THE EFFECTS OF TILLAGE PRACTICES AND CROPPING PATTERN ON NONPOINT SOURCE POLLUTION AND SOIL QUALITY

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ABSTRACT

Soil erosion is one of the most serious environmental problems facing world agriculture. In New Zealand, with the current low financial returns from pastoral-based farming, land which was previously unaffected by soil erosion is being intensively farmed and therefore becoming more susceptible to soil erosion and nonpoint source pollution.

Adoption of soil resource management and agricultural practices that seek to conserve soil and water resources and minimise environmental degradation is attracting overwhelming interest among scientists and general public. Therefore, the main objective of this study was to assess the effects of selected tillage practices on soil physical properties, soil and water runoff, and water quality under selected cropping pattern.

Experiments were conducted on a Ohakea silt loam comparing crop production (barley and oats double crop rotation) using conventional tillage (MP), no-tillage (NT), and pasture (P) (as a control treatment) and assess their impact on erosion and selected soil properties. It was expected that this relatively heavy soil type would be sensitive to cultivation management systems and was therefore suitable for a comparison of tillage methods. The treatments were arranged in a randomised complete block (RCB) design with four blocks of three treatments.

In the field experiment, soil bulk density, water content, infiltrability, penetration resistance and earthworm populations were measured during two cropping seasons after barley and oats crops harvest in March and August 1996 respectively. Generally, these soil properties were significantly *($P \leq 0.05$)* affected by tillage practices. Soil water content, infiltrability, and earthworm populations were similar in the NT and P treatments, but significantly higher

than those found in the MP treatment. Conversely, soil bulk density at 0 - 50 mm depth was in the order of MP > NT > P.

In the laboratory experiment, soil and water runoff, leachate volume, pH and nutrient losses from soil erosion were measured under a rainfall simulator. "Rainfall" intensity used was at an average application rate of 50 mm/hr for one hour, simulating a rainstorm. Mean data from the two experiments suggested that the surface water runoff and soil sediment in runoff were higher in the MP treatment than in the NT and P treatments, and were in the order of MP > NT = P and in a ratio of 4:1:1 and 30:1:1 respectively. Conversely, the volumes of water leachate were higher for the NT and P treatments than for the MP treatment, and in a ratio of 4:1:1 respectively. Soil pH from both water runoff and leachate was at an average of 7.4 and 7.2 respectively, but not different among the three treatments. Nutrient losses in surface water runoff were found to be significantly higher *($P \leq 0.05$)* in the MP treatment (N=1.45 mg/m^2, P=1.02 mg/m^2, and K=8.3 mg/m^2) than those with the NT (N=0.76 mg/m^2, P=0.65 mg/m^2, and K=6.8 mg/m^2). Nutrient losses from NT and pasture treatments were similar.

One year's data including two cropping seasons indicate that conventional tillage practices can result in high surface runoff and sediment loss and adversely affect runoff water quality. Such tillage practices are likely to lead to unsustainable land resource management and decreasing crop yields. On the other hand, conservation tillage practices such as no-tillage and continuous pasture cover reduced soil and water erosion, improved soil physical properties and runoff water quality, and conserved land resources leading to enhanced land productivity and agricultural sustainability.

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INTRODUCTION

1.1 General Introduction

In recent years there has been much concern about the effects of agricultural practices and tillage intensity on soil and water quality. Traditional agricultural tillage practices often cause water and air pollution and deterioration of the land. Of these three problems, by far the best documented is how agriculture can affect soil and water quality.

Soil is one of the most fundamental resources we have, thus soil erosion is one of the most serious environmental problems in the world today. A number of reports (e.g. FAO, 1984) have cautioned about the alarming degradation of the land by erosion and salinisation.

