment.

Research on a number of these aspects is underway. Another aspect of this research programme that assessed the soil microbial dynamics under different tillage management practices is described in this thesis.

1.2 Research Objectives

The overall objective of this study was to determine the biological status of the experimental soil under selected crop establishment and permanent pasture management.

The specific objectives of this study were as follows;

1. To measure and compare soil microbial biomass carbon, nitrogen and phosphorus in conventional tillage (CT) and no-tillage (NT) in summer fodder maize *(Zea mays L.)* and winter oats (*Avena sativa*) crop rotation, and under permanent pasture (PP) during various stages of crop growth.

2. To measure seasonal changes in field CO_2 emission (soil respiration) under these management regimes.

3. To study tillage induced changes in field CO_2 emission immediately after tillage, and compare this with CO_2 emission from untilled plots.

In addition, measurements of total soil C, N and P, metabolic quotient (qCO_2), soil pH, soil moisture content, soil temperature and earthworm population were obtained to assess their interactions with soil biological status. Seedling establishment and dry matter yields were also determined to compare the yield potential of conventional and no-tillage practices.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Crop production under different tillage systems and subsequent soil management are important factors for sustainable agriculture world-wide. Although mechanised tillage farming have had a great impact on increasing crop production and in improving labour efficiency, concern over its effects on soil degradation has led to an increasing interest in conservation tillage, because of the latter's potential to reduce the negative effects of conventional tillage .

Conventional tillage has shown a number of detrimental effects on soil physical, chemical & biological properties and thus adversely affecting the soil ecosystem (Carter, 1995). Soil structure degradation, soil erosion and soil organic matter losses, being the major issues, have brought renewed interest in alternative methods of conservation tillage such as "no-tillage". There is also a growing acceptance of no-tillage application among New Zealand farmers, although it is still mainly limited to establishing pasture and forage crops.

Previous soil tillage research in New Zealand which focused mainly on measuring changes in soil physical properties has shown that no-tillage is associated with higher bulk density, soil strength, aggregate stability, organic matter content, soil water content and earthworm population (Hughes and Baker, 1977; Choudhary and Baker, 1980; Ross and Hughes, 1985; Francis et al., 1987; Horne et al., 1992; Francis and Knight, 1993; Hermawan and Cameron, 1993). In recent years internationally, attention has been focussed on the impacts of tillage on soil biology and biochemical parameters in soils (Doran et al., 1987; Dick, 1992) because biologically

mediated processes are central to the functioning of soils and act as driving force in the decomposition of soil organic matter. More recent research has led to an interest to protect soil quality based on organic matter, microbial biomass and biological activity measures (Sparling et al., 1992; 1997; Beare et al., 1994; Saggar et al., 1997). However, little information is available on comparative effects of conventional and no-tillage cropping systems on biological status of the soils in the Manawatu region of North Island.

Microbial biomass and CO_2 emission (soil respiration) are used as indicators to assess the functioning of the system. Microbial biomass releases nutrients for plants by breaking down of organic matter and is directly influenced by tillage practices due to changes in organic matter content (Sparling et al., 1992; Jensen et al., 1996). The microbial biomass measurements have been suggested as indicators of soil quality (Doran and Parkin, 1994) and index of soil biological fertility (Swift, 1994). The soil CO_2, a by-product of microbial feeding and the biological oxidation of soil organic matter, is considered as an important part of the carbon cycling of an agricultural production system.

This literature review attempts to inter-relate and compare the impacts of conventional (CT) and no-tillage (NT) systems on soil physical, chemical, and biological properties with a major focus on soil microbial biomass, basal soil respiration, field CO_2 emission and earthworm population.

2.2 Tillage methods

Tillage is a method of physical soil manipulation to optimise conditions for seed germination, seed emergence, and seedling establishment (Lal, 1979; Lal, 1984). However, soil manipulation can bring marked changes in soil chemical and biological status and these changes are often reflected by good or poor crop performance (Ohiri and Ezumah, 1990). Different tillage methods are classified and described as shown in Table 2.1.

Appropriate tillage systems are those that avoid the degradation of soil properties but maintain crop yields as well as ecosystem stability (Greenland, 1981; Lal, 1984; Lal, 1985). Conservation tillage conserves soil water content, prevents soil erosion, maintains organic matter content and sustains economic productivity (Lal, 1976; Greenland, 1981), and has become most effective and popular, especially in areas where soil erosion is a problem, the climate is not humid and soils are well drained (Spoor, 1991).

Table 2.1 Types and description of main tillage systems.

Tillage system	Description
Conventional Tillage	Mouldboard plough plus at least one other secondary tillage operation prior to planting.
Conservation Tillage	Any tillage and planting system that maintains at least 30% of the soil surface covered by residue after planting.
No-Tillage	One of several forms of conservation tillage, usually characterised by high residue cover (60-80%) and limited field trips. The soil is left undisturbed prior to planting. Planting is usually completed in a narrow seedbed 2.5-7.5 cm wide. Weed control is accomplished primarily by herbicides.

Tillage system description is the summary of the national survey of conservation tillage practices (CTIC, 1986).

The application of different types of conservation tillage practices for crop production is rapidly expanding throughout the world. Conservation tillage is increasing in the USA and is used on more than 50% of cropland, including no-till on about 10% of cropland (Cannell and Hawes, 1994). No-tillage cropping is becoming popular world-wide as a means of crop establishment comparable to any other tillage systems. Farmers are becoming aware that

the adoption of conservation tillage is highly effective in controlling soil erosion and increasing net profits by reducing fuel and labour cost. Table 2.2 shows energy requirements for four different tillage systems, and clearly suggesting a major reduction in fuel energy (fossil fuel) use with the adoption of no-tillage.

Table 2.2 Energy required for selected tillage systems.

Tillage system	Tillage depth (cm)	Speed ($m\ sec^{-1}$)	Fuel usage ($l\ ha^{-1}$)
Mouldboard plough	21.5	2.24	17.8
Chisel plough	23.0	2.68	11.2
Disk	7.0	3.31	7.5
No-tillage	0.0	8.94	0.9

(Bauder et al., 1981).

2.3 Tillage interactions with soil properties

Tillage affects soil physical, chemical and biological properties. Research results have been widely reported on the effects of tillage on soil aggregation, temperature, water infiltration and retention as the main physical parameters affected. However, the magnitude of any changes depends on soil types as well as on soil composition. Changes in chemical properties are dependent mainly on the organic matter content of the soils. Tillage affects aeration and thus the rate of organic matter decomposition. Biological activities in the soil are vital to soil productivity through the activities of macro-organisms (earthworm and termites) and micro-organisms (microbial organisms such as fungi, algae, bacteria and protozoa) and many other living creatures in the soil. These organisms are responsible for wide range of functions which affect soil structure and act as an engine for nutrient cycling process in the soil.

The organic C and N contents of surface soil (0-7.5 cm) with NT were 20 and 25% times higher than for CT (Doran, 1980). These results also showed the rate of loss of C and N from the surface 0-7.5 cm of grassland soil was greatly accelerated by conventional tillage. Soil organic C concentration after 5 years of continuous NT practices was significantly increased as compared to the soils where CT practices were used (Rice and Smith, 1982). After approximately 20 years of continuous NT application to two soils in Ohio, USA, concentrations of organic C at the soil surface were 2.0 and 2.5 times greater than under CT (Dick, 1983). Similarly, studies from New Zealand indicate a marked loss of soil organic C (10-49%) in soils cultivated for 6-14 years (Sparling et al., 1992).

Plant available nutrient concentrations in soil are especially sensitive to changes in tillage. Eckert and Johnson (1985) found significant changes in available P levels occurring in the 0-5 cm soil layer after only three years of NT, even when no P fertiliser was applied. After approximately 20 years of NT, available P levels were 3.5 to 7.5 times higher in the surface 0-1.25 cm soil layer compared to concentrations in soil under CT (Dick et al., 1986).

Tillage interactions with crop rotation also affect soil properties because of the management practices associated with each crop, such as application and rates of fertilizer and pesticides, and amount and kind of plant residues produced. The organic matter and N mineralization of a silt loam soil in Washington State, USA were highest under a combined treatment of NT and a high residue yield rotation crop, and the lowest levels were under combination of ploughing and winter wheat-pea rotation (El-Harris et al., 1983). Similarly, Doran (1980) showed that soil enzyme activities were also affected by both tillage and crop rotation.

Tillage practices can significantly impact soil quality. No-tillage has the ability to maintain more crop residue and thus improve soil quality. However, an understanding of short and long-term effects on soil physical, chemical

and biological properties are needed to assess the changes in soil quality. Soil quality has been suggested by several authors (Lal, 1991; Karlen et, al., 1992; Karlen et al., 1994) as a tool for assessing long term sustainability of agricultural practices at local, regional, national and international levels. For evaluating soil quality, selection of such properties (or indicators) that are sensitive to management practices are required. Lal (1995) suggested important soil indicators and the frequency of their monitoring as shown in Table 2.3.

Table 2.3 Soil indicators and frequency of monitoring.

Soil Indicators	Suggested monitoring frequency
Soil physical indicators	
Soil moisture	Every week
Bulk density & penetration	Every season
Hydraulic conductivity	Yearly
Soil structure	1-2 years
Infiltration	1-2 years
Available water-holding capacity	3-5 years
Texture	3-5 years
Soil chemical indicators	
pH	Seasonal
Total nitrogen	1-2 years
Available nutrients	1-2 years
Cation-exchange capacity	-
Soil biological indicators	
Earthworm activity	Every season
Microbial Biomass carbon	1-2 years
Soil organic carbon	1-2 years

(Lal, 1995).

2.3.1 Effects on soil physical properties

The most visible effect of tillage on soil is the changes in structural degradation. CT causes degradation of soil aggregates more than NT, which leaves the soil intact. This results in a change in number, shape, continuity and size distribution of pores as well as a change in the strength and stability of the soil. These changes in pores distribution further causes changes in the ability of soil to store and transmit air, water and solutes. These changes may lead to soil degradation by soil erosion and run off and result in the loss of nutrients affecting soil fertility and decreasing long-term sustainability of agriculture. Important physical properties are discussed as below.

Bulk density is the most frequently measured soil quality physical indicator. The bulk density of most soils is between 0.8 and 1.8 Mg m^{-3}, except in coarse sandy soils, a value above 1.5 Mg m^{-3} indicates (anywhere in the soil) compaction problem (Scotter, 1996). In many experiments, the bulk density was greater and porosity was less in the topsoil with zero-tillage, or shallow tillage than ploughing (Kladivko et al. 1986, Carter and Kuneluis, 1990; Bruce et al., 1990; Mahboubi et al., 1993).

Water stable aggregates in the upper few mm of soil can improve germination and seedling establishment by reducing surface crust formation and erosion. The proportion of more stable aggregates in the upper 25-30 mm were greater in NT than ploughed soils after 2 years of continuous NT, even on weakly structured soils (Carter, 1992), but less than in grassland (Horne et al., 1992). The effects of tillage on aggregate stability can be enhanced by the type of crop grown, e.g. soybeans provided more residual material for aggregate stability compared to wheat (Kladivko et al., 1986). Similarly, Lal et al. (1989) and Beare et al. (1994) also reported that even on poorly drained soils, NT can have more stable aggregates as compared with CT practices.

Soil hydraulic conductivity is an indicator of size and continuity of the pores that determine the rate of water movement. Different methods of tillage can affect soil hydraulic properties. The importance of earthworm channels was clearly shown by Ehlers (1975) who found that in untilled soil, more earthworm channels could transmit free water to a depth of 180 mm, whereas in the tilled soil, the channels were ineffective in water transmission. Douglas et al. (1980) found that the saturated hydraulic conductivity at the interface between topsoil and subsoil in a clay was greater in direct drilled than ploughed soil.

One of the major tillage effects is soil physical degradation by erosion. Soil erosion is a process that is nearly impossible to stop, usually difficult to control and easily accelerated by man. The topic of soil degradation by surface runoff effected by tillage practices is of significant importance to farmers as well as researchers. Alegre et al. (1991) found a significant differences in surface runoff and soil loss between three tillage treatments even within a short period of 15 months (Table 2.4). Similarly, Choudhary et al. (1997) reported that reduced tillage intensity decreased soil degradation through reduced surface soil splash and soil and water erosion (Table 2.5).

Table 2.4 Short term tillage effect on surface runoff and soil loss.

Treatments	Runoff (mm)	Soil loss ($t\ ha^{-1}$)
No-Tillage	165	14.9
Minimum Tillage	120	19.4
Conventional Tillage	249	22.4
LSD $_{0.05}$	*43*	*5.5*

(Alegre et al., 1991).

This review indicates that considerable information is available on the impact of tillage practices on soil physical characteristics.

Table 2.5 Effect of tillage on soil and surface runoff and leachate.

Tillage system	Soil runoff ($g\ m^{-2}$)	Surface runoff ($g\ m^{-2}$)	Splash ($g\ m^{-2}$)	Leachate ($l\ m^{-2}$)
Mouldboard plough	44.0 [a]	4.45 [a]	50.0 [a]	0.00 [c]
Chisel plough	29.0 [b]	3.98 [b]	21.0 [b]	0.20 [b]
No-Tillage	10.0 [c]	2.40 [c]	20.0 [c]	0.56 [a]
LSD $_{0.05}$	*4.0*	*0.3*	*4.0*	*4.0*

(Choudhary et al., 1997).

2.3.2 Effects on soil chemical properties

Tillage methods have significant effects on soil chemical properties. The prominent properties influenced by tillage are soil organic matter, soil nutrients N, P & K for plant uptake, and exchangeable Ca & Mg, soil pH and cation exchange capacity, For example, as the amount of tillage is reduced, there is less mixing of applied amendments and crop residue into the soil. Thus, when the soil remains undisturbed for many years and fertilisers are surface applied, there is an accumulation of certain nutrients and organic matter at the soil surface effecting the chemical composition of a soil system.

Soil organic matter (SOM) is a heterogeneous mix of living, dead and decomposing organic compound derived from plant, animal and microbial tissue (Smith and Elliott, 1990). SOM can effect many physical, chemical and biological functions of the soil. 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; Haynes and Swift, 1990). Soil organic matter is a major reservoir of plant nutrients and plays an important role in soil fertility. It acts as a source of carbon and energy for the growth and maintenance of micro-organisms. The decomposition and degradation of SOM contributes to the supply of plant nutrients. Key trace elements such as iron, copper, zinc and boron, are held

very strongly by organic matter and are released in small amounts during degradation process (McLaren and Cameron, 1996).

Tillage practices cause both immediate and long-term soil organic matter changes. The immediate effect is the slower organic matter mineralisation rate and long-term effect results in an increase in quantity with more extractable nutrients. After 18 years of adoption of no-tillage on the poorly drained soil in Ohio, USA, organic carbon in the topsoil remained unchanged (Dick, 1983) as shown in Table 2.6. After 28 years, there was a 13% loss of organic matter following continuous ploughing, a slight increase after chisel ploughing, and a 64% increase after no-tillage (Mahboubi et al., 1993). Similar experiments in Kentucky, on a silt loam the content of organic carbon in the 0-50 mm layer in zero-tilled soil was 70% more than that in ploughed soil (Blevins et al., 1983; Ismail et al., 1994). Similarly, in Alabama, USA, at a site that had been conventionally tilled for more than 50 years, when followed by 10 years of no-tillage, organic matter increased in the surface layer but was unchanged where no-till was not adopted (Edwards et al., 1992).

Table 2.6 Organic carbon (%) in two Ohio soils under long-term soil tillage experiments.

No. of Years	Depth (mm)	Wooster silt loam			Hoytville silty clay loam	
0	0-225	1.4 [1]			2.3 [1]	
		NT	CP	MP	NT	MP
18 [1]	0-225	1.3	1.1	1.1	2.3	2.0
	0-150	1.5	1.2	1.2	2.7	2.0
28 [2]	0-150	2.3	1.5	1.0		

NT(no-till); CP(chisel plough); MP(mouldboard plough)

[1] *(Dick ,1983),* [2] *(Mahboubi et al.,1993).*

There have been a number of studies in New Zealand on the comparison of soil organic matter and microbial biomass in cultivated and pasture soils (Cotching et al., 1979; Ross et al., 1982; Sparling and Shepherd, 1986; Hart et al., 1988; Shepherd, 1992; Horne et al., 1992; Sparling et al., 1992; Francis and Knight, 1993). These studies showed that soil organic matter was higher in the topsoil of undisturbed and no-till soils as compared to ploughed soils.

Tillage practices have profound effect on soil nutrients (N, P & K) availability for plant uptake during the growth period. It is known from number of studies that after NT, concentration of phosphorus and potassium increases in the surface layer of the soil (Follet and Peterson, 1988; Lal et al., 1990; Horne et al., 1992). Similarly, Karlen et al. (1994) reported that different tillage methods affect the total N concentration within the soil. They found twice as much N at 0-25 mm in the NT (3.0 mg cm^{-3}) as compared to ploughing treatment (1.5 mg cm^{-3}). Similar trend were found at 25 to 75 mm depth, whereas at 75 to 150 mm depth, the ploughing treatment had the highest total N concentration in the soil. Such high total N under NT treatment compared to CT reflects the availability of N pool near surface which is easily incorporated into microbial biomass N, and becomes less available for mineralization or N loss.

Soil pH is the determination of soil acidity, and low or high pH levels control the availability of plant nutrients and other trace elements. It is well known that pH of surface layers of uncultivated soil often becomes acidic more rapidly than that of ploughed soil (Dick, 1983; Lal et al., 1990; Horne et al., 1992; Choudhary et al., 1997). It is because tillage mixes fertiliser within soil, whereas NT is strongly influenced by surface application of N fertilizer (Blevins et al., 1983). Similarly, Choudhary et al. (1997) found in the long-term (33 years) soil tillage experiment pH of surface water runoff was higher in mouldboard and chisel plough fields compared to those sown with no-tillage, suggesting that NT surface became rather acidic because of

continuous application of fertilizer (Table 2.7). No such pH differences occurred between NT & CT leachates collected at 150 cm soil depth. In contrast, other researchers found no significant effect on soil pH due to tillage practices (Karlen et al., 1994 and Guo, 1997).

Table 2.7 Tillage effect on surface water runoff and leachate pH.

Treatment	Runoff pH	Leachate pH
Mouldboard Ploughing	6.99 [a]	-
Chisel Ploughing	6.95 [a]	6.80 [a]
No-tillage	6.62 [b]	6.70 [a]
LSD $_{0.05}$	*0.22*	*0.20*

Values followed by same letter in column show no significant differences (P < 0.05)

(Choudhary et al., 1997).

Cation exchange capacity (CEC) is the total amount of cations that a soil can retain and SOM is the major contributor to CEC. After continuing tillage treatments for periods up to 28 years, large decreases in CEC have been found which were associated with the losses in organic matter content (Chan et al., 1992; Horne et al., 1992; Mahboubi et al., 1993). Tillage practices may have a variable influence on CEC e.g. Lal et al. (1990) found a significant decrease in CEC after 12 years of NT compared with CT on a poorly drained clay soil.

2.4 Soil biochemical properties

Most prominent biochemical properties are soil microbial biomass (labile pool of organic matter content) and soil enzyme activities (such as dehydrogenase activity, hydrolases). Soil microbial biomass are believed to be more dynamic and sensitive to changes than those based on other biochemical properties, and can therefore serve as early signals of change in soil fertility status (Insam et al., 1991; Swift, 1994), and management induced changes, such as tillage practices, incorporation of crop residues, N

fertilisation, crop rotation and changes in soil moisture (Powlson et al., 1987 and Pankhurst, 1994).

2.4.1 Soil microbial biomass

Soils contain a wide variety of macro-and micro-organisms with cross-sectional measurements ranging from 1 μm to 20 mm (Swift, 1979). Micro-organisms include bacteria, fungi, algae, protozoa and some nematodes. Macro-organisms include a range of invertebrates such as micro- and macro-arthropods, earthworms and termites. The total population of these organisms in the soil is often referred to as soil biomass. These micro- and macro-organisms are responsible for a wide range of functions which affect nutrient availability and soil structure. In most soils, the micro-organism population and the earthworm make up the bulk of soil biomass. However, the way the soils are managed, has a significant effect on the activity and survival of these organisms.

Jenkinson and Ladd (1981) defined soil microbial biomass as the living part of soil organic matter, excluding plants roots and soil animals larger than 5 x 10^3 μm^3. Thus, soil microbial biomass constitute all those organisms which can pass easily through 2 mm mesh size sieve e.g. bacteria, fungi, actinomycetes, protozoa and few nematodes. A cubic centimetre of grassland soil biomass typically contains hundreds of millions of bacteria, tens of thousand of protozoa, hundreds of metres of fungal hyphae, several hundreds nematodes, mites and insects, and a myriad of other microbes and some larger organisms (Ritz et al., 1995).

2.4.2 Function of Soil microbial biomass

Soil microbial biomass secrete polysaccharide gum materials that bind soil particles and thereby maintain a good soil structure. They are involved in cycling of number of nutrients such as carbon, nitrogen, phosphorus and

sulphur. When organic matter is added to the soil , either as plant litter or animal manure, the microbial population present in the soil decompose these dead materials and release the organic nutrients for their uptake. Similarly, when certain fertilisers are added to soils the microbes also help other organisms to solubilise these fertiliser compounds and thereby release the nutrients for plant uptake. In a nutshell, a soil without microbial population is non fertile and is unlikely to support any vegetation. A fertile soil should have an adequate microbial population.

Soil microbial biomass is also a primary catalyst of biochemical processes as well as energy and nutrient reservoir. Its significance is exemplified not only by biochemical transformations in soil but also by the quantities of fixed nitrogen it contains. Anderson and Domsch (1980) found in 26 agricultural soils, total soil nitrogen contained in the microbial biomass ranged from 0.5 to 15.3 percent with an average of approximately 5 percent. This nitrogen becomes available to the aboveground plant community upon death and decay of microbial cells. In soils not receiving supplied fixed nitrogen, this nitrogen pool is sufficiently large to maintain its stability in the ecosystem. In cultivated soils (such as when grassland soils are cultivated) , a decline in soil microbial biomass results in a release of large quantities of fixed nitrogen. This fixed nitrogen is lost from the ecosystem through leaching to groundwater or through runoff. Hence, estimating the soil microbial biomass and its stability is of unique importance in the understanding of an overall ecosystem dynamics (loc. cit).

Microbial biomass dynamics also play a critical role in mediating residue decomposition, nutrient cycling, and organic matter turnover. Microbial activity influence nutrient availability both directly and indirectly by the transformation and transfer of nutrients in the soil plant system (Oberson et al., 1993; Richardson, 1994). Nutrients in the biomass become available as dead microbial cells are attacked by other microbes (King, 1990). Consequently, loss of organic matter during cultivation and, especially the

loss of the soil microbial component, can adversely affect both physical, biological and nutrient status of soils (Carter, 1986; Carter and White, 1986).

2.4.3 Methods for measuring microbial biomass in soils

Microbial biomass is readily assessed in any ecosystem, but its measurement in soil is complicated by the complexity of the system and the fact that microbial cells comprise only a small portion of the total soil biomass. Soil microbial biomass has been commonly estimated using any of the following methods:

- Direct counting method (Rosser, 1980).
- ATP (adenosine triphosphate) extraction method (Jenkinson et al., 1979; Tate and Jenkinson, 1982; Verstraete et al., 1983).
- Substrate-induced respiration method (Anderson and Domsch, 1978 b).
- Fumigation-incubation method (Jenkinson and Powlson, 1976 b).
- Fumigation-extraction method (Vance et al., 1987 b).

A variety of inaccuracies are associated with the estimation of soil microbial biomass depending on the method used. In selecting procedures, determining constants for calculating results, and interpreting the data, it is important to consider the basic properties of the soil such as moisture, pH and organic matter content levels. Furthermore, the calculation for each of the procedures requires the use of a constant which have separate impact on results. However, there is not much data available on simultaneous comparison of all these methods. An important criteria to assess any of these methods is their potentials and limitations during application.

In considering the efficiency, reliability and acceptability of different methods, fumigation-extraction method, due to high accuracy of the automatic and sophisticated equipments, offers new opportunities and has become most common method for estimating soil microbial biomass C, N, P

and S (Vance et al., 1987; Jenkinson, 1988; Brookes et al., 1982; Hedley and Stewart, 1982; Saggar et al., 1981). Therefore, based on relative merits of these techniques, it was decided to use fumigation-extraction technique to measure soil microbial biomass C, N & P for this study. Details of this technique are described in methods and material (chapter 3).

2.5 Tillage effects on microbial carbon, nitrogen & phosphorus

Tillage methods, which require less soil tillage operations and maintain high crop residues near the soil surface, can be beneficial to crop production. The type and duration of tillage practice has a significant effect on soil organic matter levels and the nutrient cycling systems of the soils. Soil microbial biomass measurements are used in assessing and evaluating biological processes of a soil system. Few prominent indicators such as microbial biomass carbon, nitrogen, phosphorus and their interactions under conventional and no tillage management are reviewed.

Doran 1980) surveyed soil microbial biomass and biochemical characteristics of surface soils at seven locations throughout USA where long term no-till and conventional tillage field experiments were established. Soil microbial population at 0-7.5 cm depth in no-till soil were markedly higher than for conventionally tilled soil (Table 2.8). Total aerobic counts and facultative anaerobe counts in no-till soil were 35 and 57 % higher respectively than those in conventionally tilled soil. Among the aerobic organisms, the fungi and aerobic bacteria increased mostly with no-till as compared with conventional tillage. Counts of NH_4^+ and NO_2^- oxidizers for no-till at the 0- to 7.5 cm were higher than those for conventional tillage at four of the seven locations.

This study further suggested that the microbial group was also associated with depth. The concentration was high at soil surface (0-7.5 cm depth) as compared to 7.5 -15 cm depth. This was possibly because upper soil

surface in NT has the potential to retain more crop residues, less soil disturbance and creates favourable environment for micro-organisms.

Table 2.8 Key microbial population and nutrient levels between no-till (NT) and conventional tillage (CT) at two soil depths.

	Ratio NT/CT	
Microbial group	0-7.5 cm depth	7.5-15 cm depth
Aerobic bacteria	1.41	0.68
Facultative anaerobes	1.57	1.23
Actinomycetes	1.14	0.98
NH_4^+ oxidizers	1.25	0.55
NO_2^- oxidizers	1.58	0.75
Fungi	1.57	1.23

(Doran, 1980).