Soil scientists remind us that 30 - 50% of the earth's land surface is affected by soil degradation (Pimentel, 1993). In India, fertile lands are being squeezed between the advance of the deserts and increasing erosion in the hills (Narayana and Sastry, 1985; Khoshoo and Tejwani, 1993). In China, about one-third of the total cultivated surface is undergoing serious water and wind erosion (Zhao, 1989; Mclaughlin, 1993). In West Africa, low crop yields are due partly to severe past erosion and reduced fertility. Recent famines in West Africa are described not only as natural disasters, but also as cultural catastrophes following natural events (Lal, 1993). Over half the area of Australia used for agricultural and pastoral purposes needs treatment for at least one form of degradation, most commonly salinisation. Water erosion affects over half of Argentina's land area, and wind erosion does nearly as much (Edwards, 1993; Mctainsh and Boughton, 1993). Even in Britain, soil erosion, largely caused by water, has come to be recognised as having an important agricultural impact (Clarke and Evans, 1993). In the tropics generally, and in the humid tropics in particular, soil erosion is perhaps the most serious mechanism of land degradation (FAO, 1984).

In New Zealand, soil erosion throughout the land is proceeding largely uncontrolled, with minimum conservation. Soil loss from excessively tilled agricultural and horticultural market gardening areas has been estimated to be approximately 50 $t/km^2/yr$ (Basher et al., 1996). In contrast, soil loss from bare soil were higher than the basin sediment yield; in these areas soil loss rate varies from 15 to 30 t/ha/yr (NZMFE, 1994).

The concepts of soil and water quality have been suggested by several authors (Karlen et al., 1994; Doran and Parkin, 1994) as a tool for assessing long-term sustainability of agricultural land management. Assessments of soil and water quality may include physical, chemical, and biological aspects.

Environmental pollution is a major concern for many people. When sources of soil and water pollution are enumerated, agriculture is, with increasing frequency, listed as a major contributor. Many materials are designated as a source of water pollution. For example, sediments, nitrates, phosphates, and organic materials, have been entering streams and lakes in increased amounts since the first sod was ploughed. The concentration of these pollutants in water is generally increasing with time and a large proportion of such pollution is from agricultural land (Schwab et al., 1996).

Soil erosion, runoff, and sediment transport are natural processes. But in many areas, human activities on the land have accelerated the rate of these natural processes. Some areas of the world are also experiencing the problems that arise when too much nutrient-rich topsoil reaches streams and lakes.

Soil erosion is occurring in most of the agricultural land. The problems caused by growing crops increase as more marginal land is brought into production, and less crop residue is returned to the soil for protection and improvement. In some areas of world the productivity of eroded soils cannot be restored, even with heavy applications of fertilisers and other fossil energy inputs (Barrow, 1991).

Soil erosion occurs on all cropland to various degrees, including the irrigated land when water applications are excessive or inadequately controlled. When soils become compacted, water from rainfall and snowmelt infiltrates more slowly, and runoff and erosion tend to increase. This phenomenon often occurs on land repeatedly used for intensively tilled crops. Agricultural management practices that cause deterioration of the soil structure usually also increase the potential for water pollution by runoff and sediments (Beasley et al., 1984).

Soil can be transported to rivers or lakes in runoff that has originated from uniform movement of water over the land surface, a process known as sheet erosion, or from concentrated flow resulting in the formation of rills and gullies. Water erosion is often difficult to identify when visible rills or gullies are not formed.

Although farmland may contribute only a relatively small amount of sediment per unit area, the total sediment load from all agricultural land is generally significant. The presence of sediment decrease both the physical and chemical quality of water. Once the eroded soil particles are carried into waterways they create problems such as suggested by Beasley et al. (1984):

(a) the accumulation of silt, causing reduced channel capacity;
(b) the alteration and destruction of aquatic habitats;
(c) accelerated eutrophication by increased concentrations of plant nutrients, fertiliser levels, decreased recreational values and increased turbidity;

(d) increased concentration of heavy metals, pesticides, and other toxic compounds; and

(e) increased water treatment costs, which are incurred by efforts to return water quality to standards suitable for human consumption.

The above mentioned reports reflect increasing concern about how various tillage and crop management practices are affecting surface water and groundwater quality, air quality, soil erosion, off-site sedimentation, and environmental quality. Finding solutions to these problems is of the utmost importance for researchers. Further research to more accurately characterise tillage practices and their effects on soil and water quality is a part of finding these solutions.

1.2 Research Objectives

Soil conservation and land improvement are very important for environmental and agricultural sustainability. Water and wind are the most active eroding agents on the surface of the earth. Soil erosion is often caused by the use of land for agricultural and related purposes. Traditional agricultural tillage practices cause water and air pollution and deterioration of land. Conversely, conservation tillage systems reduce soil erosion and improve soil and water quality.

The specific objectives of this study were as follows:

(a) To determine the effects of selected tillage practices and a cropping pattern on the properties of a silt loam soil.

(b) To measure the amount of surface water runoff and leachate, and the concentration of soil sediment and nutrients in the surface water runoff and leachate.

Soil properties that were measured included soil physical characteristics viz. bulk density, water content, water infiltrability, penetration resistance, pH, and biological properties viz. earthworm populations. In surface water runoff, and leachate, the properties measured were concentration of nitrogen (N), phosphorus (P), potassium (K), and pH value.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Recently, scientists have been interested in the effect of land use on soil and water quality, and agricultural sustainability. But assessment is very difficult because soil and water quality evaluations are often purpose and site-specific. In this review the intention is to analyse possible reasons of the tillage effects on soil and water quality, and to examine the effects of agricultural practice on physical, chemical and biological aspects of soil and water quality.

Land is a very important element in human life. The soil is a critically important component of the earth's biosphere. Doran and Parkin (1994) have quoted the Chinese saying, "**THE SOIL IS THE MOTHER OF ALL THINGS**" as a simple statement of the importance of soil for the sustainability of life of all terrestrial living creatures. Conservation of soil is important to protect the environment against pollution and erosion.

For the survival of the human race, soil provides resources for the growth of arable crops, plants and trees, which provide food, fibre for clothes, and timber for buildings and fuel. Together with water, air and radiation from the sun, the top one and half metre or so of the earth's crust provides these essentials of life.

2.1.1 *Effects on Environment*

Land used for agriculture makes up one of the largest environmental units managed in the world. New technology and genetic improvements to plants and animals have increased farm productivity dramatically over the past three decades. Lal (1993) has described how land management is often the main factor that determines whether the environmental effects of agriculture are positive or negative. Little attention has been paid to the possible environmental consequences of many newly developed farming activities. Land deterioration and the resulting environmental problems may be difficult to recognise on individual farms because the processes involved such as surface runoff and sediment are so widely distributed.

Many scientists have stated that soil erosion and water runoff cause serious offsite environmental effects and reduce the productivity of the land. Soil erosion sediments which may fill riverbeds, lakes, and reservoirs, significantly reduce their usefulness for navigation, irrigation, hydroelectric power, fisheries, and recreation. Also sediments may interfere with fish spawning and general survival of the fishery (Beasley et al., 1984; Loehr, 1984; Carlson et al., 1993; Schwab et al., 1996).

Agricultural practices accelerate eutrophication by the nutrient load added to lakes and other water bodies. This is a major problem for fish productivity of fresh water aquatic systems. The increased concentration of plant nutrients fertilises the lake and leads to increased plant productivity. Eventually this increased productivity results in decreased oxygen concentration, and severely interferes with the food web relationship. The geological nutrient pool is the ultimate source of all nutrients for a given lake (Macgregor and Keeney, 1975; FAO, 1984; Carlson et al., 1993).

Sediments deposited in lowland agricultural lands often reduce plant growth and have a negative impact on productivity. Rapid water runoff from agriculture and other land results in flooded lowlands, destruction of crops, livestock, property, and sometimes people (Beasley et al., 1984).

The agricultural community should take precautions to protect the environment from any degradation arising from such activities. Farmers need to act urgently, and develop an understanding of the impact that various farming practices may have on the environment. Soil and water conservation may be the only way for environment conservation and agricultural land sustainability.