Carter (1991) found microbial biomass C and N responded rapidly to changes in tillage and soil management. He studied microbial C and N in the surface soil of several reduced tillage treatments (e.g. direct drilling, chisel ploughing, shallow tillage). Direct drilling and tillage system that mixed and incorporated crop residues within the surface soil increased microbial biomass C levels and the mineral N flush at the 0-5 cm soil depth compared to Mouldboard plough (Table 2.9). These results confirmed earlier work reported by Powlson and Jenkinson (1981), Carter and Rennie (1982) and Carter (1986).

In the same study, the author also measured microbial biomass C and mineral N in the adjacent grassland soil to compare with different tillage and crop rotation. His results suggested that the grassland soils had much higher levels of microbial biomass C and mineral N flush (Table 2.10). This was probably due to the higher amounts of soil organic C and total N in the grassland soils.

Table 2.9 Effects of selected tillage system and crop rotation on organic C, total N and microbial biomass C & N.

Cropping system	Tillage system	Organic C (%)	MBC (μg C g^{-1} soil)	Total N (%)	MBN (μg N g^{-1}soil)
Silage maize	MP	1.96	120.5	0.140	14.1
Silage maize	DD	2.15	237.2	0.143	21.9
Barley/maize	DD	2.08	208.9	0.153	21.3
Spring cereals	MP	2.33	150.0	0.153	18.6
Spring cereals	ST	2.54	278.0	0.168	34.5
Spring cereals	DD	2.55	299.0	0.165	32.9

(*Carter, 1991*); MP=Mouldboard plough; DD=Direct drilling; CP=Chisel plough; ST=Shallow tillage.

Table 2.10 Microbial biomass C and mineral N at the soil surface (0-50 mm) in permanent grassland soils.

Years in grass land	Microbial biomass C (μg C g^{-1} soil)	Mineral N (μg N g^{-1} soil)
10	465.7	60.8
15	619.5	74.5
20	596.7	68.6

(*Carter, 1991*).

Buchanan and King (1992) observed seasonal fluctuation in microbial biomass C and P and in microbial biomass activity over three cropping seasons using continous maize, and two years maize-wheat-soybean rotation under no-till and reduced chemical input management. They found significant seasonal fluctuations in microbial C and P under all cropping systems. Over 3 year period, microbial C was 435 mg kg^{-1} soil under reduced input maize, 289 under no-till maize, 374 under the reduced input crop rotation, and 288 mg kg^{-1} soil under the no-till rotation. Similarly, microbial P also fluctuated with season and management. The estimates for

microbial P also tended to reflect the proportion of microbial C. Thus in these specific systems, the turnover of C & P through the microbial biomass with a reduced chemical input to the soil were higher than under a no-till system. The quantity of microbial C & P was higher in the minimum tillage system possibly due to crop, weed and legumes residues left intact on soil surface. In cropping system when fertiliser use was reduced, or eliminated, and green manure legumes were used, the microbial nutrients availability were suddenly increased. Overall, continuous reduced chemical input maize management stimulated the growth of microbial biomass to a greater degree than any other system . They found that microbial C was higher in autumn and late spring, but declined during winter and early spring, whereas microbial P increased during winter and early spring. Sarathchandra et al. (1989) also observed similar seasonal changes in microbial biomass C and P in pasture soils. Similarly, Tate et al. (1991) reported that although there was little seasonal change in microbial C in permanent pasture in New Zealand, the microbial P showed greater fluctuation and was related to plants uptake of P. These studies suggest that tillage play significant role in the supply and availability of C & P substrates to the microbial biomass.

Angers et al. (1993) studied microbial and biochemical changes induced by rotation and tillage in a soil under barley production. Total organic C was affected by the tillage treatments but not by the rotations. In the top layer (0-7.5 cm), NT and CP had 20 % higher C contents than the MP treatments after two years. In the same soil layer, microbial biomass C averaged 300 mg C kg^{-1} in the MP treatment and up to 600 mg C kg^{-1} in the NT soil. Hot-water extractable and acid-hydrolyzable carbohydrates were 40 % greater under reduced tillage than under MP. The ratios of microbial biomass C and carbohydrate C to total organic C suggested that there was a significant enrichment of soil organic matter (SOM) in labile forms as tillage intensity was reduced. Alkaline phosphatase activity was 50 % higher under NT and 20 % higher under CP treatments than under MP treatment. The overall

management induced differences were greater in the top layer (0-7.5cm) than lower layer (7.5-15 cm).

These data showed that four years of conservation tillage and to a lesser extent, rotation with red clover, resulted in greater SOM in the 0-7.5 cm soil layer compared with continuous barley with conventional tillage. Lower SOM under MP may be the result of combined effects of mixing of surface soil with subsurface soil and enhanced oxidation of SOM. MP leading to a reduction in microbial biomass and carbohydrates. A similar results have been reported for the soils from South Island, New Zealand under 8-year rotation i.e. 4 year pasture followed by 4 year arable crops (Haynes and Francis, 1993).

Costantini et al. (1996) studied organic C and the microbial biomass C under three tillage systems with continuous maize. They found organic C and microbial biomass C contents in the 0-5 cm soil layer were significantly higher under zero tillage compared with reduced and conventional tillage (Table 2.11). These results were in close agreement with those found by Powlson and Jenkinson (1981) and Carter (1986). However, no differences were found for microbial biomass C and organic C with sampling depth. The authors were of the opinion that this might be because of high levels of maize straw was being added to soil for 6 years under all treatments. The authors concluded that zero tillage proved to be more efficient than the other tillage systems in the conservation of organic C and microbial biomass C.

In New Zealand conditions, Ross et al. (1982) reported larger losses of soil C (40-50 %) from the top 5 cm of Waikato soil after 11 years of cultivation. Preliminary studies have indicated a marked loss of soil organic C and decline in microbial C in Manawatu soils (Sparling and Shepherd, 1986). Sparling et al. (1992) confirmed such results in more recent study that 14 years of continuous maize cultivation resulted in a decline of 49 % in total C

and 60 % in microbial C at soil depth 0-20 cm compared with the levels under permanent pasture.

Table 2.11 Organic C and microbial biomass C at 0-5 0 mm depth under three tillage systems.

Treatments	Organic C (%)	Microbial biomass C (μg C g^{-1} soil)	MBC/OC (%)
Zero Tillage (ZT)	2.20 [a]	187 [a]	0.85 [a]
Reduced Tillage (RT)	1.75 [b]	166 [b]	0.95 [b]
ConventionalTillage (CT)	1.60 [b]	100 [b]	0.62 [b]
Control	2.88	433	1.50

Values followed by the same letter in columns show no significant differences(P<0.05) (Costantini et al., 1996).

2.6 Soil respiration (CO_2 emission)

The respiration of soil can be measured in field (CO_2 emission) under natural or controlled conditions in laboratory (basal soil CO_2) to assess soil biological activity status. Soil respiration has been used to assess the biological activity of below ground biomass, and to monitor decomposition processes (Anderson, 1982; Jordan and Kremer, 1994). In addition, the measurement has also been used to obtain a better understanding of soil C turnover (mineralization and stabilization) and to obtain insight into how mineral nutrients and soil organic matter can be used more efficiently and conserved (Anderson, 1982).

Field respiration is influenced by climate, soil physical, chemical, biological properties and the management practices, and has been widely used to assess the functioning of the system (Kowalenko et al., 1978; Buyanovsky et al., 1986; Hendrix et al., 1988; Franzluebbers et al., 1995; Costantini et al., 1996) .

2.6.1 Field soil CO_2 emission measurement methods

Efflux of carbon dioxide (CO_2) from soil to atmosphere is an important part of the carbon cycling in nature. Field CO_2 emission is a process of carbon cycling and serves as an indicator of biological activities within a soil profile and also provides a useful index for the carbon budget of an agricultural production system. Within the soil, carbon dioxide is produced mainly by the respiration of soil organisms and plant roots. Soil animals, plant roots and the majority of micro-organisms use oxygen and release CO_2 in the process of respiration by which they obtain energy. Thus, respiration rate can be measured as the amount of CO_2 respired per unit mass, or volume of soil per unit time. The respiration rate of plant roots can be many times faster than that of any soil. The respiration rate of a soil may be increased by 40-100% by the presence of plant roots, because roots provide organic exudates and residues which stimulate the activities of soil micro-organisms. More than 90% of soil respiration takes place within the topsoil (Rowell, 1994).

Several methods for measuring soil surface CO_2 emission exist (Anderson, 1982). Two important methods, static and dynamic closed chambers, for measurement of soil respiration under field conditions are discussed.

2.6.1.1 Dynamic chambers method

In dynamic chambers methods, an air circulation system is used. In dynamic open systems, fresh air of a known CO_2 concentration is admitted into the chamber while an equal volume of air is withdrawn and analyzed by infrared gas analyzers (Kanemasu et al., 1974; Ewel et al., 1987). Soil respiration is calculated by using the flow rate and the difference in CO_2 concentration between the air entering and leaving the chamber. Whereas, in dynamic closed systems, air is circulated from the chamber to a gas analyzer and returned to the chamber, and soil respiration is calculated using the rate of

increase of CO_2 concentration. Portable CO_2 analyzers have also been developed and successfully used to measure soil respiration in dynamic chambers (Hall et al., 1990; Rochette et al., 1991; Jensen et al., 1996).

2.6.1.2 Static chambers method

This method was first introduced by Lundegardh in 1927. Subsequently, the Static chambers method with absorption of CO_2 in an alkali trap over 24 hour has been widely used by several scientists (Buyanovsky et al., 1986; Hendrix et al., 1988; Beyer, 1991; Franzluebbers et al., 1995; Jensen et al., 1996). This technique is commonly used as it does not involve expensive and sophisticated equipment, and also has an advantage of integrating the CO_2 over time (hour to days) . However, placement of chamber on the soil surface for extended periods may disturb the soil microclimate condition. In this study, it was decided to use this technique for measurement of CO_2 emission. Details are provided in methods and material chapter 3.

2.6.2 Climatic factors affecting CO_2 emission

Important factors which affect the rate of CO_2 emission are soil temperature, soil water content, soil organic matter content and nutrient supply (Mclaren and Cameron, 1996). A number of studies have shown that soil temperature and moisture are important regulators of soil respiration (Bunnell et al., 1977; Kowalenko et al.1978., Buyanovsky et al. 1986). Temperature affects metabolic activity directly, while moisture serves both as a medium for microbial activity and as an agent for solublizing and increasing the availability of organic substrates. Effects of tillage and residue placement on soil biological activity have an interaction with soil moisture and temperature. For example, surface layer of NT soil tends to insulate the soil temperature extremes and protect soil surface from rapid desiccation, creating a potentially more stable environment for biological activity (Blevin et al., 1983).

2.6.2.1 Soil temperature

Soil temperature depends upon atmospheric temperature and inputs as well as losses of radiation. It is also influenced by the presence or absence of vegetation, the soil water content and depth within the soil. Generally, soil temperature vary between day and night (diurnal variation) and throughout the year. With increasing depth, diurnal temperature fluctuations are possible. The mean fluctuation in summer in surface soils in cool temperate climates may be only 10^0C and in sub-tropical and tropical regions may be 30^0C (Wood, 1989). Micro-organisms are categorised according to the range of temperature at which they grow. Psychrophiles grow at 0^0C and have an optimum temperature at or below 20^0 C. Thermophiles have a maximum temperature for growth of over 50^0 C and a minimum of over 20^0 C. Mesophiles have temperature optima between these two extremes. Soil microbial activity is often assumed to be negligible at temperature less than 5^0 C (Wood, 1989). In cold soils both the rate of chemical weathering of soil minerals and the rate of biological cycling of nutrients are slow. While on the other hand, the high temperatures in soils are often associated with dry conditions and resulting effects of high temperature on soil micro-organisms activities is somewhat complex.

2.6.2.2 Soil moisture content

The concentration of O_2 and CO_2 also depends on the presence of water content in the soil profile. The increase or decrease of water content helps in organic matter decomposition and action in biomass activity. Thus the quantity of soil water is an important variable both within a soil profile and from day to day (Mclaren and Cameron, 1993).

Water not only provides an essential medium for growth of microbial populations, it is also a primary participant in a variety of cell processes. Tate (1995) summarized major roles for soil water as i) an essential material

for flora and fauna, ii) affects gas exchange in soil, iii) affects microbial nutrient supply, iv) affects soil temperature, and v) a growth medium for microbial colonies.

2.6.3 Basal soil respiration

Basal or laboratory respiration is the release of CO_2 by living and metabolizing entities of micro-organisms such as bacterial, fungal, algal, and protozoa cells available in the soil system. These organisms represent the living and metabolic active cells in the soil, and are the main agents responsible for respiration (Anderson , 1982).

To measure the basal (or laboratory) soil respiration rate, incubation of soil samples under controlled temperature (usually at 25 ^{0} C) in laboratory is used. Basal soil respiration has been widely used to determine the biological activity in soil in relation to changes in climatic, soil physical and chemical properties, and in agricultural management practices (Nannipieri et al., 1990; Costantini et al., 1996; Saggar et al., 1997).

2.6.4 Metabolic quotient (qCO_2)

The ratio of CO_2 evolution rate to microbial biomass is termed as metabolic or respiratory quotient (Anderson and Domsch, 1986). Metabolic or respiratory quotient (qCO_2) is obtained by expressing the rate of soil respiration in terms of the microbial biomass and is obtained by a formula given as below :

$$qCO_2 = \frac{respiration}{MBC}$$

where *respiration* = mg CO_2-C kg^{-1} soil h^{-1};
Microbial biomass carbon (MBC) = g C kg^{-1} soil

The qCO_2 has been used to study soil microbial biomass maintenance energy (Anderson and Domsch, 1985), temperature effect (Anderson and Domsch, 1986), and comparisons between field managements (Anderson and Domsch, 1990). Anderson and Domsch (1990; 1993) suggested that metabolic quotient of soil organisms hold an analogy to plant ecosystems, and could be used to investigate soil development, substrate quality, ecosystem maturity, and response to stress conditions.

In comparing pasture and pine land uses in New Zealand, Saggar et al. (1997) found that soils under pasture had higher microbial biomass C and N content and a lower metabolic quotient than soils under pine. These authors suggested that the microbial biomass in soil under pine was less efficient and expend more energy for maintenance requirements. Similarly, Costantini et al. (1996) observed significantly higher respiration under zero and reduced tillage as compared to conventional tillage, and found that this related to lower metabolic quotient under zero and reduced tillage.

2.7 Tillage effect on field CO_2 emissions

Soil tillage management regimes in an agroecosystem and crop rotation seemed to have an impact on soil respiration. Literature on tillage impact on CO_2 emission is reviewed for its implication for proposed study.

Hendrix et al. (1988) measured effects of CT and NT management practices on the amount and rate of CO_2 efflux from soil and plant residues in various agroecosystems and unmanaged native ecosystem using static-absorption technique. CO_2 efflux in these experiments over 17 months observation period ranged from 5 to 50 g CO_2 $m^{-2}day^{-1}$. Overall, CO_2 efflux was significantly higher in NT than in CT soils, and from soils under clover-grain rotation than under rye-grain- sorghum rotation. However, in cool season, soil respiration was similar in NT and CT soils, and in adjacent unmanaged native fields. The authors reasoned that might be possibly because the

tillage accelerated the loss of plant materials by incorporating them into the soil and taken up by soil organisms, as compared to the material which remained on the soil surface in undisturbed ecosystem.

Buyanovsky et al. (1986) investigated annual cycles of soil CO_2 evolution from winter wheat crop fields sown with conventional tillage for serveral years in the USA. Soil temperature and water content were determined as a useful prediction parameters to view the influence on soil respiration. When soil was tilled and wheat planted, CO_2 production varied from 4-8 g $m^{-2}day^{-1}$ and responded to increasing temperature. During winter months when soil temperature was below 5^0 C, the CO_2 emission were < 1 g $m^{-2}day^{-1}$. In spring, as air temperature arose, CO_2 efflux from the soil profile increased rapidly and by April these efflux rates were 5 g $m^{-2}day^{-1}$. The rise in CO_2 within the soil profile was due to organic material decomposition as well as from root biomass. The respiration rate continued to rise gradually through May and June and reached 10 g $m^{-2}day^{-1}$ by harvest time in July. The peak daily rate in mid July ranged from 10 to 19 g $m^{-2}day^{-1}$ in the 1st year and 12 to 13 g $m^{-2}day^{-1}$ in other years. July was the most favourable month for biological activity with mean monthly soil temperature at 24^0 C and sufficient water supply through precipitation.

Over last few years, there has been a range of research data forthcoming on CO_2 emission related to tillage practices. However, there also seemed to be large variations in CO_2 efflux data. Such differences could be due to unsatisfactory measurement techniques used, specific climatic factors, soil properties and amount of organic matter available in particular soils. For example, Schimel (1986) reported higher rates of CO_2 from grasslands soils than those from cropped fields. Hendrix et al. (1988) were able to detect stimulation of CO_2 release after ploughing. Franzluebbers et al. (1995) found large seasonal differences in tillage regime and found that CO_2 emissions were related to both soil temperature and moisture.

Costantini et al. (1996) found that significantly greater amounts of CO_2 were released from NT & reduced tillage soils than from conventionally tilled soils. According to these authors, tillage caused disruption and mixing of soil that allowed soil to dry more rapidly, loose form of aggregates, more heat loss during night, and evolve less CO_2 due to reduced concentration of soil organic carbon. Moreover, in their studies NT proved to be more efficient in the conservation of organic C and microbial biomass C close to soil surface.

On the other hand, Reicosky and Lindstrom (1995) found that immediately after tillage, CO_2 emission were in the order of mouldboard ploughing > chisel ploughing > disking > NT. These authors opined that high initial CO_2 fluxes were not directly associated with microbial activity, and were more related to gaseous diffusion or rapid direct oxidation of carbon substrates. They concluded that high initial efflux of CO_2 was more related to surface soil roughness and depth of soil disturbance that released CO_2 in soil pores and from solution than to residue incorporation. Reicosky et al. (1997) also measured short-term tillage induced soil CO_2 efflux from different cropping systems and found that CO_2 effluxes were greatest in bermudagrass (*Cynodon dactylon.*) and least in the continuously cultivated sorghum. Initial effluxes in the MP were usually greatest, and effluxes in untilled soils were smaller than those from other tillage treatments. They concluded that the CO_2 effluxes from soil immediately after tillage were related to tillage-induced changes in porosity than to microbial activity. They found that the soil released as much as 290 $kg^{-1}ha^{-1}hr^{-1}$ of CO_2 immediately after tillage.

2.8 Tillage effect on earthworm population

Earthworms play an essential role in our soils. "Earthworm feed on dead plant roots, dead herbage and animal dung which is partially degraded during passage through the earthworm gut, and subsequently excreted as worm casts on or below the soil surface. These casts contain an intimate mixture of organic and mineral matter, are extremely rich in plant nutrients

and initially have an extremely stable structure "(Mclaren and Cameron, 1996). In some New Zealand pastures the weight of casts produced at the soil surface in a single year has been measured at greater than 30 tonnes ha^{-1}(loc.cit). This might seem a lot but there can be as many as 3 tonnes of live earthworms per hectare, and 30 tonnes of soil represents only 1% by weight of the soil present in the top 20 cm".

Earthworms have several effects on physical, chemical and biological properties of soil. The removal of dead roots and their general burrowing activity promote aeration and drainage of the soil, which in turn stimulate plant growth. In addition to their importance, the most important effect of earthworms is the breakdown of organic material and its incorporation with the mineral soil and thus increasing nutrient cycling rates through biological process. 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 micro-organisms (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.

Among 190 spieces of earthworms found in New Zealand, the most useful and active topsoil mixing spieces is *Aporrectodea caliginosa*. Other useful species are *A. Longa, A. Rosea, A.chlorotica and Lumbricus terrestris* (Martin, 1977; MAF, 1984; McLaren and Cameron, 1993; Fraser et al., 1992).

Tillage generally destroys or reduces soil fauna that otherwise may be directly or indirectly harmful or advantageous to crop growth. Tillage is a major factor effecting earthworm population (Janson, 1984). 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; Kladivko, 1993; Karlen et al., 1994).

In New Zealand, many pastoral, arable and agricultural soils are identified by having compartively large earthworm population. Most common earthworms in pasture are *Lumbricus rubellus* (darkisk purple in colour) and *Octolasion cyaneum* (greyish with a yellow tail). Earthworm numbers under pasture are generally 500 to 1000 m^{-2}, but numbers may exceed 2000 m^{-2} under highly favourable conditions. Springett (1992) found substantial reduction in earthworm population under two different tillage systems compared to grassland condition (Table 2.12). In Canterbury, Haynes et al. (1993) observed that populations averaged about 800-900 earthworms m^{-2} under long-term pasture, less than 200 m^{-2} under long-term arable and about 500 m^{-2} under rotations of 3 years of arable followed by 3 years of pasture. Similarly, Fraser et al.(1992) noted that when a pasture soil containing around 830 earthworms m^{-2} was cultivated the population decreased to less than 200 m^{-2} after only two years. When arable field with a population of less than 100 m^{-2} was converted to a grazed grass/clover pasture the population increased to between 400 and 600 earthworms m^{-2} after only two years. Similarly, at the Massey university experimental site, Guo (1997) found that when pasture land was converted to cropping within one year earthworm population decreased by approximately 50% in conventional tilled soil, but had only small reduction in no-tillage plots (Table 2.12).

Table 2.12 Earthworm numbers under tillage, no-tillage and grassland management.

Treatments	Earthworm population (no m^{-2})	
Grassland	$^{\cdot}$ 1005 ^{a}	$^{\cdot\cdot}$ 313 ^{a}
No-tillage	$^{\cdot}$ 499 ^{b}	$^{\cdot\cdot}$ 254 ^{b}
Conventional tillage	$^{\cdot}$ 69 ^{c}	$^{\cdot\cdot}$ 159 ^{c}

Values followed by the same letter in each column show no significant differences ($P<0.05$)

($^{\cdot}$ Springett, 1992; $^{\cdot\cdot}$ Guo, 1997).

2.9 Summary

Soils contain a wide variety of soil organisms which maintain soil ecosystem functions and affect nutrient cycling and soil structure. Soils and their processes are extremely complex and the way the soils are managed, has a significant effect on the survival and activities of these organisms. Measurements of biochemical and biological properties such as soil microbial biomass, basal soil respiration, earthworms population and CO_2 emission (soil respiration) are important to asses the biological processes in a soil system. The microbial biomass plays important role in soil development and in the maintenance of soil fertility and also acts as nutrient reservoir. The soil microbial biomass carbon, nitrogen, phosphorus and CO_2 emissions can be used as indicators of management induced changes in soil biological properties, such as tillage practices, incorporation of crop residues, N fertilisation, crop rotation sequence and changes in soil moisture regimes.

Initially, no-tillage (NT) technology evolved primarily for soil erosion control. However, recent concerns about climatic change and global warming has highlighted the importance of NT as to its impact on reducing CO_2 emissions and microbial biomass losses. NT practices encourage build up of soil carbon and organic matter in agricultural lands. Recent studies have shown that no-tillage plays an important role in sustaining high soil microbial biomass which acts as nutrient reservoir for plants uptake, improve soil fertility, and serves as an effective tool for decreasing greenhouse gases emissions and to enhance agricultural sustainability .

CHAPTER 3

METHODS AND MATERIALS

3.1 Site description

The soil tillage experimental site (latitude 40^0 23′ S, 175^0 38′ E) was established by the previous Department of Agricultural Engineering (now the Institute of Technology and Engineering) at Massey University Turitea campus, Palmerston North in 1995. Permanent pasture land was converted to a double crop rotation using conventional and no-tillage practices. The soil has been classified as Ohakea silt loam with weakly clay-illuvial pseudo-madenti-pallic representing youngest yellow-grey earth with poor natural drainage. The site has an average (30 years) rainfall of 962 mm, and well distributed throughout the year (Table 3.1).

3.1.1 Experimental design

The experimental design (Fig. 3.1) involved three treatments with four replicates each and were arranged in a randomised complete block (RCB) design. Each plot was 17 m long and 3.6 m wide with a 5 meter headland for machinery operation on both sides of the field. The three treatments were permanent pasture (PP), conventional tillage (CT) and no-tillage (NT). Summer fodder maize and winter oats were rotated as double test crops.

3.1.2 Tillage operations

The conventional tillage (CT) treatment involved mouldboard ploughing followed by rolling and two passes of a power harrow for seedbed preparation. In the no-tillage (NT) treatment there was no prior cultivation and weeds were controlled by using Roundup (*360 g l^1 glyphosate*) at 4 l ha^1. In both the treatments an Aitchison seed drill was used for sowing seed.

These operations were conducted in an ' opportunistic farming ' manner to ensure that field conditions were not impaired by climatic condition.

Table 3.1 Summary of monthly climatological observations data taken at 0900 hrs at Agri-Research station E05363, Palmerston North.

1996-97	Mean rainfall (mm)	r.h. (%)	Air Temperature (C^0)		Soil Temperature (C^0)
Months			Max	Min	(10 mm depth)
November,1996	100.5	76	17.1	9.3	14.4
December	91.1	77	20.2	11.5	16.7
January, 1997	68	75	21.0	11.8	17.6
February	58	82	22.8	13.6	17.7
March	68.1	81	19.9	12.4	15.8
April	144.7	83	17.3	8.0	12.5
May	24.3	87	17.2	8.7	11.6
June	60.4	93	13.1	3.9	8.1
July	32	91	12.7	3.0	6.4
August	60.1	84	13.1	5.4	7.3
September	79	78	14.2	6.8	9.1
October	77.8	84	16.2	8.4	12.4
Total	**864**	-	-	-	-

30 years average rainfall = 962 mm

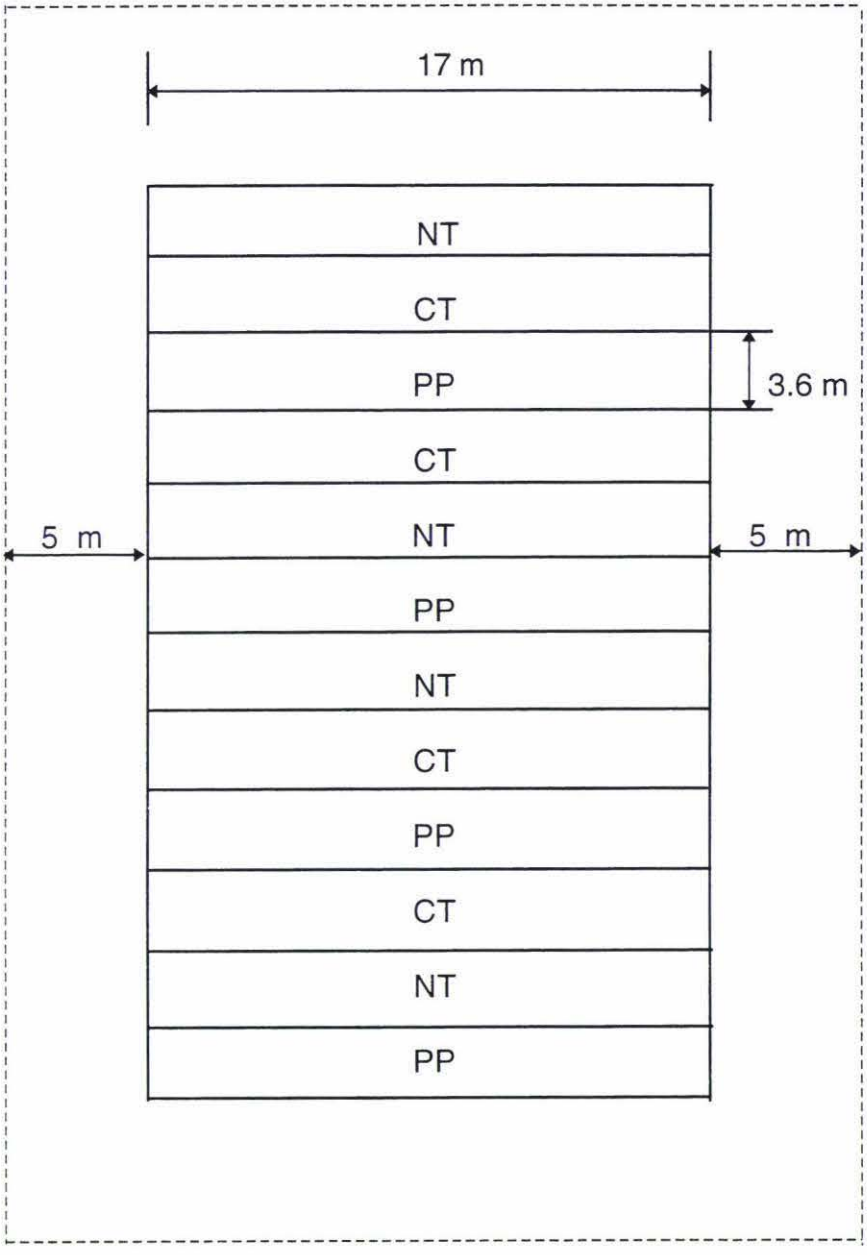


Fig. 3.1 Experimental treatment design (plots layout)

CT = Conventional tillage, NT = No-tillage, PP = Permanent pasture

3.1.3 Crop rotation

3.1.3.1 Summer fodder maize establishment

On 11 November 1996, the summer fodder maize was sown at a seed rate of 65 kg ha^{-1}. Fertilizer (Nitrophoska having 12% N, 10% P, 10% K, 1% S) was applied at rate of 120 kg ha^{-1} and sowing was done with Aitchison seed drill model Seedamatic 1112. Two weeks after sowing, plants were counted using quadrats of 0.25 m^2. The fodder maize was sheep grazed on 10th March 1997.

3.1.3.2 Winter oats establishment

On 4 April 1997, the winter oats were sown at a seed rate of 120 kg ha^{-1} with 200 kg ha^{-1} of Nitrophoska fertilizer with the Aitchison seed drill model Seedamatic 1112. Plant emergence was counted by using quadrats of 0.25 m^2. These data were later converted to obtain percentage establishment. On 9th May 1997 all plots (including pasture) were supplied with 65 kg ha^{-1} of urea as second fertiliser doze. The crop was harvested by sheep grazing on 14th July, 1997.

3.2 Soil sampling

During one year of study period, 3 sets of soil samples were collected at sowing and harvesting of maize and oat crops. Nine soil cores (25 mm diameter) were taken at two depths of 0-50 and 50-100 mm, from each of the four replicates at each time except at maize sowing, where inadvertently, only 0-100 mm depth samples were collected. The soil cores were bulked and the samples were sieved through 2-mm size sieve in a field-moist state soon after collection, and stored at 4^0 C. These "fresh" field-moist sieved samples were used for microbial biomass and respiration measurements. Subsamples were air dried before chemical analyses.

3.3 Soil analyses

3.3.1 Soil moisture content

Soil moisture content (gravimetric) was measured by standard procedure on dry weight basis by using the following formula.

$$SMC = \frac{M_w}{M_s} \times 100$$

where, SMC is the soil moisture content (%); M_w is the mass of water in the soil ; and M_s is the mass of dry soil.

3.3.2 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 ml of deionised water in a 50 ml plastic beaker and left overnight after stirring. The pH was measured at 20^0 C and 98.2% sensitivity using PHM 83 Autocal pH meter. A sample of Manawatu silt loam was used as an internal analytical standard.

3.3.3 Total C

Total C was determined by chemical oxidation method described by Walkey and Black (1934). The method involved the oxidation of organic carbon using potasium dichromate under acidic condition. The soil samples were oven dried at 105^0 C and finely ground. An amount of 0.5 g of the ground sample was mixed with 10 ml of $K_2Cr_2O_7$ and 20 ml of concentrated H_2SO_4. The solutions were kept for 30 minutes for the reaction of soil organic carbon with dichromate. The amount of the $K_2Cr_2SO_4$ remained in solution was determined by titration with 0.5 N $FeSO_4$. In this reaction, $Fe_2(SO_4)_3$ was created and caused colour of solution changing from dark to turquoise

green. The organic carbon was determined from the amount of dichromate used in the oxidation. Glucose was used as standard for checking percent recovery of the C in the samples. As chemical oxidation was not a complete oxidation of the organic carbon, a correction factor of 1.3 was used to calculate the organic carbon.

3.3.4 Total N and P

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 ml of the digest mixture in a 50 ml pyrex test-tube. The mixture was left overnight after which it was heated in an aluminium block at 350^0 C for 7 hours. When cooled, the mixture was diluted with 50 ml of deionized water, stirred in a vortex mixture and left overnight. Total N and P in the supernatant solution was measured by an autoanalyzer.

3.3.5 Microbial biomass carbon (MBC)

Microbial biomass carbon (MBC) was estimated by fumigation-extraction method described by Vance et al. (1987). Field moist soil (5 g o.d equivalent) from each replicates were divided into two sets. One set of samples were placed for fumigation in a vacuum desiccator at room temperature for 24 hours. Both fumigated and non-fumigated soils were then added with 25 ml of 0.5 M K_2SO_4, shaked on a rotating drum shaker for 30 min. and centrifuges @ 2000 rpm for 5 minutes. These fumigated and non-fumigated 0.5 M K_2SO_4 extracts were used to determine MBC on total organic carbon analyser (TOC) as shown in Fig. 3.2. Increase in extractable C from fumigated compared to non-fumigated soil was taken to represent microbial-C flush. The MBC was then estimated by multiplying the flush of oxidisable C by a factor of 0.41 (Wu et al., 1990), which represents the efficiency of extraction of microbial biomass C.

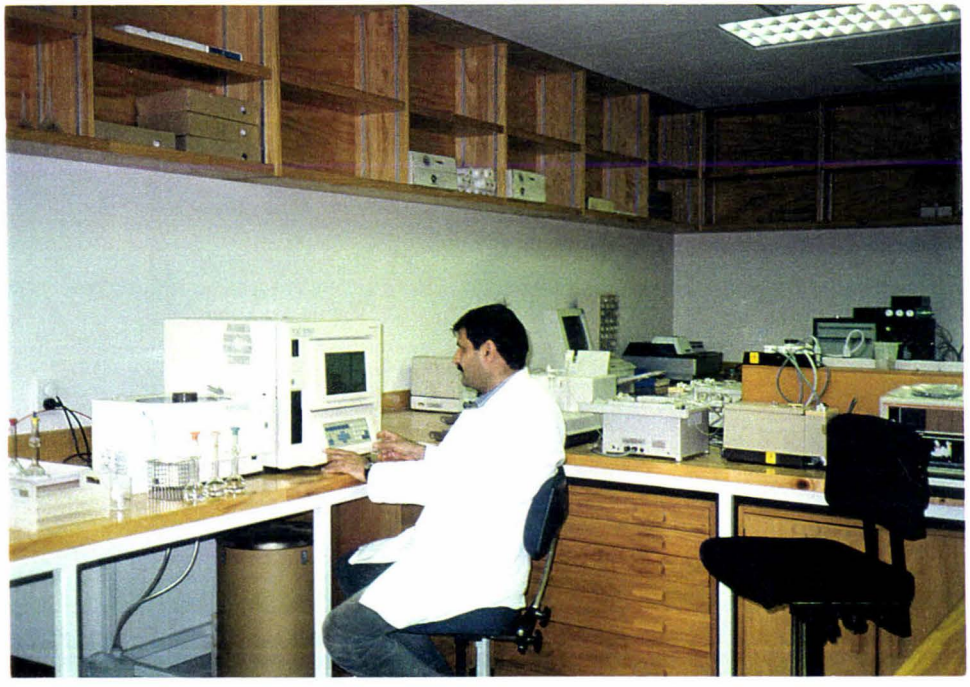


Fig.3.2 **Soil extracts being analysed on shimadzu total organic carbon (TOC) analyser.**

3.3.6 Microbial biomass nitrogen (MBN)

Microbial biomass nitrogen (MBN) was estimated by the method described by Jenkinson (1988) and Ross (1992). The fumigation-extraction procedure used for MBC was used for MBN. The K_2SO_4 extracts from fumigated and non-fumigated soil samples were digested in aqueous 0.165 M $K_2S_2O_8$ for 30 minutes at 121^{0}C in an autoclave. The resultant nitrate (NO_3-N) and ammonium (NH_4-N) nitrogen was measured by an autoanalyser procedure (Fig. 3.3). MBN was estimated using the relationship : Microbial N = N flush ÷ 0.45 developed by Jenkinson (1988).

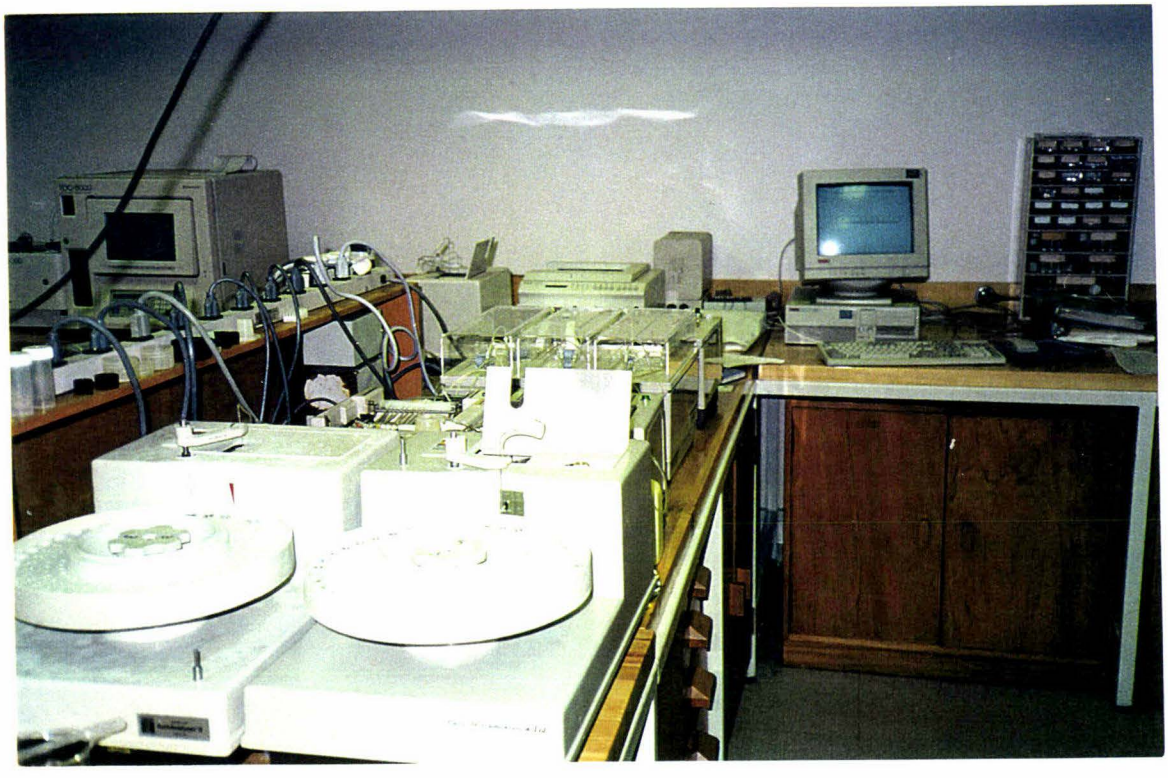


Fig.3.3 Autoanalyser used to measure NO_3-N and NH_4-N.

3.3.7 Microbial biomass phosphorus (MBP)

Microbial biomass phosphorus (MBP) was estimated using a modified fumigation and $NaHCO_3$ extraction methods described by Brookes et al. (1982) and Hedley and Stewart (1982). Fumigated, non-fumigated and spiked (with 1 ml 25 µg P/ml to estimate percentage recovery of P from the soils) were extracted with 0.5 M $NaHCO_3$ (pH 8.5) for 1 hour. The filterate was decolorised and acidified using phosphate-free charcoal and 1 M HCl. The phosphate concentration was measured (Fig. 3.4) at 882 nm by method developed by Murphy and Riley (1962). For each sample, both the extraction and subsequent analyses were performed in triplicate. MBP was estimated using the relationship: Microbial P = (P flush) ÷ (0.4 x % recovery from the spike), where 0.4 is the average proportion of microbial-P recovered from the soil as suggested by Brookes et al. (1982).

Fig. 3.4 UVspectrophotometer used to measure P.

3.3.8 Basal soil respiration

Basal soil CO_2 production was measured at 25^0 C in tightly sealed 1800 ml jars containing 25 g air-dry equivalent weight of soil at field-moisture content. A 1-ml head-space sample was collected through a septum in the lid from each jar, and the CO_2 concentration was measured by gas chromatography (Fig. 3.5). The jars were flushed with ambient air and resealed for next measurement. The measurements continued for 6 weeks.

Fig. 3.5 Gas chromatography instrument used to measure basal soil respiration (CO_2).

3.3.9 Measurement of field CO_2 emission

Static chambers were constructed (Fig. 3.6) and installed in each plot with one blank (as control) to measure field CO_2 emission. The above-ground plants were cut to 1 cm height before the installation of the chambers in each plot. Vials containing 20 ml 1 M NaOH to absorb CO_2 were placed within the chambers. The chambers were sealed with air-tight screw cap lids. After 24 hours, vials of NaOH were removed. The total CO_2 absorbed was measured by titration of aliquots (2ml) of alkali against 0.1 M HCl to determine the residual alkali, after first precipitating out of carbonates by addition of 10 ml 10% $BaCl_2$, with phenolphthalein used as indicator (Anderson, 1982).

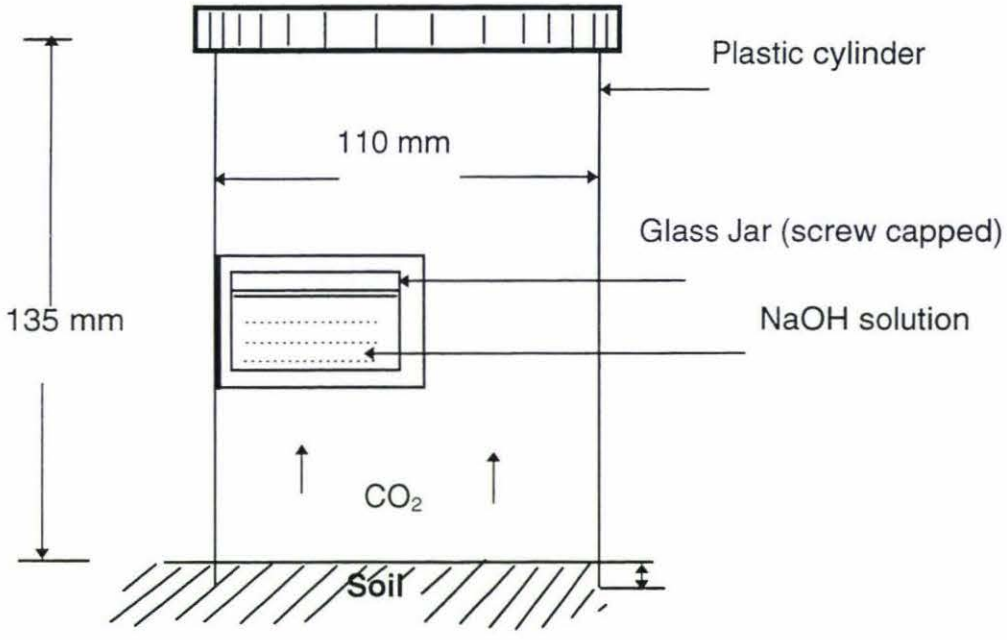


Fig 3.6 Schematic diagram of the static chambers used to collect field CO_2 emissions (size 110 mm dia. and 135 mm long).

3.3.10 Measurement of soil moisture and temperature

Gravimetric soil moisture contents at 0-50 and 50-100 mm were measured by standard procedure as described in 3.3.1.

To measure soil temperature, one thermo-couple was installed in each plot as suggested earlier. An Extech thermometer was used for direct recording of soil temperature as shown in Fig. 3.7.

Fig. 3.7 Field Soil temperature measurements using thermo-couple concurrently during CO_2 emission measurement.

3.3.11 Earthworm Population

Earthworm population was determined on pre-trimmed sites in each plot by saturating the soil with a formaldehyde solution within a 0.25 m^2 wooden frame for twenty minutes as earlier used by Raw (1959) and Edwards and Lofty (1977). Mature and immature earthworm coming to the surface within the frame area were hand picked. Earthworm population collected from each plot was counted and live weight measured.

3.3.12 Soil bulk density

Thin-walled cyclindrical aluminium samplers, 50 mm in diameter and 50 mm in length, were pressed into the soil at the desired sampling depth. The samplers, containing a known volume of sample, were then withdrawn from the soil and material outside of the sample volume removed. The samples were oven-dried at 105 ^{0}C overnight, and reweighed. Bulk density was calculated as the oven-dry mass of soil divided by the volume of the sample. Two soil sample from each plot were taken for soil bulk density measurement. Data were collected for each of 0- 50 and 50-100 mm depth.

3.4 Statistical analysis of data

A General Linear Models Procedure (GLM) with statistical analysis system (SAS) programme was used (SAS Institute Inc., 1989) to analyses all experimental data. An analysis of variance (ANOVA) and coefficient of variation, least significant differences (LSD) at 5% confidence level was obtained.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

Soil biological status is generally measured in terms of certain key plant available nutrients and level of soil microbial biomass in the topsoil. During conversion of pasture land to cropping by cultivation, the nutrient levels are likely to decline as a result of loss in soil organic matter (SOM). Consequently, loss of SOM resulting from continuous cultivation and especially, loss of the soil microbial component, can adversely affect physical, biological and nutrient status of soils (Carter, 1986; Carter and White, 1986).

In this study, the objective was to determine differences in biological nutrient status (soil microbial biomass C, N & P) of originally permanent pasture soils when converted to conventional or no-tillage cropping system. Quantitative differences in total C, N & P and soil microbial biomass carbon (MBC), nitrogen (MBN) and phosphorus (MBP), field CO_2 emission, basal soil respiration, metabolic quotient, earthworm population and pasture and crop dry matter yield were determined. These derminants were expected to indicate any differences due to conventional and no-tillage crop rotation system as compared to permanent pasture.

The results obtained from field and laboratory experiments were analysed with SAS programme for analysis of variance (ANOVA) using t-test of least significant differences (LSD) at 5% confidence level to distinguish differences between the three treatments. Raw data with statistical analysis is appended (Appendices 1.1 to 1.19). Results are described in the following sections.

4.2 Tillage effects on crop establishment and dry matter (DM) production

4.2.1 Summer fodder maize

Summer fodder maize seedling emergence was counted three weeks after sowing and the data were converted to obtain percentage of plant establishment. Data obtained showed that there were no significant differences between NT and CT treatments in plant emergence (Table 4.1). These results suggested that the two tillage practices had no affect on fodder maize crop establishment. This was not unexpected as soil conditions at the time of sowing were ideal, and that in both sowing systems the same drill was used. Therefore, method of land preparation was not expected to impact seed germination and seedling emergence. These results are similar to those of Hughes (1985) and Choudhary (1988), where crop establishment did not differ between CT and NT practices.

Table 4.1 Effects of tillage practices on maize seedling emgerence.

Treatment	Plant establishment (%)
NT	95.0 [a]
CT	96.3 [a]
$LSD_{0.05}$	*3.11*

Values followed by the same letter in column show no significant differences (P < 0.05)

4.2.2 Winter oats

Winter oats took about three weeks to germinate. Winter oats seedling emergence were counted on 8th, 12th, 16th & 22nd days after planting. This was done to observe effect of NT and CT on rate of seedling emergence over a period of time after sowing. The results show that plant numbers did not differ significantly between the two treatments except on day 12 (Table

4.2). Similar to the findings of Hughes (1985), these results suggest that the two tillage practices generally do not affect winter oats rate of plant emergence.

Table 4.2 Effects of tillage practices on oats seedling emgerence.

	Plant establishment on different days after sowing (%)			
Treatment	8	12	16	22
NT	54.6 [a]	79.1 [b]	89.2 [a]	94.4 [a]
CT	52.9 [a]	83.3 [a]	90.3 [a]	93.4 [a]
$LSD_{0.05}$	*2.10*	*2.54*	*2.32*	*3.09*

Values followed by the same letter in columns show no significant differences ($P < 0.05$)

4.2.3 Pasture and crop dry matter yield

Dry matter (DM) yield of PP after every 4-6 weeks interval was measured by using 0.25 m^2 quadrats to give a total DM yield. The total DM yield from March to September (7 months) period was 7.28 t ha^{-1}.

DM yield of winter oats was measured nine and thirteen weeks after sowing to determine yield differences at mid and full crop maturity stage. Earlier studies have shown that crops grown by conservation tillage methods often appeared smaller or stunted in early stages of growth but these differences usually diminished at later stages of plant growth (Hughes et al., 1992; Choudhary and Baker, 1994). No significant differences between NT and CT treatments during middle and maturity stage of plant growth were obtained (Table 4.3) and Fig.4.1.

4.2.4 Weed growth

In New Zealand both annual and perennial weeds are prominent and grow actively throughout the year. Tillage is recognised as one of mechanical

methods for controlling weeds. It is also known that no-tillage reduces the labour & machinery input and can effectively control weeds problem by spraying herbicides before sowing. Before planting winter oats in April, both CT and NT treatments were sprayed with a chemical herbicide (round-up) to kill and supress weed growth.

The CT treatment had resulted in a significantly higher quantity of spurry weed *(Spergula arvensis)* growth (Table 4.4). The reason could be that the existing pool of weed seeds were activated by tillage, and allowed vigorous germination and growth of spurry weed. On the other hand, the NT did not allow high spurry weed growth mainly due to less surface soil disturbance. However, the oats DM yield data (Table 4.3) suggested that proliferation of these spurry weeds did not affect final yield in CT treatment.

Table 4.3 Dry matter yield of winter oats in NT and CT.

	Dry Matter Yield ($kg\ ha^{-1}$)	
Treatment	9 weeks	13 weeks
NT	2420 [a]	3711 [a]
CT	2270 [a]	3424 [a]
$LSD_{0.05}$	*422*	*734*

Values followed by the same letter in columns show no significant differences ($P < 0.05$)

Table 4.4 Weed dry matter yield in winter oats under CT and NT.

Treatment	Weed DM ($kgha^{-1}$)
NT	40.20 [a]
CT	71.75 [b]
$LSD_{0.05}$	*25.03*

Values followed by the same letter show no significant differences ($P < 0.05$)

Fig. 4.1 Winter oats crop under CT and NT management.

4.3 Tillage impact on soil pH, total C, N and P and earthworms

As already explained in chapter 1, the overall aim of this soil tillage experiments were to evaluate long-term tillage impact on soil chemical, bio-chemical and biological properties. Research on a number of other aspects are under way. For example, at the same experimental trials, the tillage impact on soil physical properties and non-point source pollution has been completed (Guo, 1997). Similarly, another study on the same site has investigated tillage induced changes in total C, N and P (soil samples at 0-100 mm depth were taken in November, 1997) as shown in Table 4.5 (Hoang Son 1997, unpublished data).

Tillage impact on soil pH

Soil pH is a determination of soil acidity. Low or high pH levels control the availability of plant nutrients and other biological activities.

Soil pH at 0-100 mm depth in PP, NT and CT management showed no significant differences between the three treatments (Table 4.6). The average soil pH was 5.4 showing a moderately acidic condition which is common in clover-based pasture soils in New Zealand. These results indicated that after two years of tillage and no-tillage practices, and conversion from pasture to cropping had no impact on soil pH. It is unlikely for the NT and CT treatments to impact soil acidity within such a short duration. Guo (1997) also found no significant differences in soil pH between the same treatments within first year of establishing these long-term experiments. In another study, no significant effect of tillage practices on soil pH has been reported by Karlen et al. (1994), where overall pH levels were higher. Other research data from calcareous soils suggests that soil surface pH declined where no-tillage was practiced continuously for 33 years (Choudhary et al., 1997).

Tillage impact on total C

After two years of continuous cropping the total C contents at 0-100 mm depth were 33,972 and 27,608 kg ha^{-1} in NT and CT treatments respectively. This reflected a decline in total C as compared with pasture at 35,316 kg ha^{-1} (Table 4.5). The higher amount of total C in NT (19%) as compared to CT treatment apparently resulted from previous pasture organic residues and substantial input of crop residues left intact on soil surface. These results are similar to those earlier found in Manawatu soils by Sparling et al. (1992). These authors reported that total C under undisturbed and continuous grass was significantly higher than that under continuous corn in a CT system.

Tillage impact on total N

Total N content at 0-100 mm depth were 3,926, 3,776 and 3,267 kg ha^{-1} in PP, NT and CT treatments respectively (Table 4.5). Total N contents were also significantly higher in PP and NT as compared to CT treatment. CT cropping caused marked decline in soil surface organic matter which reflected in low total soil N content.