2.1.2 *Soil and Water Conservation*

Soil and water conservation remains vitally important to the future of world food production and, therefore, to humanity's survival. Since 1930s basic erosion research has led to a better understanding of the mechanics of soil erosion processes and the way in which erosion can be controlled. As a result of this work it is frequently argued today, though perhaps not completely justifiably, that the technology for soil and water conservation exists and that the major research effort ought now to be placed on the problems of implementation. It is in the social and economic environment that the reasons for the failure of soil and water conservation schemes too often lie. Improvements in the design and implementation of soil and water conservation strategies will only come about if the agricultural engineers and geomorphologists carrying out the bulk of the erosion research learn more from the economists and sociologists about the conditions in which the results of their work will be applied.

Lal (1991) described that the principal method of controlling soil erosion and its accompanying rapid water runoff is maintenance of adequate vegetative cover. Plants and biomass intercept and dissipate the enormous energy in raindrops, enabling the water to reach the soil without damage. Furthermore, plant stems, roots, and organic matter help reduce runoff by 90% or more and enhance water infiltration and percolation into the soil. Lessons from natural forest performance indicate the extreme importance of forest litter, and thus low-lying ground covers, in imparting effective protection against runoff and erosion.

A variety of conservation technologies are available, that are effective in preventing soil erosion. The proven conservation technologies for different soils, slopes, crops, and rainfall and wind conditions include: (a) crop rotations, (b) strip cropping; (c) contour planting; (d) terraces; (e) mulches; (f) no-till planting; (g) ridge planting; (h) grass strips; and various combinations of these conservation technologies. The matching of alternative practices with specific soil, climates, and topographies remains a high-priority subject for future quantitative research. It is encouraging to learn about the actions of individual farmers in all nations who have implemented integrated soil and water conservation programs (Lal. 1991; Carlson et al., 1993; Schwab et al., 1996; Carter, 1994; Choudhary and Baker, 1994).

2.2 Principles of Tillage

Tillage systems play an important role in maintaining productivity of soils. The choice of a suitable tillage system depends on soil characteristics, the nature of the crop to be grown, agro-ecological environments, and the socio-economic status of the farming community. Different tillage systems are required for a range of soil management problems. Farmers prefer to have a choice of tillage systems, so that they may select appropriate methods of seedbed preparation which fit in with the specific soil management constraints (Lal, 1979).

Marshall and Holmes (1979) described the still widely accepted practice of traditional tillage as based on a series of primary cultivations (aimed at breaking the soil mass into a loose system of clods of mixed sizes) followed by secondary cultivation (aimed at further pulverisation, repacking, and smoothing of the soil surface). These practices, performed uniformly over the entire field, often involved a whole series of successive operations, each of which was necessary to correct or supplement the previous operation. In the process, energy was often wasted and natural soil structure destroyed.

Hillel (1980) described the more modern approach to soil structure management of a field typically planted to row crops as consisting of at least two distinctly different zones:

(a) A planting zone, where conditions are to be optimal for sowing and conducive to rapid and complete germination and seeding establishment.

(b) A management zone in the inter-row areas, where soil structure is to be coarse and open, allowing maximal intake of water and air, and minimal erosion and weed infestation.

These two zones differ in function as well as in mode of preparation and management.

Hence, there are no universal prescriptions for what constitutes efficient tillage. Some but not all soils have suitable tilth quite naturally and require little, if any, tillage to serve as favourable media for crop growth. Others, however, exhibit pans or barriers which inhibit root penetration and hence can be improved by appropriate tillage.