Tillage impact on total P

Total P values at 0-100 mm depth were 882, 860 and 751 kg ha^{-1} in PP, NT and CT treatments (Table 4.5). As for total C and N, the total P contents were similar in PP and NT but significantly higher in comparison to CT treatment. This difference occurred despite application of a similar amount of P fertilizer in all three treatments at the time of sowing both maize and oat crops. Once again, the effect of two years of continuous cultivation reflected in loss of total P levels in CT treatment.

Table 4.5 Tillage practices effect on soil chemical properties (0-100 mm) two years after conversion from pasture to cropping.

Treatment	Organic C (kg ha^{-1}) 0-100 mm	Total N (kg ha^{-1}) 0-100 mm	Total P (kg ha^{-1}) 0-100 mm
PP	35316	3926 [a]	882 [a]
NT	33972	3776 [a]	860 [a]
CT	27608	3267 [b]	751 [b]
$LSD_{0.05}$	*ND*	*425*	*76*

Values followed by the same letter in columns show no significant differences ($P < 0.05$)

ND = not determined as organic C analysis was done on composite sample.

Tillage effect on earthworm population

An important effect of earthworms in soil system is to increase soil biological fertility by enhancing nutrient cycling. Earthworm consume large amounts of soil organic matter and influence the supply of plant nutrients in the soil by increasing the rate of mineralization of crop residue and by making further mineralization by micro-organisms (De Vleeschauwer and Lal, 1981).

In this study, earthworm population and live biomass was significantly higher in the PP and NT than in CT treatment and were in the order of PP > NT > CT (Table 4.6). The amount of crop residue cover on the soil surface and low soil disturbance under PP and NT treatments were most likely factors which encouraged earthworm population. These results are similar to those reported by other researchers (House, 1985; Francis et al., 1987; Francis and Knight, 1993 and Karlen et al., 1994).

This data (Table 4.6) when compared with the data collected the previous year in July, 1996 from the same experimental plots by Guo (1997), the

earthworm population further decreased by 31% in CT, increased by 30 and 27% in NT and in PP respectively. These results further confirmed that continuous tillage practices had major deleterious impact on earthworm population. The greater the intensity and frequency of tillage, the lower the population density of earthworms as suggested by many previous researchers (Gerard and Hay, 1979; Mackay and Kladivko, 1985). These results further suggest that earthworm population can be maintained by providing an effective environment to their needs, e.g. least soil disturbance and high surface residue as that in NT. Therefore, a NT cropping system can enhance soil fertility by encouraging earthworm population.

Table 4.6 Soil pH & earthworm population in PP, NT & CT (June, 1997).

Treatment	Earthworm population (numbers m^{-2})	Earthworm live mass (g m^{-2})	Soil pH (0-100 mm)
PP	429 [a]	140 [a]	5.43 [a]
NT	363 [b]	99 [b]	5.44 [a]
CT	110 [c]	33 [c]	5.48 [a]
$LSD_{0.05}$	*48*	*23*	*0.13*

Values followed by the same letter in columns show no significant differences ($P < 0.05$)

4.4 Tillage interactions with microbial biomass C, N & P

At the start of summer season in November, 1996, first soil samples were collected from 0-100 mm depth before planting fodder maize. Second sets of soil samples were collected at two depths, 0-50 and 50-100 mm, immediately after maize harvest in autumn (April, 1997). The third set of soil samples were collected after oat crop harvest in winter (July, 1997) at 0-50 and 50-100 mm depths. Another concurrent study had highlighted that majority of pasture roots were distributed in the surface 50 mm depth and have a pronounced rhizosphere effect on microbial biomass and its activity

as compared to subsoil. Therefore, it was decided to seperately analyse the soil samples at these two depths. Furthermore, these samples were used to determine effect of tillage depth on microbial biomass C, N and P status as well as to assess seasonal changes in microbial biomass contents.

4.4.1 Effect of tillage on microbial biomass carbon

Tillage practices significantly affected microbial biomass carbon (MBC) contents during the three seasons (Table 4.7). The PP and NT contained similar but significantly higher amount of MBC compared to CT treatment. During summer season, MBC contents at 0-100 mm depth were 844 kg C ha^{-1} in PP, 947 kg C ha^{-1} in NT and 596 kg C ha^{-1} in CT, respectively.

In autumn and winter the soil samples at 0-50 and 50-100 mm depths were taken separately (Table 4.8). In general, MBC contents were higher in the 0-50 mm depth as compared to 50-100 mm depth. However, MBC contents in CT treatment did not differ significantly at both depths. MBC levels at 0-50 mm depth were nearly twice as much in PP and NT as compared to CT plots (Table 4.8). Samples from 50-100 mm soil depth showed no significant differences in MBC among the three treatments. This is clearly appeared to be because crop residues and organic compounds were deposited and retained at the soil surface in PP and NT, whereas in CT were uniformly mixed throughout the soil profile of tillage depth. Similar findings were also reported earlier by Carter and Rennie (1982) and Carter (1986).

When considering combined depth of 0-100 mm, MBC contents declined by 29% within two years of converting pastures to double forage cropping with CT. No such decline in MBC occurred with NT cropping. The significantly lower level of MBC (46%) at 0-50 mm depth in CT compared to NT indicated that CT over two years had markedly decreased MBC near soil surface. The greater MBC levels in NT were possibly due to less soil disturbance and accumulation of more crop residues. The NT has an

advantage in retaining greater crop residues which resulted in build up of more MBC. In CT treatment, the crop residues were mixed to a greater depth and resulted in loss of surface organic matter and subsequently MBC through oxidation. High MBC has been suggested as an indicator of an enlarging pool of soil organic matter (Powlson et al., 1987).

Table 4.7 MBC status in a silt loam soil after two years of NT and CT cropping following permanent pasture (PP).

Treatment	Microbial biomass carbon (kg ha^{-1})			
	Summer Nov, 1996	Autumn April, 1997	Winter July, 1997	Mean
	0-100 mm	0-100 mm	0-100 mm	0-100 mm
PP	844 [a]	1023 [a]	762 [a]	876
NT	947 [a]	1016 [a]	786 [a]	916
CT	596 [b]	749 [b]	526 [b]	624
LSD $_{0.05}$	*197*	*123*	*71*	-

Values followed by the same letter in columns show no significant differences (P < 0.05)

Table 4.8 MBC status in a silt loam soil at different depths after two years of NT and CT cropping following permanent pasture.

Treatments	Microbial biomass carbon (kg ha^{-1})			
	Autumn (April, 1997)		Winter (July, 1997)	
	0-50 mm	50-100 mm	0-50 mm	50-100 mm
PP	642 [a]	379 [a]	476 [a]	286 [a]
NT	636 [a]	380 [a]	491 [a]	295 [a]
CT	349 [b]	400 [a]	258 [b]	268 [a]
LSD $_{0.05}$	*78*	*69*	*57*	*42*

Values followed by the same letter in columns show no significant differences (P < 0.05)

These data confirm earlier findings by a number of researchers both in New Zealand and overseas. Higher proportions of MBC in reduced tillage practices compared to conventional tillage have also been observed previously by Carter and Rennie (1982) and Carter (1991). In Manawatu soils, Sparling et al. (1992) found that 14 years of continuous maize cultivation resulted in a decline of 49 % in total C and 60 % in microbial C compared with the levels under permanent pasture.

4.4.2 Effect of seasonal changes on MBC

Seasonal variations in MBC were observed during summer, autumn and winter period (Figure 4.2). The MBC content in all the three treatments during autumn were significantly higher as compared to summer and winter periods and were in order of autumn > summer = winter. These results showed that in autumn, quantitatively MBC contents were 22% higher in PP, 15% in NT and 25% in CT as compared to levels obtained in summer or winter. These results indicated an enhancement in MBC during autumn period, which could be most probably due to moderate warm environment for microbial biomass activity and high availability of root mass in surface soil, which could have helped to enhance MBC contents during the autumn period.

The decline in MBC following winter oat harvest was probably related to the climatic conditions. Soil moisture content increased and soil temperature declined during winter resulted in reduced soil microbial growth and activity. This was not totally unexpected as it has been suggested earlier that seasonal changes often stimulate a change in the size of the soil microbial biomass (Lynch and Panting, 1980; Carter and Rennie, 1982).

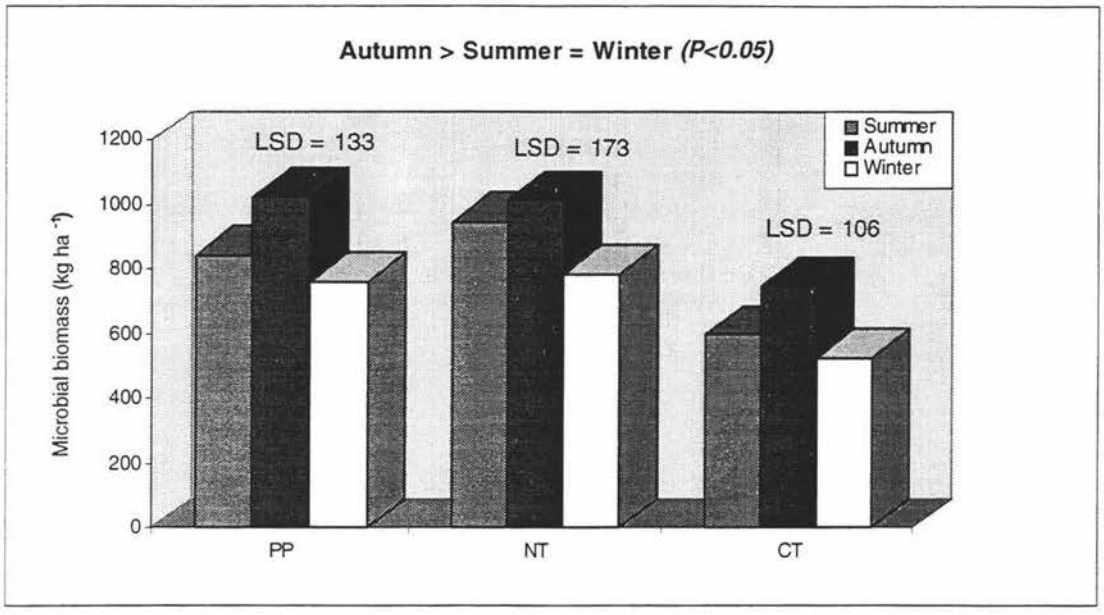


Fig. 4.2 Seasonal changes in MBC at 0-100 mm depth in PP, NT and CT management.

However, the results from the present study clearly show that short-term changes caused by tillage practices also have an impact on MBC levels and suggest that MBC can be used as an index for detecting land management and seasonal effects. The long-term beneficial effects of crop rotation on microbial biomass have been demonstrated by Granatstein et al. (1987). Powlson et al. (1987) and Carter (1986) have suggested that MBC can be a good indicator for detecting management effects on soil biological or biochemical properties before any other seasonal or crop rotation changes can be detected.

4.4.3 Effects of tillage on microbial biomass nitrogen

The nitrogen turnover in soil is mainly influenced by the microbial biomass. The microbial biomass nitrogen (MBN) contains an important pool of easily mineralized N, and is essential for N transformations in the soils (Jenkinson, 1988). Therefore, the amount of MBN is another measure of biological active soil N pool that has the potential to provide plant available N.

In these experiments, tillage practices significantly affected MBN during the three seasons (Table 4.9). The treatment and seasonal effects of tillage on MBN were similar to those observed for MBC. MBN (averaged over three seasons) accounted for 2.63% of total N in PP, 2.79% in NT and 2.14% in CT, respectively. These values obtained are within the reported MBN range of 1-5% as suggested by Smith and Paul (1990). Combined data from 0-100 mm depth showed that PP and NT contained significantly higher amount of MBN content as compared to CT treatment.

When the two depths were analysed separately, significant differences in MBN values were also found. The MBN levels at 0-50 mm depth were in order of PP = NT > CT (Table 4.10). However, at 50-100 mm depth, there were no significant differences between the three treatments. Moreover, MBN in PP and NT were higher at 0-50 mm depth as compared to 50-100 mm depth, but in CT treatment, there were no differences between depths.

These results suggested that N in the microbial biomass is closely associated with C. Reduced MBN was result of reduction in the topsoil organic matter content and MBC in CT treatment. Inversion and mixing of crop residue by CT influenced MBN levels only at 0-50 mm depth. Overall results indicate that NT sustained the soil C status equivalent to that in PP and also helped in building up the microbial N pool.

4.4.4 Effect of seasonal changes on MBN

In all three treatments, seasonal changes in MBN followed similar pattern as those of MBC and were in order of summer = autumn > winter (Fig. 4.3). The increase in MBN during summer and autumn as compared to winter may be an indirect result of greater mineralizable C at that period.

Table 4.9 Effect of tillage practices and permanent pasture on MBN.

	Microbial biomass nitrogen (kg ha^{-1})		
Treatment	Summer Nov, 1996 0-100 mm	Autumn April, 1997 0-100 mm	Winter July, 1997 0-100 mm
PP	113 [a]	116 [a]	81 [a]
NT	116 [a]	121 [a]	80 [a]
CT	80 [b]	74 [b]	56 [b]
LSD $_{0.05}$	*27.32*	*20.64*	*11.92*

Values followed by the same letter in columns show no significant differences (P < 0.05)

Table 4.10 MBN status in PP, NT and CT at two soil depths.

Treatments	Microbial biomass nitrogen (kg ha^{-1})			
	Autumn (April, 1997)		Winter (July, 1997)	
	0-50 mm	50-100 mm	0-50 mm	50-100 mm
PP	78 [a]	39 [a]	53 [a]	29 [a]
NT	82 [a]	39 [a]	50 [a]	30 [a]
CT	32 [b]	42 [a]	29 [b]	27 [a]
LSD $_{0.05}$	*17*	*10*	*11*	*6*

Values followed by the same letter in columns show no significant differences (P < 0.05)

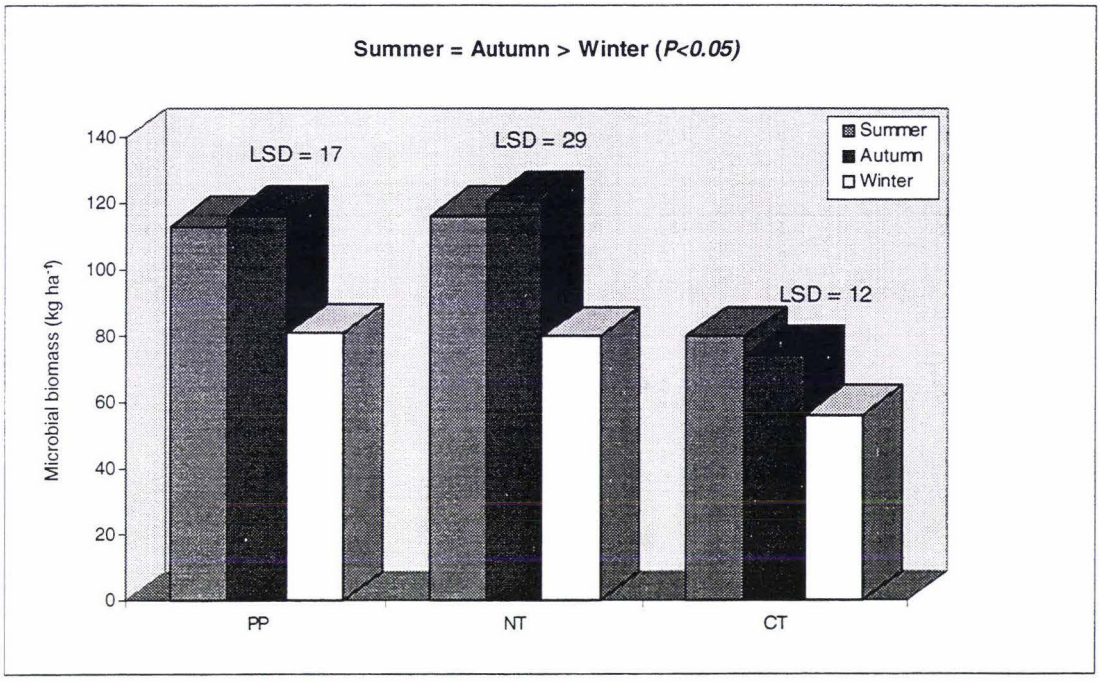


Figure 4.3 Seasonal changes in MBN in PP, NT & CT management.

4.4.5 Effect of tillage on microbial biomass phosphorus

In New Zealand, soils generally have a low available P status and P fertiliser is usually applied at the time of planting crops. However, the effects of P cycling in relation to soil nutrient status is of significant importance. Soil microbial biomass plays a central role in the cycling of soil phosphorus (Stewart and Tiessen, 1987). Indeed, micro-organisms are important both as a sink for phosphorus and in the production of enzymes such as phosphatases and hydrolases, which catalyse the mineralization of organic-P (Jenkinson and Ladd, 1981). Microbial biomass phosphorus (MBP) enables aspects of P cycling in soils to be monitored directly (Vance et al., 1987; Hedley and Stewart, 1982).

Tillage practices significantly affected MBP contents during three seasons (Table 4.11). The pooled data suggested that MBP concentration at 0-100 mm depth in PP and NT were similar but significantly higher than CT and were in order of PP = NT > CT. Moreover, the data of autumn and winter at 0-50 mm and 50-100 mm followed similar pattern as obtained for MBC and

MBN (Table 4.12). As expected, these losses in MBP reflected the decline in soil organic matter in the CT treatment. It is estimated that MBP contribution to total P in the soil ranges from 2.7-19.1 % (Smith and Paul, 1990). In this study, MBP (averaged over three seasons) accounted for 7.7, 8 and 6% of the total P in PP, NT and CT treatments, respectively. All these values were within the range suggested by Smith and Paul (loc.cit.).

Table 4.11 Effect of tillage practices and permanent pasture on MBP.

	Microbial biomass phosphorus ($kg\ ha^{-1}$)		
Treatment	Summer Nov, 1996 0-100 mm	Autumn April, 1997 0-100 mm	Winter July, 1997 0-100 mm
PP	66 [a]	59 [a]	81 [a]
NT	69 [a]	55 [a]	85 [a]
CT	48 [b]	39 [b]	50 [b]
$LSD_{0.05}$	*13.01*	*6.71*	*7.0*

Values followed by the same letter in columns show no significant differences ($P < 0.05$)

Table 4.12 MBP status in PP, NT and CT at 0-50 and 50-100 depths.

Treatments	Microbial biomass phosphorus ($kg\ ha^{-1}$)			
	Autumn (April, 1997)		Winter (July, 1997)	
	0-50 mm	50-100 mm	0-50 mm	50-100 mm
PP	38 [a]	21 [a]	54 [a]	27 [a]
NT	37 [a]	18 [a]	57 [a]	27 [a]
CT	19 [b]	20 [a]	26 [b]	24 [a]
$LSD_{0.05}$	*5*	*3*	*7*	*4*

Values followed by the same letter in columns show no significant differences ($P < 0.05$)

4.4.6 Effect of seasonal changes on MBP

Seasonal responses in MBP (Fig. 4.4) showed a different pattern from those seen for MBC and MBN. The MBP in PP and CT during winter were significantly higher than in summer and autumn. Whereas in NT significant differences were found between the three seasons. The MBP increase in winter period indicated a marked gain of P from biomass which could be due to higher application of Nitrophoska fertilizer (200 kg ha^{-1}) at the time of planting oats in April, 1997. This result also suggested that phosphorus taken up by the plants was less during winter season. The fluctuations in MBP observed in the present study was similar to those reported in the literature. Buchanan and King (1992) observed an increase in MBP during winter and early spring period and a decline in autumn and late spring. In Manawatu soils, Saggar et al. (1994) also observed a marked seasonal pattern for MBP, with microbial P greater in spring and summer than autumn and winter. The MBP values ranging between 15-82 kg P ha^{-1} were closely related to Olsen P values.

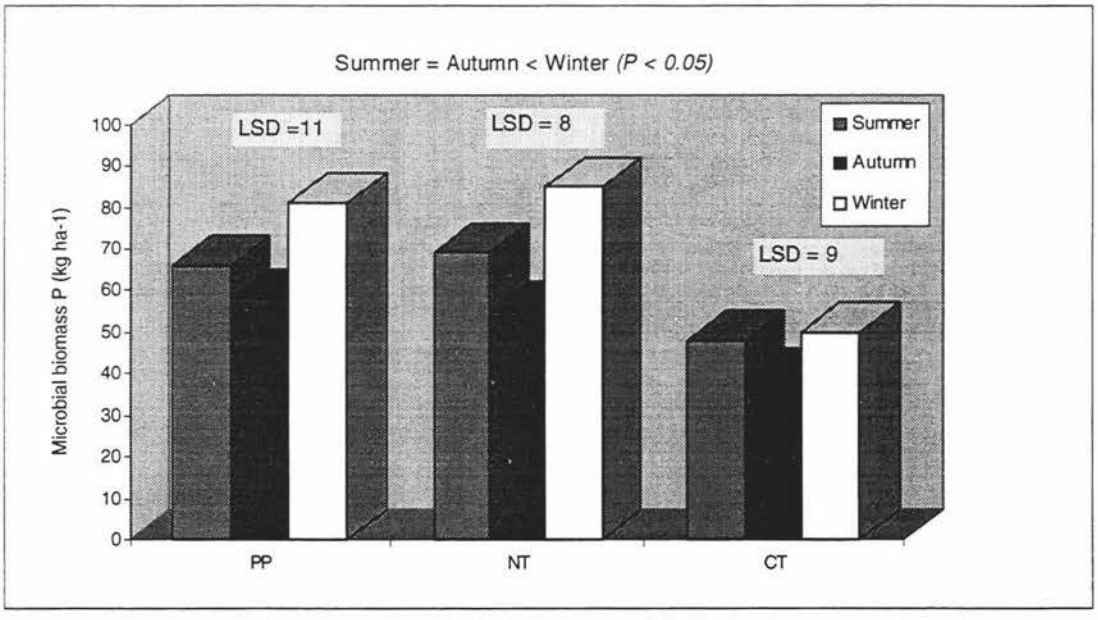


Fig. 4.4 Seasonal changes in MBP(0-100 mm) in PP, NT and CT.

4.4.7 Summary

These results indicate that tillage practices have a significant effect on total C, N, and P contents, earthworm population as well as microbial C, N and P concentrations.

Two years of CT after PP resulted in 29% decline in microbial C, 33% in microbial N and 34% in microbial P when measured at 0-100 mm soil depth. This decline in microbial biomass is an early indication of possible future decline in soil organic matter with CT practices.

Microbial nutrients in NT were markedly higher than for CT at 0-50 mm depth (Table 4.13). The ratio of microbial biomass in NT/CT showed that the MBC, MBN and MBP were almost twice as much in NT as compared to CT at 0-50 mm soil depth. However, no quantatative differences in microbial biomass nutrients occurred in 50-100 mm depths between the two tillage treatments.

Table 4.13 Ratios of microbial nutrients between NT and CT at two soil depths.

Microbial nutrients	Ratio NT/CT	
	0-50 mm	50-100 mm
Microbial biomass carbon (MBC)	1.85	1.01
Microbial biomass nitrogen (MBN)	2.16	1.00
Microbial biomass phosphorus (MBP)	2.08	1.02

Values in columns represents means of 4 replicates each

After fodder maize harvest in autumn resulted in an increased MBC and MBN levels as compared to late spring/early summer fallow period and winter season (cold temperature with high moisture levels). This is an indication that microbial biomass activity was enhanced during moderately warm but wetter period following rather dry or cold periods of the year.

4.5 Tillage effects on basal soil respiration

Basal or Laboratory soil respiration is the amount of CO_2 released by living and metabolizing entities of soil microbial biomass, which are the agents responsible for respiration (Anderson, 1982). Basal respiration has been widely used to determine biological activity in soil in relation to changes in climatic, soil physical and chemical properties, and in agricultural management practices (Nannipieri et al., 1990; Costantini et al., 1996; and Saggar et al., 1997).

In these laboratory experiments, basal soil respiration was measured to assess the activities of microbial biomass under PP, NT and CT practices. The soil samples collected in autumn (April, 1997) from two different depths for microbial biomass measurements were used for measuring basal soil respiration. These samples were incubated in controlled temperature room set at 25 ^{0} C. The amount of CO_2 respired were measured by G. C. analyzar on weekly basis for a period of 6 weeks.

In this study, basal soil respiration was high in the 1st week and then reached an equilibrium levels in the following weeks. This was not unexpected and is probably the effect of sieving moist soil samples which may have released labile root C for immediate microbial growth and respiration. It is not uncommon to pre-incubate sieved soil samples for a week before measuring the basal respiration. Therefore, for calculating the mean daily respiration rate, week 1 values were not considered.

The results obtained from 0-50 mm and 50-100 mm depth samples are summarised in Tables 4.14 and 4.15. The PP and NT treatments had similar but significantly higher basal soil CO_2-C evolved at 0-50 mm depth as compared to CT treatment (Table 4.14). The cumulative basal soil respiration (averaged over five weeks) at 0-50 mm depth were 19, 16 and 10 mg CO_2-C kg^{-1} soil day^{-1} in PP, NT and CT respectively. This suggested that

during five weeks of soil incubation at 25^{0}C, CO_2 emission was 38% higher in NT than in CT treatments. Such high levels of basal soil CO_2-C emission indicated that there was more soil carbon substrate and microbial activities in NT treatment as shown in section 4.4.1. NT treatment had increased surface organic matter which reflected in high microbial biomass population and soil respiration.

Basal respiration in the 50-100 mm soil depth were significantly higher in CT compared to PP and NT treatments except in the 1st and 5th week (Table 4.15).

Table 4.14 Basal soil CO_2 under PP, NT & CT at 0-50 mm depth.

	Basal soil respiration (mg CO_2-C kg^{-1} soil day^{-1})					
Treatment	1st week	2nd week	3rd week	4th week	5th week	6th week
PP	41 ^{a}	22 ^{a}	20 ^{a}	17 ^{a}	18 ^{a}	17 ^{a}
NT	39 ^{a}	18 ^{b}	17 ^{a}	14 ^{b}	15 ^{a}	15 ^{a}
CT	27 ^{b}	12 ^{c}	10 ^{b}	9 ^{c}	10 ^{b}	8 ^{b}
LSD $_{0.05}$	*9.50*	*3.61*	*3.68*	*2.71*	*3.45*	*4.03*

Values followed by same the same letter in columns show no significant differences (P<0.05)

Table 4.15 Basal soil CO_2 under PP, NT & CT at 50-100 mm depth

	Basal soil respiration mg CO_2-C kg^{-1} soil day^{-1}					
Treatment	1st week	2nd week	3rd week	4th week	5th week	6th week
PP	34 ^{a}	12 ^{ab}	9 ^{b}	9 ^{ab}	10 ^{a}	8 ^{b}
NT	27 ^{a}	10 ^{b}	9 ^{b}	7 ^{b}	10 ^{a}	8 ^{b}
CT	35 ^{a}	15 ^{a}	12 ^{a}	10 ^{a}	12 ^{a}	10 ^{a}
LSD $_{0.05}$	*11.42*	*4.10*	*2.81*	*1.79*	*2.20*	*1.10*

Values followed by same the same letter in column no significant differences (P < 0.05)

The average (over five weeks) basal soil respiration at 50-100 mm depth were 10, 9 and 12 mg CO_2-C kg^{-1} soil day^{-1} in PP, NT and CT respectively. This suggested that during 5 weeks of soil incubation at 25^0C, CO_2 emission was 25% higher under CT than NT treatments. This is possible because the CT tends to invert and incorporate the organic matter uniformly within soil tillage profile resulting in relatively high microbial activities near tillage depth.

Franzluebbers et al. (1995) and Costantini et al. (1996) have also found higher 9-12% amount of CO_2 released from NT and reduced tillage as compared to tilled soils. These authors hypothised that tillage caused more distruption and mixing of soil that allowed soil to dry more rapidly, lost form of aggregates, and caused more heat loss during night, and evolved less CO_2 due to reduced concentration of soil organic carbon contents.

4.5.1 Effect on metabolic quotient

In seived soils the amount of CO_2 evolved is mainly due to microbial respiration. Metabolic or respiratory quotient (qCO_2) was obtained by expressing the rate of soil respiration in terms of the microbial biomass by using the data obtained for microbial biomass C values and basal respiration measurements of 1 and averaged of 5 weeks. The qCO_2 values showed no significant differences among the tillage treatments at both depths, except 6th week at 50-100 mm (Table 4.16). Previous results obtained in these experiments indicated that tillage significantly affected MBC and basal soil respiration. The qCO_2 values suggest that the high basal soil respiration in PP and NT treatment resulted from greater microbial biomass. These are not a reflection of differential C use efficiency. These results are similar to those found by Costantini et al.(1996).

Table 4.16 Metabolic quotient (qCO_2) under PP, NT & CT treatments

	Metabolic quotient(qCO_2)			
	1st week		average of 5 weeks	
Treatments	0-50 mm	50-100 mm	0-50 mm	50-100 mm
PP	1.73 [a]	2.32 [a]	0.72 [a]	0.63 [a]
NT	1.58 [a]	1.87 [a]	0.62 [a]	0.59 [a]
CT	1.53 [a]	2.21 [a]	0.63 [a]	0.73 [a]
$LSD_{0.05}$	*0.49*	*0.93*	*0.11*	*0.16*

Values followed by the same letter in columns show no significant differences ($P < 0.05$)

4.6 Tillage impact on field CO_2 emissions

Field soil CO_2 emission serve as an indicator of biological activities and provide an index for carbon budget for an ecosystem. It includes amounts of CO_2 respired by microbial activity as well as plant roots. In this study, field CO_2 emissions were measured every 3 to 4 weeks over a period of one year in CT and NT summer fodder maize and winter oats double crop rotation. These data were compared to that from adjacent PP plots to study likely seasonal changes, and to assess effects of tillage systems on soil biological activities. Field CO_2 emissions were measured using static chamber technique in which an amount of CO_2 respired for 24 hours is absorbed by NaOH alkali solution. Soil moisture content at 0-50 and 50-100 mm depth and soil temperature at 0-50 mm were also measured concurrently. The data obtained throughout the year is discussed below.

4.6.1 Pilot experiment

A pilot experiment was conducted initially to assess the influence of soil moisture content on field CO_2 efflux. Static chambers were installed during fallow period in NT and CT plots and CO_2 emissions were measured before and after rain.

The amount of CO_2 evolved and moisture content of the soil for the three treatments is given in Table 4.17. There was higher CO_2 emission in PP as compared to NT and CT treatments. This was most probably due to high root biomass in PP treatment. A 5 mm of the rainfall on 9.11.96 slightly increasing the soil moisture content and subsequently resulted in increased CO_2 emission in all the treatments. Increase in CO_2 emission was highest in PP (18%) followed by CT(11%) and NT(8%). The results suggested that SMC was one of the key factors controlling the microbial activity and CO_2 emissions.

Table 4.17 Effects of tillage intensity and soil moisture on CO_2 emissions

	(Before rain on 7.11.96)		(After rain on 10.11.96)	
Treatment	Soil CO_2-C (kg ha^{-1} day^{-1})	soil moisture (kg kg^{-1})	Soil CO_2-C (kg ha^{-1} day^{-1})	soil moisture (kg kg^{-1})
PP	58 [a]	0.21 [a]	71 [a]	0.23 [a]
NT	51 [b]	0.21 [a]	56 [b]	0.22 [a]
CT	45 [b]	0.19 [b]	51 [b]	0.20 [b]
$LSD_{0.05}$	*6.93*	*.016*	*10.96*	*.017*

Values followed by the same letter in columns show no significant differences ($P < 0.05$)

4.6.2 Tillage and seasonal effects on field CO_2 emissions

In order to assess the effect of previous tillage intensity for seedbed preparation and crop on the below ground biomass biological activities and seasonal changes, the CO_2 emissions were measured during cropped as well as fallow period in PP, NT & CT management. The monthly field CO_2 emissions data (November 1996 to October 1997) are shown in Table 4.18.

Table 4.18 Monthly field CO_2 emission data from November 1996 to October 1997 from PP, NT & CT managment.

Treatments	Field CO_2 emissions (kg CO_2-C $ha^{-1}day^{-1}$)											
	November (10.11.96)	December (12.12.96)	January (9.1.97)	February (11.2.97)	March (3.3.97)	April (11.4.97)	May (27.5.97)	June (24.6.97)	July (5.7.97)	August (29.8.97)	September (25.9.97)	October (17.10.97)
PP	71 [a]	102 [a]	117 [a]	122 [a]	108 [a]	132 [a]	90 [a]	76 [a]	66 [a]	55 [a]	68 [a]	93 [a]
NT	56 [b]	43 [b]	91 [b]	72 [b]	50 [b]	57 [b]	70 [a]	82 [a]	62 [a]	47 [ab]	44 [b]	76 [b]
CT	51 [b]	36 [b]	81 [b]	62 [b]	49 [b]	75 [b]	82 [a]	79 [a]	58 [a]	38 [b]	36 [c]	73 [b]
$LSD_{0.05}$	*11.09*	*11.09*	*12.96*	*27.68*	*13.91*	*22.90*	*26.16*	*20.88*	*11.09*	*12.61*	*6.12*	*9.85*

Values followed by the same letter in columns show no significant differences ($P < 0.05$)

The results showed a generally higher soil CO_2 efflux from PP as compared to NT and CT treatments (Table 4.18). During one year of the measurements, the CO_2 emissions ranged from 55 -132 kg C $ha^{-1}day^{-1}$ (20-50 t C $ha^{-1}year^{-1}$) in PP, 43-91 kg C $ha^{-1}day^{-1}$ (20-33 t C $ha^{-1}year^{-1}$) in NT and 36-81 kg C $ha^{-1}day^{-1}$ (13-30 t C $ha^{-1}year^{-1}$) in CT treatments respectively. However, the overall results showed prior tillage practices had only minor effects on field CO_2 emissions throughout the period. These results are similar to those reported by Schimel (1986), who compared CO_2 on the soil under cereals, grassland and fallow and found highest soil CO_2 under grassland but lowest under fallow conditions.

During fodder maize growth period (December to March), the tillage practices had little influence on CO_2 emission (Table 4.18). CO_2 emission were highest in January indicating that during early maize growth period in summer, the biological activities were at peak. In February, CO_2 emission decreased by 26% in NT and 30% in CT which corresponded with a decline in soil moisture content of 37% in NT and 40% in CT treatments (Table 4.21). February was also the low rainfall period during that summer (Table 3.1). The PP, however, continued to maintain higher CO_2 emissions as compared to NT and CT treatments even with the decline in soil moisture content. In March, when the crop was fully matured and soil moisture remained low, CO_2 emission decreased. This could be possibly due to the slowing down of biological activities due to dry soil conditions.

The results obtained after land preparation and oats crop establishment in April showed relatively, although insignificantly, higher CO_2 efflux from CT (24%) as compared to NT . Similarly, the CO_2 emissions in May also remained slightly higher in CT (14%) as compared to NT. These results suggested that freshly ploughed land may have enhanced CO_2 emission as compared to untilled soil. However, once cultivated seedbed was recompacted after few weeks, the differences in CO_2 emissions retarded to levels akin to untilled soils. This data

showed some insight into effects on CO_2 efflux of recently cultivated soil as earlier suggested by Reicosky (1997) and additional experiments were deemed necessary to further investigate the tillage impact on short-term CO_2 emissions (see section 4.6.4).

The CO_2 emissions data obtained from June to August (winter) period generally reflected reduced microbial activity irrespective of tillage or cropping system used. This suggested that CO_2 emissions were significantly affected by climate. During winter period, the high rainfall increased the soil moisture content and soil temperature dropped progressively. These two parameters combined together reduced the CO_2 emissions. This phenomena has been observed by a number of other researchers. For example, Hendrix et al. (1988) had earlier found similar trend in CO_2 emissions during winter period from NT, CT and adjacent unmanaged native fields.

During September and October (spring), as the soil warmed up increasing plant growth and soil biological activity, the CO_2 emission levels showed an upturn and significant differences appeared between the treatments. These findings were consistent with those found by Buyanovsky (1986), who suggested that during spring, as the air and soil temperature arose, CO_2 emissions increased.

4.6.3 Seasonal effects on CO_2 emissions

New Zealand has four seasons, but the changes from one season to another occur gradually. Seasonal changes showed significant differences in the CO_2 emissions in all three treatments (Table 4.19). Seasonal variation in CO_2 emission from PP was in order of summer = autumn > winter > spring. Whereas, in the NT seasonal variations in CO_2 emission was in order of summer = autumn > winter = spring. Similarly, in CT the CO_2 emission was in order of summer > autumn = winter = spring.

Table 4.19 Seasonal field CO_2 emissions in PP, NT and CT management

	Field CO_2 emissions (kg CO_2-C ha^{-1} day^{-1})				
Treatment	Summer (Dec-Jan-Feb)	Autumn (Mar-April-May)	Winter (June-July-Aug)	Spring (Sept-Oct-Nov)	*$LSD_{0.05}$*
PP	340 [a]	330[a]	232 [b]	196 [c]	*32*
NT	207 [a]	195 [a]	177 [b]	171 [b]	*16*
CT	206 [a]	178 [b]	175 [b]	165 [b]	*24*

Values followed by the same letter in rows show no significant differences ($P < 0.05$)

The seasonal data shows that CO_2 emissions were generally higher in Manawatu's summer and autumn period as compared to winter and spring. This suggests warm weather promotes favourable environment for biological activities of below ground biomass as compared to winter and spring period. The data also show large seasonal variation in CO_2 emission. Some of this variability was presumably caused by soil moisture and temperature under the climatic limits of the experimental site. It is also possible that the contribution of maize and oat crop roots proliferation during different stages of crop growth period were somehow also effective in their contribution to CO_2 production. The seasonal as well as monthly variations in CO_2 emissions in three treatments are shown in Fig. 4.5. The interrelations among field CO_2 emissions, and the influence of soil moisture and temperature during different months are discussed below.

4.6.3.1 Effect of soil moisture content

Tillage practices had a significant effect on SMC during different months of the year. Across all three treatments the SMC was higher at 0-50 mm depth (Table 4.21) as compared to 50-100 mm depth (Table 4.20). During summer, autumn

and spring seasons, the SMC at 0-50 mm depth were significantly higher in NT as compared to CT. However, at 50-100 mm depth, SMC did not differ significantly between the three treatments. The loss of SMC at 0-50 mm depth in CT in that particular season was most likely through evaporation. Generally, the tillage has been shown to increase evaporation rates and to decrease soil moisture content (Lal, 1991).

Generally, CO_2 emission were affected by SMC. CO_2 efflux declined in the two tillage treatments in the month of February, which had lowest SMC due to dry summer period. However, a number of regression models to obtain a good fit equation between SMC and long-term (monthly) CO_2 emission were used. No one model could accurately predict the influence of SMC on monthly CO_2 emission data (Fig. 4.6). These relationships suggested that the long-term CO_2 emission measurements where crop growth, root respiration, variations in SMC and soil temperature are involved, it was difficult to isolate influence of SMC on CO_2 emission.

Table 4.20 Soil moisture content at 50-100 mm depth during CO_2 emission measurement in PP, NT and CT management.

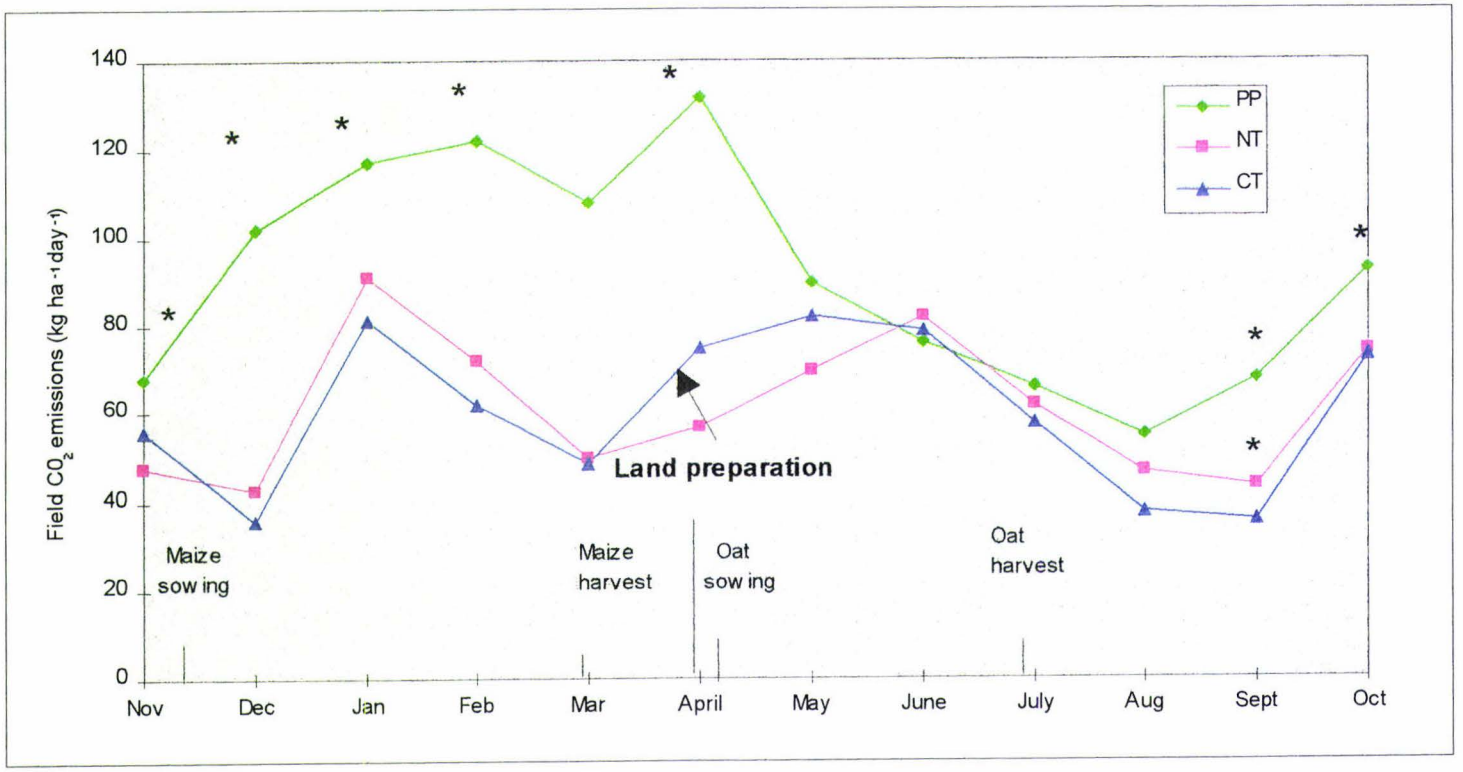
	Gravimetric moisture content (kg kg^{-1})					
Treatment	March (3.3.97)	April (11.4.97)	May (27.5.97)	July (5.7.97)	September (25.9.97)	October (17.10.97)
PP	0.17 [a]	0.30 [b]	0.25 [b]	0.28 [a]	0.32 [a]	0.34 [a]
NT	0.19 [a]	0.32 [ab]	0.27 [a]	0.29 [a]	0.32 [a]	0.34 [a]
CT	0.19 [a]	0.35 [a]	0.26 [ab]	0.30 [a]	0.32 [a]	0.32 [a]
$LSD_{0.05}$	*.028*	*.046*	*.024*	*.028*	*.039*	*.032*

Values followed by the same letter in columns show no significant differences ($P < 0.05$)

Table 4.21 Soil moisture content at 0-50 mm depth during CO_2 emission measurements in PP, NT and CT management.

	Gravimetric moisture content (kg kg^{-1})										
Treatment	December (12.12.96)	January (9.1.97)	February (11.2.97)	March (3.3.97)	April (11.4.97)	May (27.5.97)	June (24.6.97)	July (5.7.97)	August (29.8.97)	September (25.9.97)	October (17.10.97)
PP	0.23 ^{b}	0.25 ^{ab}	0.16 ^{a}	0.21 ^{b}	0.37 ^{a}	0.31 ^{b}	0.28 ^{a}	0.34 ^{a}	0.48 ^{a}	0.38 ^{a}	0.46 ^{a}
NT	0.28 ^{a}	0.26 ^{a}	0.16 ^{a}	0.25 ^{a}	0.36 ^{ab}	0.35 ^{a}	0.27 ^{a}	0.35 ^{a}	0.44 ^{a}	0.39 ^{a}	0.41 ^{a}
CT	0.24 ^{b}	0.23 ^{b}	0.18 ^{a}	0.18 ^{b}	0.32 ^{b}	0.31 ^{ab}	0.26 ^{a}	0.30 ^{a}	0.35 ^{b}	0.31 ^{b}	0.32 ^{b}
$LSD_{0.05}$	*.028*	*.031*	*.036*	*.041*	*.041*	*.044*	*.044*	*.017*	*.063*	*.047*	*.053*

Values followed by the same letter in columns show no significant differences ($P < 0.05$)



* ***LSD = P < 0.05*** (PP > NT= CT)

Fig. 4. 5 **Seasonal variation in field soil CO_2 emission rate from November 1996 to October 1997 in PP, NT & CT management.**

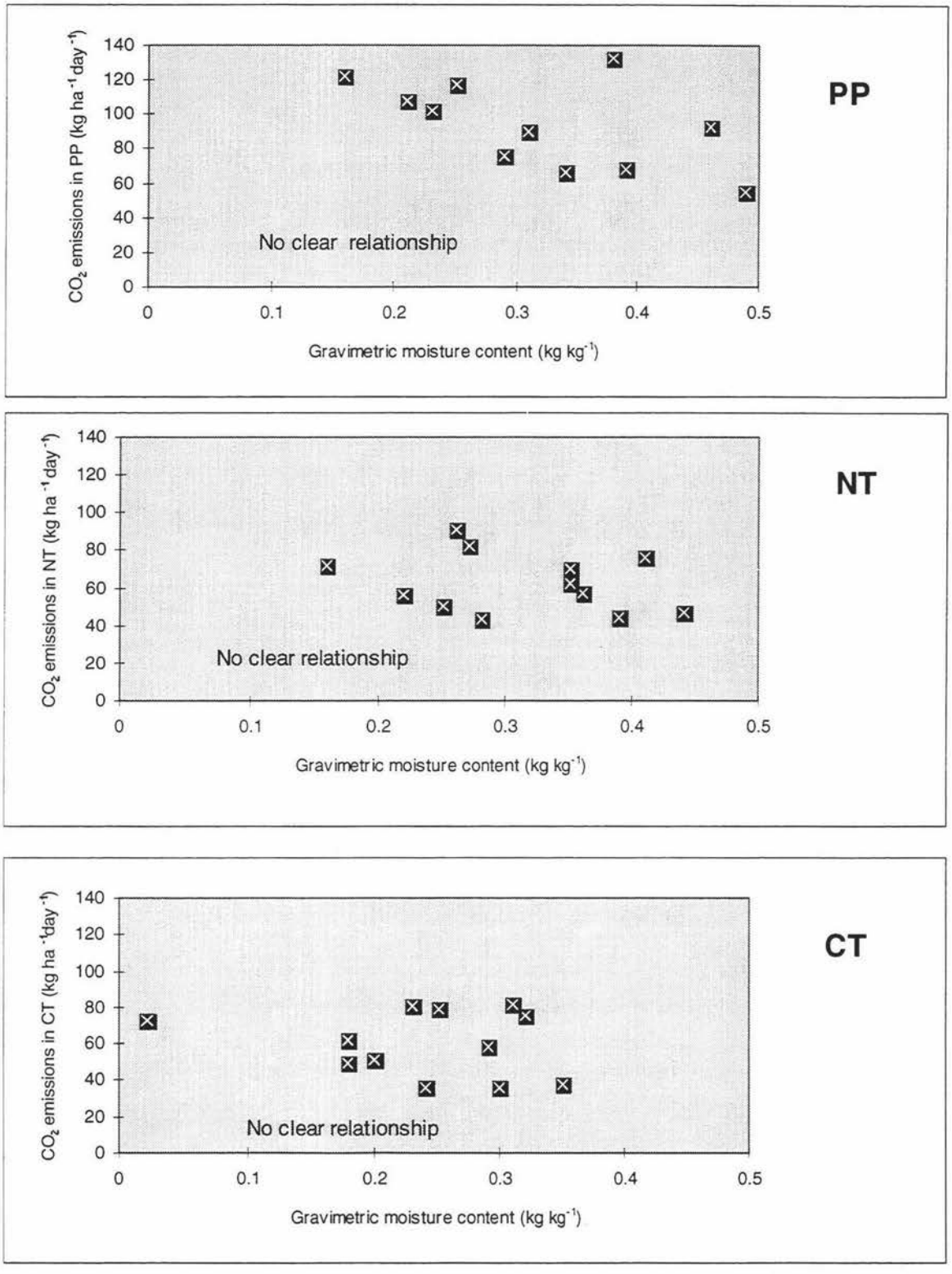


Fig. 4.6 Regression analysis between SMC and long-term CO_2 emissions (monthly) in PP, NT and CT management.

4.6.3.2 Effect of soil Temperature

Soil temperature at 50 mm depth was measured to determine likely tillage effect on soil temperature and on CO_2 emission. The soil temperature was measured in the morning, afternoon and evening at the time of CO_2 emission measurements to determine the maximum and minimum temperature range on that particular day (Table 4.22).

Soil temperature (at 50 mm depth) did not differ between PP, NT and CT treatments (Table 4.22). This was not unexpected as the three treatments were in the same vicinity and had same ambient temperature.

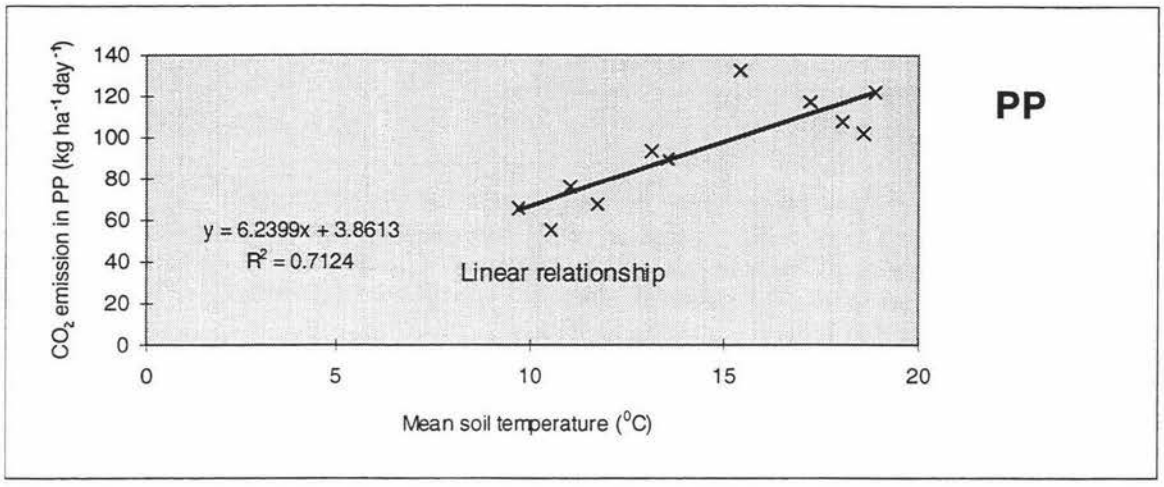
Generally, soil temperature appeared to affect CO_2 emission only in PP treatment during winter period. This was reflected by a significant decline in CO_2 emission in PP treatment during winter period (May-July). However, during the winter period, soil temperature had no effect on CO_2 emission between the two tillage treatments. Due to an increase in temperature in August to October (spring period), the CO_2 emission levels increased and also showed significant differences between the treatments.