2.3 Types of Tillage

The objectives of soil tillage have been stated by many authors. In the early stages, the tillage was defined in simple terms such as 'turn over the top layer', 'loosen the soil' or 'increase the fertility of the soil', but these statements were without any apparent knowledge or clear view of how these objectives improved soil properties or benefited crop growth. Generally, the main purpose of tillage was to improve the physical and nutritive value of the soil. Kuipers (1970) described that the tillage operations were done with the idea of increasing the 'fertility' of the soil by creating favourable soil physical conditions and raising the 'natural productivity' of the soil to a higher level than under natural uncultivated conditions. Hillel (1980) stated that tillage is usually defined as the mechanical manipulation of the soil aimed at improving soil conditions affecting crop production. Considering the purposes of tillage, Lal (1979) has defined tillage as the physical, chemical or biological soil manipulation to optimise conditions for seed germination, emergence, and seedling establishment.

Three primary aims are generally attributed to tillage: (a) control of weeds, (b) incorporation of organic matter into the soil, and (c) improvement of soil structure (McKyes, 1985). An auxiliary function of tillage is the conservation of soil moisture mainly due the removal of weeds where the processes of rain infiltration, runoff, and evaporation are involved.

Dickey et al. (1992) have described tillage more broadly as a sequence of mechanical operations that manipulates the soil to produce a crop including:

- Tillage.
- Planting.
- Harvesting.
- Chopping or shredding residue.
- Applying pesticides and fertilisers.

The advent of chemical herbicides seems to have reduced the importance of tillage as the primary method for eradication of weeds. However, lately there have been growing objections to the application of more and more toxic chemicals in agriculture, owing to their residual damage to the larger environment and their increasing cost. Hence, there is once again increasing interest in the weed-controlling aspects of tillage. In the less developed countries, the unavailability, as well as the lack of knowledge of appropriate herbicides may limit their use in any case.

Hillel (1980) argues that tillage practices suitable in one location may become harmful in another. Arid-zone soils with low organic matter contents and unstable aggregates are particularly vulnerable to compaction, crusting, and erosion. The precise effects of tillage on soil structure and quality must be defined and optimised in each case, if tillage is to be transformed from a hit or miss art to a scientifically based, dependable, and sustainable part of food and fibre production.

2.3.1 *Conventional Tillage*

Conventional tillage is the sequence of operations most commonly used in a given geographic area to prepare a seedbed and produce a given crop (Dickey et al., 1992). Because operations vary considerably under different climatic, agronomic and other conditions, the definition of conventional tillage varies from one region to another and even within a region. The series of operations in conventional tillage usually leave much less than 30% residue from the previous crop on the surface after planting (Phillips and Young, 1973; Dickey et al., 1992). Conventional tillage is often used as a standard or check in experiments to assess the potential of other tillage systems to maintain residue cover in a given area.

Many conventional tillage systems leave the surface bare, particularly those based on the use of the mouldboard plough. However, a bare soil surface can be achieved with other tools, depending on the previous crop, the amount of surface residue, and number and timing of tillage operations.

Primary tillage of soil is mainly for the cutting and loosening of soil to a depth of 15 to 45 cm. The mouldboard plough is the most common primary tillage tool in the world, and has the capacity to break up many types of soil. It has the further ability to turn over and cover sod, crop residues and weeds. For special applications there are a great many types of plough, including stubble, clay soil, stiff-sod, blackland, chilled general purpose and slatted ploughs. They may be used singly or in groups from two to a large number of shares, with the width of each ploughshare being between 25 and 45 cm or more (Hillel, 1980; Mckyes, 1985).

There are also other common primary tillage tools such as the disc plough, chisel plough, and rotary plough. The disc plough has a hardened steel round concave discs of 50 to 95 cm in diameter. The discs have sharpened and sometimes serrated edges, and are often fitted with self-cleaning scrapers (McKyes, 1985).

Chisel ploughs are well adapted to loosening hard dry soils, shattering hard pans and soles, and conserving the mulch of crop residues on the field surface, which is useful for soil and water conservation in some areas (Lal, 1979).

The rotary plough requires a mechanical power source, usually provided by an auxiliary drive on the towing tractor. Using this tillage systems, a good level seedbed of very loose soil is created, but it is expensive due to increased capital, maintenance and energy costs compared to other primary tillage tools. The rotary plough is used extensively in intensive vegetable production, but is not recommended in areas where severe soil erosion due to wind or water flow are prevalent, especially in light or organic soils. It is quite destructive to soil aggregates.