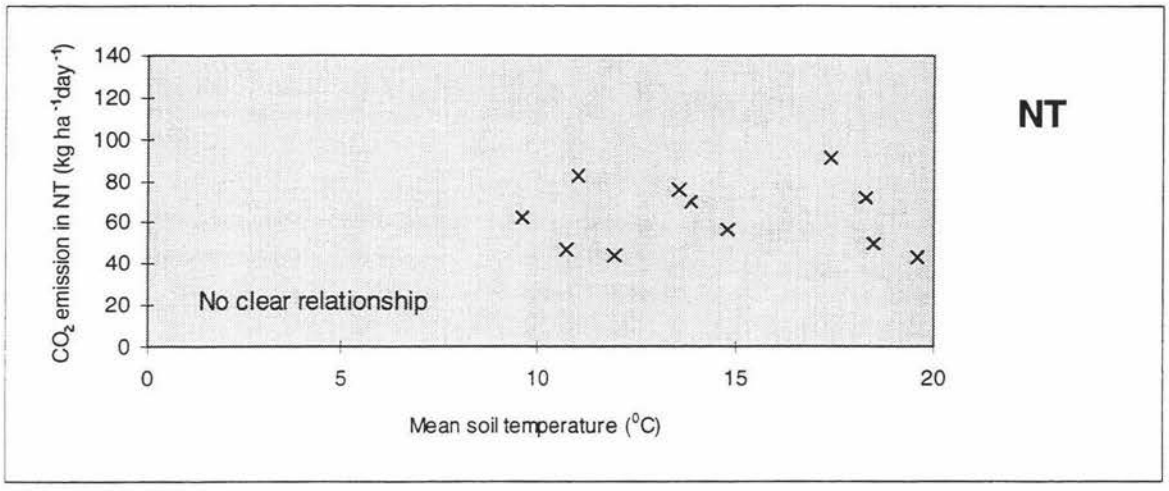
Regression analysis between soil temperature (50 mm depth) and CO_2 emission for the three treatments were also computed. A linear relationship ($r=0.83$) was found only in PP (Fig. 4.7). However, no significant relationship was found between CO_2 emission and soil temperature in the two tillage treatments (Fig. 4.7). These findings show that CO_2 emission were effected by soil temperature in PP because temperature fluctuations during different months of the year enhanced or limited pasture growth and rhizosphere activity. Whereas in NT and CT, crop growth probably had a pronounced effect on CO_2 emissions and therefore, had confounding effects.

Table 4.22 Soil temperature at 50 mm depth during CO_2 emission measurements in PP, NT and CT management.

Treatment	Soil temperature (^{0} C) at 50 mm depth																					
	December (12.12.96)		January (9.1.97)		February (11.2.97)		March (3.3.97)		April (11.4.97)		May (27.5.97)		June (24.6.97)		July (5.7.97)		August (29.8.97)		September (25.9.97)		October (17.10.97)	
	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
PP	21.4	15.8	18.6	15.7	18.9	17.0	20.3	15.8	18.3	12.5	15.6	12.5	11.7	10.5	12.5	6.9	11.5	9.8	14.4	9.2	16.2	10.3
NT	22.1	17.1	18.7	16.1	19.6	17.0	20.8	16.1	17.4	12.3	15.4	12.4	11.9	10.4	12.3	6.9	12.0	9.6	14.7	9.4	16.9	10.4
CT	21.7	16.8	18.5	16.7	18.9	17.1	19.8	15.4	17.3	11.4	15.5	12.2	12.5	10.3	12.3	6.6	12.0	9.8	15.3	9.4	17.4	10.4

values in each columns show mean of 4 replicates





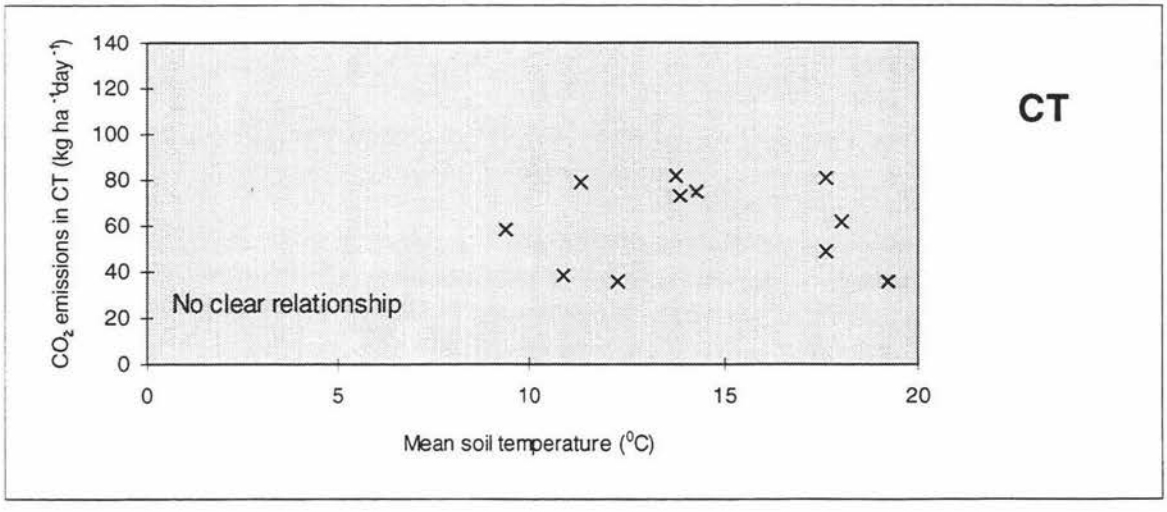


Fig. 4.7 Regression analysis between soil temperature at 50 mm depth and CO_2 emission rates in PP, NT and CT management.

4.6.4 Tillage induced changes in short-term CO_2 emission

The year-round seasonal data on CO_2 emission showed that intensity or lack of tillage for seedbed preparation generally had little impact on CO_2 emissions. However, CO_2 emissions data a week after land preparation and sowing of winter oats showed that the CO_2 emission levels in CT were comparatively 15-24% higher than NT treatment. This led to a belief that tillage may have enhanced soil respiration and encouraged the CO_2 emissions as reported by a number of studies (Reicosky, 1990; Reicosky and Lindstrom, 1993; Reicosky et al.,1990, 1995, 1997; and Dugas et al.,1997).

To examine the immediate impact of tillage operations on CO_2 emission, another experiment was conducted at the same site and treatments. At the time of land preparation for planting fodder maize crop on 28th October, 1997, static chambers to trap CO_2 were installed in all the plots within two hours of the primary tillage. In CT, CO_2 measurements were cummulated for first 4 hours, 4-15 hours and 15-20 hours to obtain the amount respired in 24 hrs. This data was compared with that obtained at the same time from NT and PP treatments. Soil gravimetric moisture content at 0-50 mm and 50-100 mm depth was obtained in close proximity to the CO_2 emissions measurement areas.

The data obtained for short-term CO_2 emission showed significant differences between the three treatments (Table 4.23). Once again, the PP had a higher CO_2 emission than the two tillage practices. These results also showed significantly higher CO_2 emission in NT as compared to CT treatment. These data were similar to those found by Hendrix et al. (1988), who observed greater soil CO_2 efflux from NT than from CT soils.

Cultivation seemed to have reduced CO_2 emission as compared to NT within first three days of cultivation (Table 4.23). These findings contradicted to those of

Reicosky (1997), who was emphatic in suggesting that soil tillage encouraged oxidation of C, resulting in high CO_2 emission (290 kg ha^{-1} hr^{-1}) compared with no-till. However, a probable explanation for the present results could be that bottom layer of the ploughed soil had limited micro-organisms present, which did not encourage much soil respiration. Another possible reason could be that as ploughing fractured soil pores, it released CO_2 within minutes. Since in this study, first CO_2 measurements were taken 4 hours after ploughing, possibly most of CO_2 may have effluxed prior to beginning of measurements. Such findings were earlier reported by Steensel (1995), who had suggested that the soil was turned over, the substrate for the micro-organisms disappeared from the top 5 cm and gave a significant drop in soil respiration.

Table 4.23 Short-term field CO_2 emissions in PP, NT and CT practices

	CO_2 emissions (kg CO_2-C ha^{-1} day^{-1})							
	Days 1-3 after ploughing and Days 5-11 after power harrow							
Treat	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 11
PP	118 [a]	124 [a]	109 [a]	113 [a]	ND	ND	98 [a]	85 [a]
NT	92 [b]	97 [b]	88 [b]	90 [b]	ND	ND	80 [b]	38 [b]
CT	35 [c]	50 [c]	40 [c]	73 [c]	80	81	62 [c]	26 [c]
$LSD_{0.05}$	*11.33*	*21.74*	*13.27*	*9.11*	-	-	*6.80*	*9.86*

Values followed by the same letter in columns show no significant differences ($P < 0.05$)

ND = not determined

To confirm this phenomenon, a power harrow was operated for seedbed preparation on 4th day after mouldboard ploughing. Within minutes after the operation, the CO_2 emission samples were collected.

Data obtained gave somewhat different results. CO_2 emissions levels in CT markedly increased by 45% from the previously mouldboard ploughed surface. These results suggested that soil cultivation, shattering and mixing by a tool like power harrow may have immediately increased soil aeration which stimulated soil biological activities. This is also probably due to degasing from soil pores and mixing of organic matter after turning the soil, which speeded up the decomposition process for soil micro-organisms.

These results further suggested that mouldboard ploughing followed by immediate power harrowing may increase soil aeration and may enhance CO_2 emission above levels of untilled soil. On the other hand, the NT still had significantly higher CO_2 emissions as compared to CT. This might be due to the higher availability of carbon substrate in the NT treatment.

Not withstanding, it would be realistic to suggest that interrelationship between tillage intensity and CO_2 efflux were complex, and rather difficult to fully explain. Further detailed experiments were needed to more comprehensively understand such relationships.

4.6.4.1 Effect of soil moisture content

Soil moisture content (SMC) data showed that SMC were in the order of PP > NT > CT during each day of the measurement. Moreover, in all the three treatments the SMC was higher at 0-50 mm depth (Table 4.24) as compared to 50-100 mm depth (Table 4.25). SMC at 0-50 mm were higher in NT as compared to CT treatment. Higher SMC in NT was most likely due to higher soil organic matter and less soil surface disturbance, whereas in CT the SMC was lost most likely through evaporation after cultivation.

SMC fluctuations at both depths were also observed during each day. No rainfall occurred during these days. Generally, as SMC decreased from day 1 to day 11, field CO_2 emissions were significantly reduced. In PP, with a decrease of 25% in SMC, there was a proportional drop in CO_2 emissions levels. In NT, with 25% drop in SMC, CO_2 emissions levels dropped by 58%. Similarly, in CT, with SMC reduction of 36%, a 25% drop in CO_2 emissions levels were observed.

Regression analysis show a strong relationship between SMC and short-term (daily) CO_2 emissions in both PP and NT treatments. A linear relationship was existed in the PP (r=0.96) and NT (r=0.90) treatments (Fig.4.8). These findings suggested that the daily CO_2 efflux was affected by changes in SMC in the PP and NT, where no soil disturbance occurred and uniform conditions prevailed. On the other hand, a poor relationship existed between SMC and CO_2 efflux in CT (r=0.59) treatment as shown in Fig. 4.8. This could be possible because in CT treatment, the soil was cultivated two times with power harrow and the residual material was mixed together. Therefore, it was possible that because of lack of surface organic matter and loose soil conditions, the SMC did not directly influence CO_2 efflux in tilled soil as it did in untilled conditions.

Table 4.24 Soil moisture content at 0-50 mm depth during short-term field CO_2 emissions in PP, NT and CT practices.

	Gravimetric moisture content (kg kg^{-1}) after ploughing (1-3 days) and power harrowing (5-11 days)							
Treat	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 11
PP	0.37	0.38	0.35	0.33	0.31	0.28	0.28	0.23
NT	0.36	0.36	0.33	0.32	0.30	0.27	0.26	0.21
CT	0.30	0.25	0.23	0.24	0.20	0.20	0.19	0.18

Values in each columns are means of two replicates, therefore no statistical analysis was performed on these data.

Table 4.25 Soil moisture content at 50-100 mm depth during short-term field CO_2 emissions in PP, NT and CT practices.

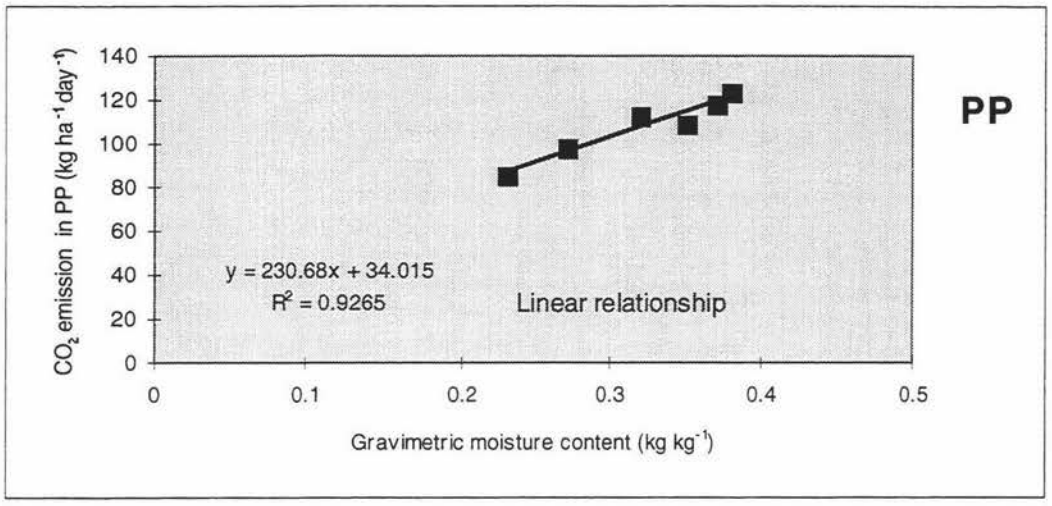
	Gravimetric moisture content (kg kg^{-1}) after ploughing (1-3 days) and power harrowing (5-11 days)							
Treat	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 11
PP	0.34	0.24	0.31	0.27	0.26	0.25	0.25	0.24
NT	0.34	0.27	0.30	0.29	0.29	0.26	0.27	0.26
CT	0.32	0.27	0.26	0.28	0.28	0.27	0.27	0.26

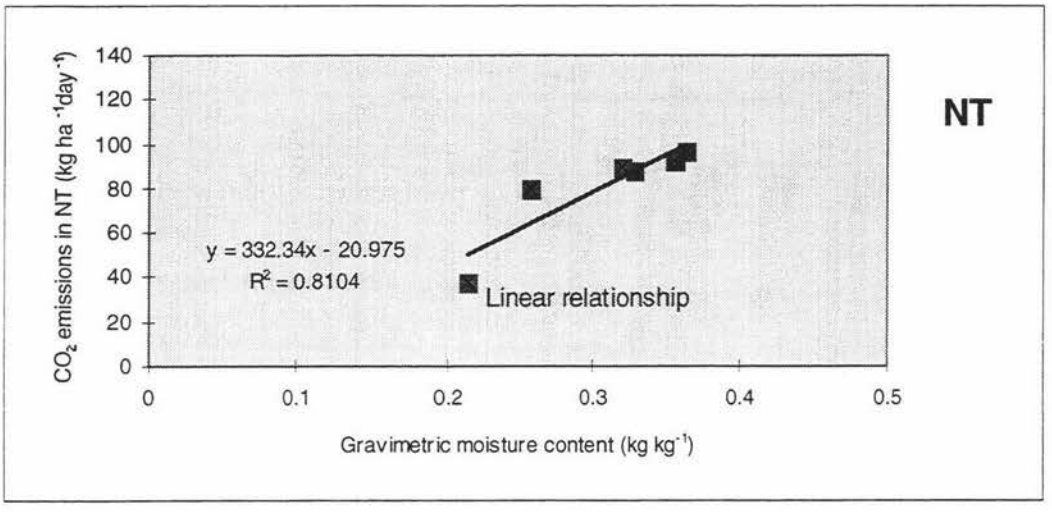
Values in each columns are means of two replicates, therefore no statistical analysis was performed on these data.

4.6.5 Summary

These experimental results have indicated that CO_2 efflux from permanent pasture was higher as compared to two tillage practices. The tillage intensity had, in general, little or no effect on CO_2 emission rates. Such trends continued during fodder maize crop in summer-autumn season and winter oats crop growth in winter-spring period. CO_2 emission were higher in summer and autumn as compared to winter and spring.

Short-term(daily) CO_2 emissions showed significant differences in CO_2 levels between the three treatment and were in order of PP > NT > CT . Such short-term CO_2 emission appeared to be influenced by SMC irrespective of the tillage method. It appeared that the freshly cultivated land may enhance CO_2 emission during April and May as compared with untilled soil. However, once seedbed was recompacted 3-4 weeks after cultivation, the differences in CO_2 emissions retarded to levels akin to untilled soils.





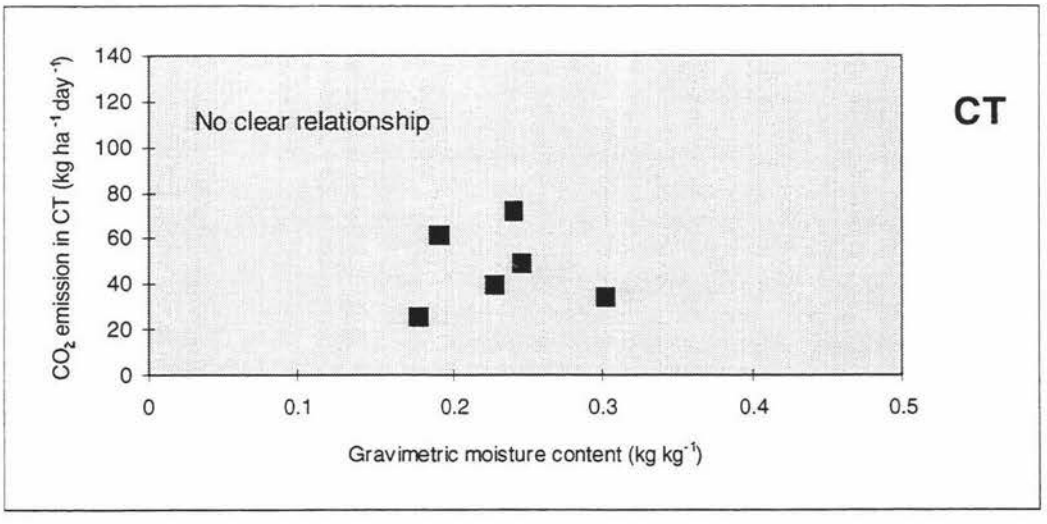


Fig.4.8 **Regression analysis between SMC and short-term (daily) CO_2 emissions in PP, NT and CT management.**

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

The data obtained from field and laboratory experiments involving a comparison of permanent pasture (PP) and two tillage treatments (CT and NT) supported following specific conclusions:

1. In a summer-fodder maize and winter-oats crop rotation, both the tillage treatments (NT and CT) provided similar plant establishment and crop yields. Adoption of NT reduced spurry weeds which proliferated in CT soil without significantly influencing crop yield.

2. Soil moisture content (SMC) data suggested that NT had significantly higher moisture content compared with CT at 0-50 mm depth. No significant differences in SMC were found among the three treatments at 50-100 mm depth. Low moisture content at 0-50 mm depth in CT probably was a reflection of high evaporation rates from tilled soil. Soil temperature did not differ among the three treatments at 0-50 mm depth.

3. Tillage affected earthworm population and live weight. Within two years of conversion from permanent pasture to cropping with CT reduced earthworm population by 74%. However, NT cropping had minimal effect on earthworm population. It indicated that adoption of NT will sustain earthworm population and activity thereby improving soil physical conditions, and biological status.

4. Within two years of cropping with NT resulted in a quantitative increase in total C, N and P levels (0-100 mm depth) as well as microbial biomass carbon (MBC), nitrogen (MBN) and phosphorus (MBP) contents (0-50 mm soil depth) as compared with CT. Conversion of PP to CT cropping resulted in 45% decline in MBC, 53% in MBN and 51% in MBP at 0-50

mm soil depth. Such decline in microbial biomass is an early and clear indication of probable future decline in soil organic matter with CT practices. However, there were no significant differences in microbial biomass contents at 50-100 mm depth between tillage practices or cropping regimes.

5. The MBC, MBN and MBP contents in PP and NT were almost twice as much in quantity in the surface soil (0-50 mm) as compared to 50-100 mm soil depth. No quantitative differences in microbial biomass contents occurred between 0-50 and 50-100 mm depths in CT plots.

6. When comparing seasonal variations, MBC and MBN levels in autumn were higher as compared to both summer and winter seasons. This was likely due to enhanced microbial activities during moist but warm period (autumn) as compared to dry (summer) and cold winter and early spring period in Manawatu, New Zealand.

7. Basal soil respiration measured was generally high in week 1 and then decreased to equilibrium levels. Basal soil respiration averaged over 5 weeks was 19,16 and 10 mg CO_2-C $kg^{-1}day^{-1}$ for PP, NT and CT respectively at 0-50 mm , and was 10, 9 and 12 mg CO_2-C $kg^{-1}day^{-1}$ for PP, NT and CT respectively at 50-100 mm soil depth. Basal soil respiration data further indicated that biological activities at 0-50 mm depth were 38% lower in CT as compared with NT. At 50-100 mm depth, the activity in CT were 25% higher as compared to NT treatment. Metabolic quotient (qCO_2) did not differ among the three treatments at 0-50 and 50-100 mm depths.

8. Field CO_2 emission (efflux) measured over 12 month period indicated that PP had consistently higher CO_2 efflux levels as compared to two cropping practices. The CT or NT, in general, had little effect on the rates of CO_2 efflux at any time during 12 months period.

9. The field CO_2 emission data in April and May (New Zealand autumn) suggested that the freshly cultivated land may enhance field CO_2 efflux as compared with untilled soil. However, if soils were mouldboard ploughed and then immediately recompacted with a heavy roller, this was unlikely to enhance soil aeration, microbial activity, and CO_2 efflux. Once prepared seedbed was recompacted naturally within few days of cultivation, or after rainfall, the differences in CO_2 emissions retarded to levels akin to untilled soils during crop growth period.

10. Seasonal variations in field CO_2 emission were significant. It was higher in summer and autumn as compared with winter and early spring. This suggested that warm weather promoted favourable environment for biological activity which, in turn, enhanced CO_2 emission. A number of factors such as crop growth, root respiration and seasonal variations in soil moisture and temperature interacted and influenced field CO_2 emission. The influence of soil moisture content (SMC) and temperature on CO_2 emission was assessed through regression analyses. The SMC had a significant linear relationship with short-term (daily) CO_2 emission in PP and NT treatments. However, long-term (monthly) CO_2 emission did not show any relationship with SMC. There was a positive linear relationship between soil temperature and CO_2 emission in PP only.

11. Annual field soil CO_2 losses were calculated from the montly data. Field CO_2 emission from an Ohakea silt loam soil in Manawatu, New Zealand during cold wet winter months to moist warm months ranged from 55 - 132 kg C $ha^{-1}day^{-1}$ in PP, 43-91 kg C $ha^{-1}day^{-1}$ in NT and 36-81 kg C $ha^{-1}day^{-1}$ in CT treatment, respectively.

12. This research has been first of its kind in the Manawatu region, New Zealand, which studied the impact of tillage and no-tillage systems, and permanent pasture on soil microbial biomass C, N and P, and CO_2 emission. This study has demonstrated that no-tillage system sustains high soil organic matter and biological fertility, enhances soil quality, and

assists in environmental protection as compared with conventional tillage system.

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APPENDIX 1

1.1 Detailed data of Table 4.1 on effects of tillage practices on maize seedling emergence (%)

Treatment	plot 1	plot 2	plot 3	plot 4
NT	95.6 91.5	95.6 95.6	94.5 92.4	95.6 99.3
CT	95.6 99.7	91.4 95.6	99.7 99.7	91.4 95.6

Statistical analysis of above using GLM

General Linear Models Procedure

Dependent Variable: A FODDER MAIZE

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	6.50250000	6.50250000	0.77	0.3952
Error	14	118.33750000	8.45267857		
Corrected Total	15	124.84000000			

R-Square	C.V.	Root MSE	A Mean
0.052087	3.037982	2.9073490	95.70000000

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TREAT	1	6.50250000	6.50250000	0.77	0.3952

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TREAT	1	6.50250000	6.50250000	0.77	0.3952

1.2 Detailed data of Table 4.2 on effects of tillage practices on oats seedling emgerence (%)

Treatment	8th day	12th day	16th day	23rd day
NT plot 1	55.1	81.7	88.6	96.5
	57.1	77.8	89.6	94.5
plot 2	56.7	78.8	86.6	91.6
	54.1	80.7	90.6	87.6
plot 3	51.2	78.8	89.6	97.5
	54.1	74.8	92.6	96.5
plot 4	55.1	81.7	87.6	96.5
	54.1	78.8	88.6	94.5
CT plot 1	52.2	82.7	91.6	93.5
	54.1	78.8	88.6	92.6
plot 2	49.2	86.6	89.6	96.5
	51.2	84.7	85.7	94.5
plot 3	54.1	83.7	93.5	89.6
	53.2	82.7	90.6	90.6
plot 4	56.1	85.7	92.6	95.5
	53.2	81.7	90.6	94.5

Statistical analysis of above using GLM

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General Linear Models Procedure

Dependent Variable: 8th DAY WINTER OAT SEEDLING EMERGENCE

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	12.60250000	12.60250000	3.28	0.0916
Error	14	53.77750000	3.84125000		
Corrected Total	15	66.38000000			

R-Square	C.V.	Root MSE	Mean
0.189854	3.642957	1.9599107	53.80000000

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TREAT	1	12.60250000	12.60250000	3.28	0.0916

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TREAT	1	12.60250000	12.60250000	3.28	0.0916

General Linear Models Procedure

Dependent Variable: 12th DAY WINTER OAT SEEDLING EMERGENCE

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	70.14062500	70.14062500	12.46	0.0033
Error	14	78.81375000	5.62955357		
Corrected Total	15	148.95437500			

R-Square	C.V.	Root MSE	Mean
0.470887	2.920881	2.3726680	81.23125000

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TREAT	1	70.14062500	70.14062500	12.46	0.0033

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TREAT	1	70.14062500	70.14062500	12.46	0.0033

General Linear Models Procedure

Dependent Variable: 16th DAY WINTER OAT SEEDLING EMERGENCE

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	5.17562500	5.17562500	1.10	0.3127
Error	14	66.05375000	4.71812500		
Corrected Total	15	71.22937500			

R-Square	C.V.	Root MSE	Mean
0.072661	2.419015	2.1721245	89.79375000

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TREAT	1	5.17562500	5.17562500	1.10	0.3127

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TREAT	1	5.17562500	5.17562500	1.10	0.3127

General Linear Models Procedure

Dependent Variable: 23rd DAY WINTER OAT SEEDLING EMERGENCE

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	3.90062500	3.90062500	0.47	0.5044
Error	14	116.30875000	8.30776786		
Corrected Total	15	120.20937500			

R-Square	C.V.	Root MSE	Mean
0.032449	3.069359	2.8823198	93.90625000

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TREAT	1	3.90062500	3.90062500	0.47	0.5044

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TREAT	1	3.90062500	3.90062500	0.47	0.5044

1.3 Detailed data of table 4.3 on dry matter yield of winter oats in NT and CT plots (kg ha^{-1}).

Treatment	9 weeks	13 weeks
NT plot 1	2120	3352
plot 2	2320	4400
plot 3	2520	3720
plot 4	2720	3372
CT plot 1	1960	3044
plot2	2240	3216
plot 3	2400	3760
plot 4	2480	3676

Statistical analysis of above data using GLM

General Linear Models Procedure

Dependent Variable: DM YIELD 9 WEEKS

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	45000.00000000	45000.00000000	0.75	0.4185
Error	6	358000.00000000	59666.66666667		
Corrected Total	7	403000.00000000			

R-Square	C.V.	Root MSE	Mean
0.111663	10.41653	244.2676128	2345.00000000

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TREAT	1	45000.00000000	45000.00000000	0.75	0.4185

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TREAT	1	45000.00000000	45000.00000000	0.75	0.4185

General Linear Models Procedure

Dependent Variable: DM YIELD 13 WEEKS

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	164738.00000000	164738.00000000	0.91	0.3762
Error	6	1082668.00000000	180444.66666667		
Corrected Total	7	1247406.00000000			

R-Square	C.V.	Root MSE	Mean
0.132064	11.90716	424.7877901	3567.50000000

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TREAT	1	164738.00000000	164738.00000000	0.91	0.3762

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TREAT	1	164738.00000000	164738.00000000	0.91	0.3762

1.4 Detailed data of Table 4.4 on weed dry matter yield in winter oats under CT and NT (kg ha^{-1})

Treatment	plot 1	plot 2	plot 3	plot 4
NT	31	36	46	48
CT	48	67	92	80

Statistical analysis of above data using GLM

General Linear Models Procedure

Dependent Variable: DM YIELD WEEDS IN WINTER OATS

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	1990.80500000	1990.80500000	9.51	0.0216
Error	6	1255.95000000	209.32500000		
Corrected Total	7	3246.75500000			

R-Square	C.V.	Root MSE	Mean
0.613168	25.84738	14.4680682	55.97500000

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TREAT	1	1990.80500000	1990.80500000	9.51	0.0216

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TREAT	1	1990.80500000	1990.80500000	9.51	0.0216

1.5 Detailed data of Table 4.6 on soil pH, earthworm population and live weight under PP, NT & CT (June, 1997)

Treatment	Earthworm Population (numbers m^{-2})	Eathworm Live weight (g m^{-2})	soil pH (0-100 mm)
PP	420	165.40	5.54
	464	133.48	5.51
	424	135.16	5.32
	408	127.12	5.36
NT	380	112.36	5.44
	404	103.96	5.36
	356	82.64	5.48
	312	98.40	5.48
CT	100	26.48	5.56
	140	53.44	5.42
	116	27.24	5.42
	94	25.92	5.51

Statistical analysis of above using GLM

General Linear Models Procedure

Dependent Variable: EARTHWORM POPULATION (JUNE, 1997)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	223038.00000000	111519.00000000	131.04	0.0001
Error	9	7659.00000000	851.00000000		
Corrected Total	11	230697.00000000			

R-Square	C.V.	Root MSE	Mean
0.966801	9.675590	29.1719042	301.50000000

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TREAT	2	223038.00000000	111519.00000000	131.04	0.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TREAT	2	223038.00000000	111519.00000000	131.04	0.0001

General Linear Models Procedure

Dependent Variable: EARTHWORM LIVE WEIGHT (JUNE, 1997)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	23327.23706667	11663.61853333	55.52	0.0001
Error	9	1890.60880000	210.06764444		
Corrected Total	11	25217.84586667			

R-Square	C.V.	Root MSE	Mean
0.925029	15.93299	14.4937105	90.96666667

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TREAT	2	23327.23706667	11663.61853333	55.52	0.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TREAT	2	23327.23706667	11663.61853333	55.52	0.0001

General Linear Models Procedure

Dependent Variable: SOIL pH

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	0.00465000	0.00232500	0.35	0.7130
Error	9	0.05955000	0.00661667		
Corrected Total	11	0.06420000			

R-Square	C.V.	Root MSE	A Mean
0.072430	1.492530	0.0813429	5.45000000

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TREAT	2	0.00465000	0.00232500	0.35	0.7130

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TREAT	2	0.00465000	0.00232500	0.35	0.7130

1.6 Detailed data of Table 4.7 on MBC (kg ha^{-1}) under PP, NT & CT

	Summer Nov., 1996 0-100 mm	Autumn April, 1997 0-100 mm	Winter July, 1997 0-100 mm
PP	963	1041	757
	843	972	816
	910	1068	738
	658	1011	738
NT	872	694	865
	979	574	789
	805	589	714
	1130	686	775
CT	558	817	510
	661	674	505
	675	796	565
	488	708	522

Statistical analysis of above using GLM

General Linear Models Procedure

Dependent Variable: SUMMER (NOVERMBER)-1996

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	260418.66666667	130209.33333333	8.55	0.0083
Error	9	136987.00000000	15220.77777778		
Corrected Total	11	397405.66666667			

R-Square	C.V.	Root MSE	Mean
0.655297	15.51530	123.37251630	795.16666667

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TREAT	2	260418.66666667	130209.33333333	8.55	0.0083

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TREAT	2	260418.66666667	130209.33333333	8.55	0.0083

General Linear Models Procedure

Dependent Variable: AUTUMN (APRIL)-1997

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	195406.16666667	97703.08333333	16.50	0.0010
Error	9	53279.50000000	5919.94444444		
Corrected Total	11	248685.66666667			

R-Square	C.V.	Root MSE	Mean
0.785756	8.280665	76.94117522	929.16666667

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TREAT	2	195406.16666667	97703.08333333	16.50	0.0010

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TREAT	2	195406.16666667	97703.08333333	16.50	0.0010

General Linear Models Procedure

Dependent Variable: WINTER (JULY)-1997

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	165777.16666667	82888.58333333	41.72	0.0001
Error	9	17880.50000000	1986.72222222		
Corrected Total	11	183657.66666667			

R-Square	C.V.	Root MSE	Mean
0.902642	6.448902	44.57266227	691.16666667

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TREAT	2	165777.16666667	82888.58333333	41.72	0.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TREAT	2	165777.16666667	82888.58333333	41.72	0.0001

1.7 Detailed data of Table 4.8 on MBC (kg ha^{-1}) at 0-50 & 50-100 mm depth under PP, NT & CT.

Treatments	Microbial biomass carbon (kg ha^{-1})			
	Autumn (April, 1997)		Winter (July, 1997)	
	0-50 mm	50-100 mm	0-50 mm	50-100 mm
PP	653	388	457	300
	575	397	543	273
	692	376	443	295
	648	363	461	277
NT	694	440	512	353
	574	373	497	292
	589	318	436	278
	686	387	520	255
CT	345	472	246	264
	323	351	240	265
	388	408	282	283
	340	368	264	258

Statistical analysis of above using GLM

General Linear Models Procedure

Dependent Variable: AUTUMN (APRIL) AT 0-50 MM DEPTH

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	224151.50000000	112075.75000000	47.23	0.0001
Error	9	21356.75000000	2372.97222222		
Corrected Total	11	245508.25000000			

R-Square	C.V.	Root MSE	A Mean
0.913010	8.983525	48.71316272	542.25000000

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TREAT	2	224151.50000000	112075.75000000	47.23	0.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TREAT	2	224151.50000000	112075.75000000	47.23	0.0001

General Linear Models Procedure

Dependent Variable: B AUTUMN (APRIL) AT 50-100 MM DEPTH

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	990.16666667	495.08333333	0.26	0.7740
Error	9	16900.75000000	1877.86111111		
Corrected Total	11	17890.91666667			

R-Square	C.V.	Root MSE	B Mean
0.055345	11.19990	43.33429486	386.91666667

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TREAT	2	990.16666667	495.08333333	0.26	0.7740

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TREAT	2	990.16666667	495.08333333	0.26	0.7740

General Linear Models Procedure

Dependent Variable: WINTER (JULY) AT 0-50 MM DEPTH

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	136216.16666667	68108.08333333	52.90	0.0001
Error	9	11586.75000000	1287.41666667		
Corrected Total	11	147802.91666667			

R-Square	C.V.	Root MSE	C Mean
0.921607	8.785290	35.88058900	408.41666667

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TREAT	2	136216.16666667	68108.08333333	52.90	0.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TREAT	2	136216.16666667	68108.08333333	52.90	0.0001

General Linear Models Procedure

Dependent Variable: WINTER (JULY) AT 50-100 MM DEPTH

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	1531.50000000	765.75000000	1.12	0.3669
Error	9	6136.75000000	681.86111111		
Corrected Total	11	7668.25000000			

R-Square	C.V.	Root MSE	D Mean
0.199720	9.235180	26.11247041	282.75000000

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TREAT	2	1531.50000000	765.75000000	1.12	0.3669

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TREAT	2	1531.50000000	765.75000000	1.12	0.3669

1.8 Detailed data of Table 4.9 on effects of tillage and permanent pasture on MBN (kg ha^{-1}).

	Summer Nov., 1996 0-100 mm	Autumn April, 1997 0-100 mm	Winter July, 1997 0-100 mm
PP	122	111	77
	115	124	82
	130	121	77
	93	108	89
NT	112	136	71
	126	140	72
	86	98	85
	140	110	91
CT	77	72	54
	90	78	48
	86	78	59
	66	67	62

Statistical analysis of above using GLM

General Linear Models Procedure

Dependent Variable: A SUMMER (NOVERMBER)-1996

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	3198.50000000	1599.25000000	5.48	0.0277
Error	9	2625.75000000	291.75000000		
Corrected Total	11	5824.25000000			

R-Square	C.V.	Root MSE	Mean
0.549169	16.62354	17.08069085	102.75000000

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TREAT	2	3198.50000000	1599.25000000	5.48	0.0277

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TREAT	2	3198.50000000	1599.25000000	5.48	0.0277

General Linear Models Procedure

Dependent Variable: AUTUMN (APRIL)-1997

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	5390.16666667	2695.08333333	16.18	0.0010
Error	9	1498.75000000	166.52777778		
Corrected Total	11	6888.91666667			

R-Square	C.V.	Root MSE	Mean
0.782440	12.45815	12.90456422	103.58333333

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TREAT	2	5390.16666667	2695.08333333	16.18	0.0010

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TREAT	2	5390.16666667	2695.08333333	16.18	0.0010

General Linear Models Procedure

Dependent Variable: WINTER (JULY) 1997

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	1638.00000000	819.00000000	14.73	0.0014
Error	9	500.25000000	55.58333333		
Corrected Total	11	2138.25000000			

R-Square	C.V.	Root MSE	Mean
0.766047	10.31892	7.45542308	72.25000000

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TREAT	2	1638.00000000	819.00000000	14.73	0.0014

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TREAT	2	1638.00000000	819.00000000	14.73	0.0014

1.9 Detailed data of Table 4.10 on MBN status in PP, NT and CT at two soil depths.

Treatments	Microbial biomass nitrogen (kg ha^{-1})			
	Autumn (April, 1997)		Winter (July, 1997)	
	0-50 mm	50-100 mm	0-50 mm	50-100 mm
PP	73	38	51	26
	79	45	55	27
	89	32	48	29
	69	39	57	32
NT	92	44	36	35
	95	45	49	23
	65	33	52	33
	75	35	61	30
CT	41	31	28	26
	36	42	24	24
	29	49	32	27
	21	46	30	32

Statistical analysis of above using GLM

General Linear Models Procedure

Dependent Variable: AUTUMN (APRIL) AT 0-50 MM

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	6148.16666667	3074.08333333	26.09	0.0002
Error	9	1060.50000000	117.83333333		
Corrected Total	11	7208.66666667			

R-Square	C.V.	Root MSE	A Mean
0.852885	17.04991	10.85510633	63.66666667

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TREAT	2	6148.16666667	3074.08333333	26.09	0.0002

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TREAT	2	6148.16666667	3074.08333333	26.09	0.0002

General Linear Models Procedure

Dependent Variable: AUTUMN (APRIL) AT 50-100 MM DEPTH

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	27.16666667	13.58333333	0.32	0.7351
Error	9	383.75000000	42.63888889		
Corrected Total	11	410.91666667			

R-Square	C.V.	Root MSE	B Mean
0.066112	16.35870	6.52984601	39.91666667

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TREAT	2	27.16666667	13.58333333	0.32	0.7351

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TREAT	2	27.16666667	13.58333333	0.32	0.7351

General Linear Models Procedure

Dependent Variable: WINTER (JULY)AT 0-50 MM DEPTH

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	1386.16666667	693.08333333	15.41	0.0012
Error	9	404.75000000	44.97222222		
Corrected Total	11	1790.91666667			

R-Square	C.V.	Root MSE	C Mean
0.773998	15.38692	6.70613318	43.58333333

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TREAT	2	1386.16666667	693.08333333	15.41	0.0012

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TREAT	2	1386.16666667	693.08333333	15.41	0.0012

General Linear Models Procedure

Dependent Variable: WINTER (JULY) AT 50-100 MM DEPTH

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	18.16666667	9.08333333	0.59	0.5743
Error	9	138.50000000	15.38888889		
Corrected Total	11	156.66666667			

R-Square	C.V.	Root MSE	D Mean
0.115957	13.68442	3.92286743	28.66666667

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TREAT	2	18.16666667	9.08333333	0.59	0.5743

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TREAT	2	18.16666667	9.08333333	0.59	0.5743

1.10 Detailed data of table 4.11 on effects of tillage and permanent pasture on MBP (kg ha^{-1})

	Summer Nov., 1996 0-100 mm	Autumn April, 1997 0-100 mm	Winter July, 1997 0-100 mm
PP	78	54	79
	68	60	84
	65	60	77
	52	58	82
NT	72	57	80
	75	60	82
	64	53	91
	63	49	86
CT	39	34	44
	53	36	47
	54	43	55
	46	43	52

Statistical analysis of above using GLM

General Linear Models Procedure

Dependent Variable: SUMMER (NOVEMBER) 1996

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	990.50000000	495.25000000	7.48	0.0122
Error	9	595.75000000	66.19444444		
Corrected Total	11	1586.25000000			

R-Square	C.V.	Root MSE	Mean
0.624429	13.39259	8.13599683	60.75000000

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TREAT	2	990.50000000	495.25000000	7.48	0.0122

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TREAT	2	990.50000000	495.25000000	7.48	0.0122

General Linear Models Procedure

Dependent Variable: AUTUMN (APRIL) 1997

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	826.16666667	413.08333333	23.42	0.0003
Error	9	158.75000000	17.63888889		
Corrected Total	11	984.91666667			

R-Square	C.V.	Root MSE	Mean
0.838819	8.302869	4.19986772	50.58333333

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TREAT	2	826.16666667	413.08333333	23.42	0.0003

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TREAT	2	826.16666667	413.08333333	23.42	0.0003

General Linear Models Procedure

Dependent Variable: WINTER (JULY) 1997

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	2962.16666667	1481.08333333	77.16	0.0001
Error	9	172.75000000	19.19444444		
Corrected Total	11	3134.91666667			

R-Square	C.V.	Root MSE	Mean
0.944895	6.120344	4.38114648	71.58333333

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TREAT	2	2962.16666667	1481.08333333	77.16	0.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TREAT	2	2962.16666667	1481.08333333	77.16	0.0001

1.11 Detailed data of Table 4.12 on MBP status in PP, NT and CT at 0-50 & 50-100 mm depths.

Treatments	Microbial biomass phosphorus (kg ha^{-1})			
	Autumn (April, 1997)		Winter (July, 1997)	
	0-50 mm	50-100 mm	0-50 mm	50-100 mm
PP	32	22	50	29
	40	20	59	25
	41	19	50	27
	37	21	57	25
NT	37	20	52	28
	41	19	53	29
	36	17	63	28
	34	15	61	25
CT	17	17	24	20
	18	18	26	21
	20	23	28	27
	22	21	25	27

Statistical analysis of above using GLM

General Linear Models Procedure

Dependent Variable: AUTUMN (APRIL) AT 0-50 MM DEPTH

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	864.50000000	432.25000000	43.35	0.0001
Error	9	89.75000000	9.97222222		
Corrected Total	11	954.25000000			

R-Square	C.V.	Root MSE	A Mean
0.905947	10.10522	3.15788255	31.25000000

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TREAT	2	864.50000000	432.25000000	43.35	0.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TREAT	2	864.50000000	432.25000000	43.35	0.0001

General Linear Models Procedure

Dependent Variable: AUTUMN (APRIL)AT 50-100 MM DEPTH

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	16.16666667	8.08333333	1.71	0.2344
Error	9	42.50000000	4.72222222		
Corrected Total	11	58.66666667			

R-Square	C.V.	Root MSE	B Mean
0.275568	11.24000	2.17306747	19.33333333

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TREAT	2	16.16666667	8.08333333	1.71	0.2344

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TREAT	2	16.16666667	8.08333333	1.71	0.2344

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General Linear Models Procedure

Dependent Variable: WINTER (JULY) AT 0-50 MM DEPTH

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	2401.16666667	1200.58333333	64.51	0.0001
Error	9	167.50000000	18.61111111		
Corrected Total	11	2568.66666667			

R-Square	C.V.	Root MSE	C Mean
0.934791	9.446846	4.31405970	45.66666667

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TREAT	2	2401.16666667	1200.58333333	64.51	0.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TREAT	2	2401.16666667	1200.58333333	64.51	0.0001

General Linear Models Procedure

Dependent Variable: WINTER (JULY)AT 50-100 MM DEPTH

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	30.16666667	15.08333333	2.16	0.1709
Error	9	62.75000000	6.97222222		
Corrected Total	11	92.91666667			

R-Square	C.V.	Root MSE	D Mean
0.324664	10.18841	2.64049659	25.91666667

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TREAT	2	30.16666667	15.08333333	2.16	0.1709

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TREAT	2	30.16666667	15.08333333	2.16	0.1709

1.12 Detailed data of Table 4.14 on basal soil CO_2 (mg CO_2-C $kg^{-1}day^{-1}$) under PP, NT and CT at 0-50 mm depth.

Treatment	1st week	2nd week	3rd week	4th week	5th week	6th week
PP	45.27	23.34	20.20	17.71	18.22	16.56
	43.56	21.92	17.44	14.66	16.23	14.48
	37.87	24.20	22.03	18.32	19.07	17.81
	37.58	19.93	21.30	16.89	20.21	19.98
NT	37.58	19.36	17.44	14.96	15.09	17.70
	42.14	20.78	20.50	10.99	18.82	17.41
	30.46	13.66	13.16	13.16	12.24	11.99
	46.12	19.64	18.05	15.88	16.07	19.13
CT	17.65	10.25	7.95	7.02	7.97	6.56
	28.75	11.67	9.48	8.24	8.82	6.85
	33.03	12.81	10.71	9.16	11.95	8.85
	30.18	13.09	11.63	9.77	12.09	10.85

Statistical analysis of above using GLM

General Linear Models Procedure

Dependent Variable: BASAL RESPIRATION AT 0-50 MM DEPTH (1ST WEEK)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	436.03711667	218.01855833	6.17	0.0206
Error	9	318.04997500	35.33888611		
Corrected Total	11	754.08709167			

R-Square	C.V.	Root MSE	Mean
0.578232	16.58240	5.94465189	35.84916667

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TREAT	2	436.03711667	218.01855833	6.17	0.0206

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TREAT	2	436.03711667	218.01855833	6.17	0.0206

General Linear Models Procedure

Dependent Variable: BASAL RESPIRATION AT 0-50 MM DEPTH (2ND WEEK)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	219.90431667	109.95215833	21.50	0.0004
Error	9	46.03617500	5.11513056		
Corrected Total	11	265.94049167			

R-Square	C.V.	Root MSE	Mean
0.826893	12.88392	2.26166544	17.55416667

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TREAT	2	219.90431667	109.95215833	21.50	0.0004

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TREAT	2	219.90431667	109.95215833	21.50	0.0004

General Linear Models Procedure

Dependent Variable: BASAL RESPIRATION AT 0-50 MM DEPTH (3RD WEEK)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	225.02806667	112.51403333	21.21	0.0004
Error	9	47.75102500	5.30566944		
Corrected Total	11	272.77909167			

R-Square	C.V.	Root MSE	Mean
0.824946	14.55624	2.30340388	15.82416667

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TREAT	2	225.02806667	112.51403333	21.21	0.0004

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TREAT	2	225.02806667	112.51403333	21.21	0.0004

General Linear Models Procedure

Dependent Variable: BASAL RESPIRATION AT 0-50 MM DEPTH (4TH WEEK)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	142.17001667	71.08500833	24.65	0.0002
Error	9	25.95425000	2.88380556		
Corrected Total	11	168.12426667			

R-Square	C.V.	Root MSE	Mean
0.845625	12.99957	1.69817713	13.06333333

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TREAT	2	142.17001667	71.08500833	24.65	0.0002

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TREAT	2	142.17001667	71.08500833	24.65	0.0002

General Linear Models Procedure

Dependent Variable: BASAL RESPIRATION AT O-50 MM DEPTH (5TH WEEK)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	139.36851667	69.68425833	14.22	0.0016
Error	9	44.10465000	4.90051667		
Corrected Total	11	183.47316667			

R-Square	C.V.	Root MSE	E Mean
0.759613	15.02689	2.21371106	14.73166667

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TREAT	2	139.36851667	69.68425833	14.22	0.0016

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TREAT	2	139.36851667	69.68425833	14.22	0.0016

General Linear Models Procedure

Dependent Variable: BASAL RESPIRATION AT O-50 MM DEPTH (6TH WEEK)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	200.62186667	100.31093333	16.27	0.0010
Error	9	55.48662500	6.16518056		
Corrected Total	11	256.10849167			

R-Square	C.V.	Root MSE	Mean
0.783347	17.67978	2.48297816	14.04416667

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TREAT	2	200.62186667	100.31093333	16.27	0.0010

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TREAT	2	200.62186667	100.31093333	16.27	0.0010

1.13 Detailed data of Table 4.15 on basal soil CO_2 (mg CO_2-C $kg^{-1}day^{-1}$) under PP, NT and CT at 50-100 mm depth

Treatment	1st week	2nd week	3rd week	4th week	5th week	6th week
PP	28.75	10.82	9.18	7.63	10.53	8.56
	43.56	16.80	12.24	9.46	11.95	9.13
	29.75	10.25	7.95	8.74	9.11	6.85
	35.30	11.67	7.65	9.06	9.96	7.13
NT	29.89	10.53	9.18	7.63	11.95	7.70
	24.77	9.96	9.18	7.94	10.25	7.99
	30.18	10.53	9.48	-	9.96	7.42
	21.92	9.11	7.95	6.10	9.39	7.99
CT	23.65	11.95	10.71	10.08	9.96	9.99
	45.55	19.07	14.99	11.91	13.09	10.27
	38.44	16.23	12.54	10.99	13.95	11.13
	30.46	13.09	10.40	8.24	11.67	10.27

Statistical analysis of above using GLM

General Linear Models Procedure

Dependent Variable: BASAL RESPIRATION AT 50-100 MM DEPTH (1ST WEEK)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	159.92526667	79.96263333	1.57	0.2603
Error	9	458.77330000	50.97481111		
Corrected Total	11	618.69856667			

R-Square	C.V.	Root MSE	Mean
0.258487	22.41536	7.13966464	31.85166667

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TREAT	2	159.92526667	79.96263333	1.57	0.2603

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TREAT	2	159.92526667	79.96263333	1.57	0.2603

General Linear Models Procedure

Dependent Variable: BASAL RESPIRATION AT 50-100 MM DEPTH (2ND WEEK)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	51.13601667	25.56800833	3.88	0.0611
Error	9	59.36167500	6.59574167		
Corrected Total	11	110.49769167			

R-Square	C.V.	Root MSE	B Mean
0.462779	20.54437	2.56821761	12.50083333

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TREAT	2	51.13601667	25.56800833	3.88	0.0611

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TREAT	2	51.13601667	25.56800833	3.88	0.0611

General Linear Models Procedure

Dependent Variable: BASAL RESPIRATION AT 50-100 MM DEPTH (3RD WEEK)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	25.13831667	12.56915833	4.05	0.0557
Error	9	27.93497500	3.10388611		
Corrected Total	11	53.07329167			

R-Square	C.V.	Root MSE	C Mean
0.473653	17.40751	1.76178492	10.12083333

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TREAT	2	25.13831667	12.56915833	4.05	0.0557

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TREAT	2	25.13831667	12.56915833	4.05	0.0557

General Linear Models Procedure

Dependent Variable: BASAL RESPIRATION AT 50-100 MM DEPTH (4TH WEEK)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	20.03445000	10.01722500	8.02	0.0100
Error	9	11.23597500	1.24844167		
Corrected Total	11	31.27042500			

R-Square	C.V.	Root MSE	Mean
0.640684	12.80982	1.11733686	8.72250000

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TREAT	2	20.03445000	10.01722500	8.02	0.0100

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TREAT	2	20.03445000	10.01722500	8.02	0.0100

General Linear Models Procedure

Dependent Variable: BASAL RESPIRATION AT 50-100 MM DEPTH (5TH WEEK)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	8.44906667	4.22453333	2.23	0.1636
Error	9	17.06342500	1.89593611		
Corrected Total	11	25.51249167			

R-Square	C.V.	Root MSE	Mean
0.331174	12.53939	1.37692996	10.98083333

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TREAT	2	8.44906667	4.22453333	2.23	0.1636

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TREAT	2	8.44906667	4.22453333	2.23	0.1636

General Linear Models Procedure

Dependent Variable: BASAL RESPIRATION AT 50-100 MM DEPTH (6TH WEEK)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	17.63655000	8.81827500	17.25	0.0008
Error	9	4.60067500	0.51118611		
Corrected Total	11	22.23722500			

R-Square	C.V.	Root MSE	Mean
0.793109	8.215717	0.71497280	8.70250000

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TREAT	2	17.63655000	8.81827500	17.25	0.0008

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TREAT	2	17.63655000	8.81827500	17.25	0.0008

1.14 Detailed data of Table 4.16 on metabolic quotient(qCO_2) under PP, NT & CT.

	Metabolic quotient (q CO_2)			
Treatment	1st week		6th week	
	0-50 mm	50-100 mm	0-50 mm	50-100 mm
PP	1.71	1.91	0.62	0.57
	1.86	2.83	0.63	0.59
	1.35	2.04	0.68	0.47
	1.42	2.51	0.76	0.51
NT	1.35	1.78	0.64	0.46
	1.83	1.74	0.76	0.56
	1.29	2.49	0.51	0.61
	1.68	1.48	0.70	0.54
CT	1.14	1.24	0.42	0.52
	1.99	3.22	0.47	0.73
	1.83	2.33	0.49	0.68
	1.98	2.05	0.71	0.69

Statistical analysis of above data using GLM

General Linear Models Procedure

Dependent Variable: METABOLIC QUOTIENT AT 0-50 MM (1ST WEEK)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	0.08501667	0.04250833	0.44	0.6555
Error	9	0.86407500	0.09600833		
Corrected Total	11	0.94909167			

R-Square	C.V.	Root MSE	Mean
0.089577	19.13652	0.30985212	1.61916667

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TREAT	2	0.08501667	0.04250833	0.44	0.6555

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TREAT	2	0.08501667	0.04250833	0.44	0.6555

General Linear Models Procedure

Dependent Variable: METABOLIC QUOTIENT AT 50-100 MM DEPTH(1ST WEEK)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	0.43875000	0.21937500	0.64	0.5517
Error	9	3.10515000	0.34501667		
Corrected Total	11	3.54390000			

R-Square	C.V.	Root MSE	Mean
0.123804	27.51200	0.58738119	2.13500000

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TREAT	2	0.43875000	0.21937500	0.64	0.5517

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TREAT	2	0.43875000	0.21937500	0.64	0.5517

General Linear Models Procedure

Dependent Variable: METABOLIC QUOTIENT AT 0-50 MM DEPTH(6TH WEEK)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	0.05306667	0.02653333	2.49	0.1381
Error	9	0.09602500	0.01066944		
Corrected Total	11	0.14909167			

R-Square	C.V.	Root MSE	Mean
0.355933	16.77288	0.10329300	0.61583333

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TREAT	2	0.05306667	0.02653333	2.49	0.1381

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TREAT	2	0.05306667	0.02653333	2.49	0.1381

General Linear Models Procedure

Dependent Variable: METABOLIC QUOTIENT AT 50-100 MM DEPTH(6TH WEEK)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	0.03615000	0.01807500	3.50	0.0751
Error	9	0.04647500	0.00516389		
Corrected Total	11	0.08262500			

R-Square	C.V.	Root MSE	Mean
0.437519	12.44333	0.07186020	0.57750000

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TREAT	2	0.03615000	0.01807500	3.50	0.0751

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TREAT	2	0.03615000	0.01807500	3.50	0.0751

1.15 Detailed data of Table 4.17 on effects of tillage intensity and soil moisture on CO_2 emissions (kg CO_2-C $ha^{-1}day^{-1}$)

	(Before rain on 7.11.96)		(After rain on 10.11.96)	
Treatment	Soil CO_2-C (kg ha^{-1} day^{-1})	soil moisture (kg kg^{-1})	Soil CO_2-C (kg ha^{-1} day^{-1})	soil moisture (kg kg^{-1})
PP	53	.208	70	.234
	55	.217	66	.242
	56	.222	75	.213
	51	.202	73	.224
NT	53	.223	58	.233
	48	.201	67	.214
	54	.227	49	.238
	49	.204	50	.212
CT	45	.188	60	.206
	46	.192	53	.208
	42	.176	42	.196
	45	.189	50	.201

Statistical analysis of above using GLM

General Linear Models Procedure

Dependent Variable: SOIL CO_2 EMISSIONS (BEFORE RAIN ON 7.11.96)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	364.66666667	182.33333333	9.71	0.0057
Error	9	169.00000000	18.77777778		
Corrected Total	11	533.66666667			

R-Square	C.V.	Root MSE	Mean
0.683323	8.469055	4.33333333	51.16666667

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TREAT	2	364.66666667	182.33333333	9.71	0.0057

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TREAT	2	364.66666667	182.33333333	9.71	0.0057

General Linear Models Procedure

Dependent Variable: SOIL CO_2 EMISSIONS (AFTER RAIN ON 11.11.96)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	850.16666667	425.08333333	9.05	0.0070
Error	9	422.75000000	46.97222222		
Corrected Total	11	1272.91666667			

R-Square	C.V.	Root MSE	Mean
0.667889	11.53486	6.85362840	59.41666667

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TREAT	2	850.16666667	425.08333333	9.05	0.0070

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TREAT	2	850.16666667	425.08333333	9.05	0.0070

General Linear Models Procedure

Dependent Variable: SOIL MOISTURE DURING CO_2 EMISSIONS (BEFORE RAIN ON 7.11.96)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	0.00191267	0.00095633	9.48	0.0061
Error	9	0.00090825	0.00010092		
Corrected Total	11	0.00282092			

R-Square	C.V.	Root MSE	Mean
0.678030	4.922366	0.01004573	0.20408333

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TREAT	2	0.00191267	0.00095633	9.48	0.0061

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TREAT	2	0.00191267	0.00095633	9.48	0.0061

General Linear Models Procedure

Dependent Variable: SOIL MOISTURE DURING CO_2 EMISSIONS (AFTER RAIN ON 11.11.96)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	0.00150467	0.00075233	6.27	0.0197
Error	9	0.00108025	0.00012003		
Corrected Total	11	0.00258492			

R-Square	C.V.	Root MSE	D Mean
0.582095	5.015972	0.01095572	0.21841667

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TREAT	2	0.00150467	0.00075233	6.27	0.0197

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TREAT	2	0.00150467	0.00075233	6.27	0.0197

1.16 Detailed data of Table 4.18 on field soil CO_2 emissions from December 1996 to October 1997 under PP, NT & CT

	CO_2 emissions (kg CO_2-C $ha^{-1}day^{-1}$)										
Treat	Dec	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct
PP	93	131	100	112	136	88	63	54	44	72	96
	99	118	162	124	103	99	94	71	67	66	102
	112	113	106	95	149	93	68	69	48	66	93
	104	104	118	102	140	81	78	70	59	66	82
NT	42	95	68	56	54	45	76	54	49	39	74
	46	89	75	50	47	93	69	69	49	41	74
	35	97	82	44	70	74	86	59	44	43	81
	49	84	64	50	58	67	95	67	44	52	73
CT	30	79	56	57	73	60	67	49	42	37	70
	34	86	71	50	83	75	75	66	40	34	72
	33	73	56	47	60	91	74	61	26	36	81
	45	84	63	41	83	103	99	56	46	38	69

Statistical analysis of above using GLM

General Linear Models Procedure

Dependent Variable: DEC CO_2 EMISSIONS

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	10612.66666667	5306.33333333	110.29	0.0001
Error	9	433.00000000	48.11111111		
Corrected Total	11	11045.66666667			

R-Square	C.V.	Root MSE	Mean
0.960799	11.52834	6.93621735	60.16666667

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TREAT	2	10612.66666667	5306.33333333	110.29	0.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TREAT	2	10612.66666667	5306.33333333	110.29	0.0001

General Linear Models Procedure

Dependent Variable: JAN CO_2 EMISSIONS

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	2732.16666667	1366.08333333	20.95	0.0004
Error	9	586.75000000	65.19444444		
Corrected Total	11	3318.91666667			

R-Square	C.V.	Root MSE	Mean
0.823210	8.403443	8.07430768	96.08333333

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TREAT	2	2732.16666667	1366.08333333	20.95	0.0004

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TREAT	2	2732.16666667	1366.08333333	20.95	0.0004

General Linear Models Procedure

Dependent Variable: FEB CO_2 EMISSIONS

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	8188.16666667	4094.08333333	13.66	0.0019
Error	9	2696.75000000	299.63888889		
Corrected Total	11	10884.91666667			

R-Square	C.V.	Root MSE	Mean
0.752249	20.34485	17.31008056	85.08333333

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TREAT	2	8188.16666667	4094.08333333	13.66	0.0019

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TREAT	2	8188.16666667	4094.08333333	13.66	0.0019

General Linear Models Procedure

Dependent Variable: MARCH CO_2 EMISSIONS

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	9246.50000000	4623.25000000	61.06	0.0001
Error	9	681.50000000	75.72222222		
Corrected Total	11	9928.00000000			

R-Square	C.V.	Root MSE	Mean
0.931356	12.61138	8.70185165	69.00000000

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TREAT	2	9246.50000000	4623.25000000	61.06	0.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TREAT	2	9246.50000000	4623.25000000	61.06	0.0001

General Linear Models Procedure

Dependent Variable: APRIL CO_2 EMISSIONS

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	12228.50000000	6114.25000000	29.82	0.0001
Error	9	1845.50000000	205.05555556		
Corrected Total	11	14074.00000000			

R-Square	C.V.	Root MSE	Mean
0.868872	16.27246	14.31976102	88.00000000

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TREAT	2	12228.50000000	6114.25000000	29.82	0.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TREAT	2	12228.50000000	6114.25000000	29.82	0.0001

General Linear Models Procedure

Dependent Variable: MAY CO_2 EMISSIONS

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	854.00000000	427.00000000	1.60	0.2552
Error	9	2408.25000000	267.58333333		
Corrected Total	11	3262.25000000			

R-Square	C.V.	Root MSE	Mean
0.261783	20.25755	16.35797461	80.75000000

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TREAT	2	854.00000000	427.00000000	1.60	0.2552

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TREAT	2	854.00000000	427.00000000	1.60	0.2552

General Linear Models Procedure

Dependent Variable: JUNE CO_2 EMISSIONS

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	66.16666667	33.08333333	0.19	0.8270
Error	9	1534.50000000	170.50000000		
Corrected Total	11	1600.66666667			

R-Square	C.V.	Root MSE	Mean
0.041337	16.59860	13.05756486	78.66666667

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TREAT	2	66.16666667	33.08333333	0.19	0.8270

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TREAT	2	66.16666667	33.08333333	0.19	0.8270

General Linear Models Procedure

Dependent Variable: JULY CO_2 EMISSIONS

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	128.16666667	64.08333333	1.16	0.3573
Error	9	498.75000000	55.41666667		
Corrected Total	11	626.91666667			

R-Square	C.V.	Root MSE	Mean
0.204440	11.99072	7.44423714	62.08333333

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TREAT	2	128.16666667	64.08333333	1.16	0.3573

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TREAT	2	128.16666667	64.08333333	1.16	0.3573

General Linear Models Procedure

Dependent Variable: AUGUST CO_2 EMISSIONS

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	544.66666667	272.33333333	4.38	0.0470
Error	9	560.00000000	62.22222222		
Corrected Total	11	1104.66666667			

R-Square	C.V.	Root MSE	Mean
0.493060	17.02469	7.88810638	46.33333333

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TREAT	2	544.66666667	272.33333333	4.38	0.0470

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TREAT	2	544.66666667	272.33333333	4.38	0.0470

General Linear Models Procedure

Dependent Variable: SEPTEMBER CO_2 EMISSIONS

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	2155.16666667	1077.58333333	73.61	0.0001
Error	9	131.75000000	14.63888889		
Corrected Total	11	2286.91666667			

R-Square	C.V.	Root MSE	Mean
0.942390	7.795070	3.82608009	49.08333333

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TREAT	2	2155.16666667	1077.58333333	73.61	0.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TREAT	2	2155.16666667	1077.58333333	73.61	0.0001

General Linear Models Procedure

Dependent Variable: OCTOBER CO_2 EMISSIONS

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	975.16666667	487.58333333	12.84	0.0023
Error	9	341.75000000	37.97222222		
Corrected Total	11	1316.91666667			

R-Square	C.V.	Root MSE	Mean
0.740492	7.646942	6.16216052	80.58333333

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TREAT	2	975.16666667	487.58333333	12.84	0.0023

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TREAT	2	975.16666667	487.58333333	12.84	0.0023

1.17 Detailed data of Table 4.21 on soil water content at 0-50 mm depth during CO_2 emissions under PP, NT & CT management

	Gravimetric moisture content (kg kg^{-1})										
Treat	Dec	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct
PP	.219	.261	.194	.228	.355	.322	.293	.347	.445	.356	.471
	.243	.273	.159	.228	.388	.301	.310	.347	.550	.399	.399
	.218	.251	.138	.216	.374	.268	.325	.324	.495	.352	.523
	.242	.217	.135	.186	.390	.338	.219	.359	.453	.443	.460
NT	.272	.250	.144	.255	.351	.352	.281	.347	.406	.425	.414
	.314	.271	.173	.214	.378	.394	.263	.333	.434	.380	.440
	.281	.254	.170	.284	.336	.319	.263	.359	.427	.394	.404
	.257	.267	.168	.273	.399	.353	.281	.340	.502	.361	.393
CT	.240	.204	.216	.216	.346	.333	.257	.294	.317	.295	.315
	.245	.234	.167	.167	.280	.292	.249	.299	.379	.318	.317
	.217	.256	.157	.157	.344	.303	.257	.299	.362	.302	.335
	.245	.222	.187	.187	.331	.325	.262	.287	.345	.317	.305

Statistical analysis of above using GLM

General Linear Models Procedure

Dependent Variable: SOIL MOISTURE CONTENT AT 0-50 MM (DEC, 1996)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	0.00606317	0.00303158	9.54	0.0060
Error	9	0.00285975	0.00031775		
Corrected Total	11	0.00892292			

R-Square	C.V.	Root MSE	A Mean
0.679505	7.146893	0.01782554	0.24941667

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TREAT	2	0.00606317	0.00303158	9.54	0.0060

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TREAT	2	0.00606317	0.00303158	9.54	0.0060

General Linear Models Procedure

Dependent Variable: SOIL MOISTURE CONTENT AT 0-50 MM (JAN, 1997)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	0.00207267	0.00103633	2.69	0.1217
Error	9	0.00347200	0.00038578		
Corrected Total	11	0.00554467			

R-Square	C.V.	Root MSE	Mean
0.373813	7.962659	0.01964123	0.24666667

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TREAT	2	0.00207267	0.00103633	2.69	0.1217

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TREAT	2	0.00207267	0.00103633	2.69	0.1217

General Linear Models Procedure

Dependent Variable: SOIL MOISTURE CONTENT AT 0-50 MM (FEB, 1997)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	0.00135217	0.00067608	1.27	0.3260
Error	9	0.00478050	0.00053117		
Corrected Total	11	0.00613267			

R-Square	C.V.	Root MSE	C Mean
0.220486	13.77314	0.02304705	0.16733333

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TREAT	2	0.00135217	0.00067608	1.27	0.3260

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TREAT	2	0.00135217	0.00067608	1.27	0.3260

General Linear Models Procedure

Dependent Variable: SOIL MOISTURE CONTENT AT 0-50 MM (MARCH, 1997)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	0.01123217	0.00561608	8.36	0.0089
Error	9	0.00604675	0.00067186		
Corrected Total	11	0.01727892			

R-Square	C.V.	Root MSE	Mean
0.650050	11.91281	0.02592028	0.21758333

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TREAT	2	0.01123217	0.00561608	8.36	0.0089

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TREAT	2	0.01123217	0.00561608	8.36	0.0089

General Linear Models Procedure

Dependent Variable: SOIL MOISTURE CONTENT AT 0-50 MM (APRIL, 1997)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	0.00590450	0.00295225	4.43	0.0459
Error	9	0.00600350	0.00066706		
Corrected Total	11	0.01190800			

R-Square	C.V.	Root MSE	Mean
0.495843	7.254893	0.02582742	0.35600000

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TREAT	2	0.00590450	0.00295225	4.43	0.0459

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TREAT	2	0.00590450	0.00295225	4.43	0.0459

General Linear Models Procedure

Dependent Variable: SOIL MOISTURE CONTENT AT 0-50 MM (MAY, 1997)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	0.00547517	0.00273758	3.49	0.0757
Error	9	0.00706775	0.00078531		
Corrected Total	11	0.01254292			

R-Square	C.V.	Root MSE	Mean
0.436515	8.633624	0.02802330	0.32458333

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TREAT	2	0.00547517	0.00273758	3.49	0.0757

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TREAT	2	0.00547517	0.00273758	3.49	0.0757

General Linear Models Procedure

Dependent Variable: SOIL MOISTURE CONTENT AT 0-50 MM (JUNE, 1997)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	0.00186117	0.00093058	1.19	0.3482
Error	9	0.00704350	0.00078261		
Corrected Total	11	0.00890467			

R-Square	C.V.	Root MSE	Mean
0.209010	10.29762	0.02797519	0.27166667

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TREAT	2	0.00186117	0.00093058	1.19	0.3482

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TREAT	2	0.00186117	0.00093058	1.19	0.3482

General Linear Models Procedure

Dependent Variable: SOIL MOISTURE CONTENT AT 0-50 MM (JULY, 1997)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	0.00660067	0.00330033	26.80	0.0002
Error	9	0.00110825	0.00012314		
Corrected Total	11	0.00770892			

R-Square	C.V.	Root MSE	H Mean
0.856238	3.384029	0.01109680	0.32791667

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TREAT	2	0.00660067	0.00330033	26.80	0.0002

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TREAT	2	0.00660067	0.00330033	26.80	0.0002

General Linear Models Procedure

Dependent Variable: SOIL MOISTURE CONTENT AT 0-50 MM (AUGUST, 1997)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	0.03798600	0.01899300	12.01	0.0029
Error	9	0.01422825	0.00158092		
Corrected Total	11	0.05221425			

R-Square	C.V.	Root MSE	Mean
0.727503	9.328033	0.03976074	0.42625000

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TREAT	2	0.03798600	0.01899300	12.01	0.0029

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TREAT	2	0.03798600	0.01899300	12.01	0.0029

General Linear Models Procedure

Dependent Variable: SOIL MOISTURE CONTENT AT 0-50 MM (SEPTEMBER, 1997)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	0.01740067	0.00870033	9.75	0.0056
Error	9	0.00803300	0.00089256		
Corrected Total	11	0.02543367			

R-Square	C.V.	Root MSE	Mean
0.684159	8.256748	0.02987567	0.36183333

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TREAT	2	0.01740067	0.00870033	9.75	0.0056

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TREAT	2	0.01740067	0.00870033	9.75	0.0056

General Linear Models Procedure

Dependent Variable: SOIL MOISTURE CONTENT AT 0-50 MM (OCTOBER, 1997)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	0.04285217	0.02142608	19.08	0.0006
Error	9	0.01010875	0.00112319		
Corrected Total	11	0.05296092			

R-Square	C.V.	Root MSE	K Mean
0.809128	8.429451	0.03351409	0.39758333

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TREAT	2	0.04285217	0.02142608	19.08	0.0006

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TREAT	2	0.04285217	0.02142608	19.08	0.0006

1.18 Detailed data of Table 4.20 on soil moisture content at 50-100 mm depth during CO_2 emissions under PP, NT & CT management

	Gravimetric moisture content (kg kg^{-1})										
Treat	Dec	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct
PP	-	-	-	.189	.295	.233	-	.301	-	.322	.338
				.161	.281	.250		.285		.336	.364
				.173	.306	.248		.273		.291	.334
				.166	.298	.259		.262		.311	.329
NT	-	-	-	.192	.386	.294	-	.318	-	.359	.317
				.226	.296	.288		.276		.307	.367
				.174	.315	.257		.291		.317	.344
				.179	.273	.251		.260		.292	.313
CT	-	-	-	.210	.350	.258	-	.299	-	.290	.309
				.200	.350	.251		.309		.347	.330
				.182	.333	.268		.302		.338	.347
				.179	.352	.278		.290		.323	.307

Statistical analysis of above using GLM

General Linear Models Procedure

Dependent Variable: SOIL MOISTURE CONTENT AT 50-100 MM (MARCH, 1997)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	0.00112067	0.00056033	1.83	0.2146
Error	9	0.00274825	0.00030536		
Corrected Total	11	0.00386892			

R-Square	C.V.	Root MSE	Mean
0.289659	9.399149	0.01747458	0.18591667

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TREAT	2	0.00112067	0.00056033	1.83	0.2146

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TREAT	2	0.00112067	0.00056033	1.83	0.2146

General Linear Models Procedure

Dependent Variable: SOIL MOISTURE CONTENT AT 50-100 MM (APRIL, 1997)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	0.00526817	0.00263408	3.13	0.0931
Error	9	0.00758150	0.00084239		
Corrected Total	11	0.01284967			

R-Square	C.V.	Root MSE	Mean
0.409985	9.074707	0.02902394	0.31983333

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TREAT	2	0.00526817	0.00263408	3.13	0.0931

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TREAT	2	0.00526817	0.00263408	3.13	0.0931

General Linear Models Procedure

Dependent Variable: SOIL MOISTURE CONTENT AT 50-100 MM (MAY, 1997)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	0.00128750	0.00064375	2.67	0.1230
Error	9	0.00217075	0.00024119		
Corrected Total	11	0.00345825			

R-Square	C.V.	Root MSE	Mean
0.372298	5.944665	0.01553044	0.26125000

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TREAT	2	0.00128750	0.00064375	2.67	0.1230

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TREAT	2	0.00128750	0.00064375	2.67	0.1230

General Linear Models Procedure

Dependent Variable: SOIL MOISTURE CONTENT AT 50-100 MM (JULY, 1997)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	0.00082017	0.00041008	1.30	0.3204
Error	9	0.00284950	0.00031661		
Corrected Total	11	0.00366967			

R-Square	C.V.	Root MSE	Mean
0.223499	6.160497	0.01779357	0.28883333

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TREAT	2	0.00082017	0.00041008	1.30	0.3204

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TREAT	2	0.00082017	0.00041008	1.30	0.3204

General Linear Models Procedure

Dependent Variable: SOIL MOISTURE CONTENT AT 50-100 MM (SEPTEMBER, 1997)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	0.00018317	0.00009158	0.15	0.8615
Error	9	0.00543975	0.00060442		
Corrected Total	11	0.00562292			

R-Square	C.V.	Root MSE	Mean
0.032575	7.696808	0.02458489	0.31941667

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TREAT	2	0.00018317	0.00009158	0.15	0.8615

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TREAT	2	0.00018317	0.00009158	0.15	0.8615

General Linear Models Procedure

Dependent Variable: SOIL MOISTURE CONTENT AT 50-100 MM (OCTOBER, 1997)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	0.00067200	0.00033600	0.81	0.4737
Error	9	0.00372025	0.00041336		
Corrected Total	11	0.00439225			

R-Square	C.V.	Root MSE	Mean
0.152997	6.100910	0.02033128	0.33325000

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TREAT	2	0.00067200	0.00033600	0.81	0.4737

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TREAT	2	0.00067200	0.00033600	0.81	0.4737

1.19 Detailed data of Table 4.23 on Short-term field CO_2 emissions in PP, NT and CT practices.

	CO_2 emissions (kg CO_2-C ha^{-1} day^{-1})							
	Day 1-3 after ploughing and Day 5-11 after power harrow							
Treat	Day-1	Day- 2	Day -3	Day -4	Day -5	Day- 6	Day- 7	Day -11
PP	124	134	110	117	-	-	92	86
	124	130	119	120			97	85
	118	122	108	111			95	85
	106	109	98	104			107	85
NT	93	103	91	92	-	-	79	30
	89	90	85	83			76	24
	100	107	90	96			72	24
	84	86	85	87			75	27
CT	34	34	31	68	65	70	62	25
	39	61	43	74	84	80	60	39
	28	35	31	77	89	94	64	36
	42	69	54	71	83	80	60	50

Statistical analysis of above using GLM

General Linear Models Procedure

Dependent Variable: SHORT TERM CO_2 EMISSIONS (DAY 1)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	14564.66666667	7282.33333333	145.00	0.0001
Error	9	452.00000000	50.22222222		
Corrected Total	11	15016.66666667			

R-Square	C.V.	Root MSE	Mean
0.969900	8.713234	7.08676388	81.33333333

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TREAT	2	14564.66666667	7282.33333333	145.00	0.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TREAT	2	14564.66666667	7282.33333333	145.00	0.0001

General Linear Models Procedure

Dependent Variable: SHORT TERM CO_2 EMISSIONS (DAY 2)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	11286.16666667	5643.08333333	30.54	0.0001
Error	9	1662.75000000	184.75000000		
Corrected Total	11	12948.91666667			

R-Square	C.V.	Root MSE	Mean
0.871592	15.11653	13.59227722	89.91666667

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TREAT	2	11286.16666667	5643.08333333	30.54	0.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TREAT	2	11286.16666667	5643.08333333	30.54	0.0001

General Linear Models Procedure

Dependent Variable: SHORT TERM CO_2 EMISSIONS (DAY 3)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	10008.00000000	5004.00000000	72.61	0.0001
Error	9	620.25000000	68.91666667		
Corrected Total	11	10628.25000000			

R-Square	C.V.	Root MSE	Mean
0.941641	10.54172	8.30160627	78.75000000

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TREAT	2	10008.00000000	5004.00000000	72.61	0.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TREAT	2	10008.00000000	5004.00000000	72.61	0.0001

General Linear Models Procedure

Dependent Variable: SHORT TERM CO_2 EMISSIONS (DAY 4)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	3308.66666667	1654.33333333	50.99	0.0001
Error	9	292.00000000	32.44444444		
Corrected Total	11	3600.66666667			

R-Square	C.V.	Root MSE	Mean
0.918904	6.213821	5.69600250	91.66666667

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TREAT	2	3308.66666667	1654.33333333	50.99	0.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TREAT	2	3308.66666667	1654.33333333	50.99	0.0001

General Linear Models Procedure

Dependent Variable: SHORT TERM CO_2 EMISSIONS (DAY 7)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	2673.50000000	1336.75000000	73.92	0.0001
Error	9	162.75000000	18.08333333		
Corrected Total	11	2836.25000000			

R-Square	C.V.	Root MSE	Mean
0.942618	5.434441	4.25245027	78.25000000

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TREAT	2	2673.50000000	1336.75000000	73.92	0.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TREAT	2	2673.50000000	1336.75000000	73.92	0.0001

General Linear Models Procedure

Dependent Variable: SHORT TERM CO_2 EMISSIONS (DAY11)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	7850.16666667	3925.08333333	103.14	0.0001
Error	9	342.50000000	38.05555556		
Corrected Total	11	8192.66666667			

R-Square	C.V.	Root MSE	Mean
0.958194	12.42064	6.16891851	49.66666667

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TREAT	2	7850.16666667	3925.08333333	103.14	0.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TREAT	2	7850.16666667	3925.08333333	103.14	0.0001