McKyes (1985) has described that secondary tillage operations usually are performed after a primary treatment on a field for one or more purposes. The aims are improved seedbed levelness and soil structure, increased soil pulverisation, conservation of moisture, destruction of weeds, and chopping of crop residues.

2.3.2 *Conservation Tillage*

Conservation tillage has been defined as a system in which crop residues are retained either on or near the soil surface, a rough soil surface is maintained, or both, to control soil erosion and to achieve good soil-water relations (Dickey et al., 1992). Mannering and Fenster (1983) have defined conservation tillage as: "any tillage system that reduces loss of soil or water relative to conventional tillage; often a form of noninversion tillage that retains protective amounts of residue mulch on the surface".

To be conservation tillage, the system must produce, on or in the soil, conditions that resist the erosive effects of wind, rain and flowing water. This resistance is achieved by:

- Protecting the soil surface with crop residue or growing plants.
- Increasing surface roughness.
- Increasing soil permeability.
- A combination of the above.

Conservation tillage is most commonly defined as any tillage system that maintains at least 30% residue cover on the soil surface after planting, to reduce water erosion, or small grain residue equivalent on the surface during the critical erosion period to reduce wind erosion. Conservation tillage is an umbrella term used for tillage intensity ranging from zero-tillage (no-tillage) to other forms of non-inversion soil tillage practices that have the potential to increase (or at least maintain) crop yield, and reduce soil and water runoff relative to conventional tillage. In contrast, conservation tillage systems allow the retention of surface residues, reduce soil erosion, improve soil structure, enhance soil moisture retention, increase organic matter exchange and nutrient levels, and improve environmental quality and agricultural sustainability (Mannering et al., 1987; Lal, 1991; Dickey et al., 1992; Choudhary and Baker, 1994).

Taking into account different tillage practices, Mannering et al. (1987) have defined the types of conservation tillage as follows:

1. **No-till or slot planting**: The soil is left undisturbed prior to planting. Planting is completed in a narrow seedbed approximately 2-8 cm wide. Weed control is accomplished primarily with herbicides.

2. **Ridge-till** (includes no-till on ridges): The soil is left undisturbed prior to planting. Approximately 1/3 of the soil surface is tilled at planting with sweeps or row cleaners. Planting is completed on ridges usually 10-15 cm higher than row middles. Weed control is accomplished with a combination of herbicides and cultivation. Cultivation is used to rebuild ridges.

3. **Strip-till**: The soil is left undisturbed prior to planting. Approximately 1/3 of the soil surface is tilled at planting time. Tillage in the row may consist of a rototiller, in-row chisel, row cleaners, etc. Weed control is accomplished with a combination of herbicides and cultivation.

4. **Mulch-till**: The total surface is disturbed by tillage prior to planting. Tillage tools such as chisels, field cultivators, discs, sweeps, or blades are used. Weed control is accomplished with a combination of herbicides and cultivation.

5. **Reduced-till**: Any other tillage and planting system not covered above that meets the 30 percent residue cover requirement.

2.4 Soil and Water Quality

Soil and water quality can impact on land use, sustainability, and productivity. Human and animal health are closely linked to soil and water productivity and environmental quality. So soil and water quality investigations are needed to provide information for management and regulatory decisions.

Loehr (1984) has found that many potential soil and water quality problems are associated with the residues from agricultural production operations. These residues can be in the form of animal waste at animal production facilities, runoff and leachate from fertilised and manured fields, and liquid and solid wastes generated from agricultural practices processing operations. Residues of this nature always have been associated with agriculture, but have become more noticeable because the natural cycles associated with agriculture have been altered and in some situations broken.

2.4.1 *Soil Quality*

Doran and Parkin (1994) state that a good soil acts in the following ways :

1. It provides water, nutrients and anchorage for plants and trees in natural forests and grasslands, and for annual and perennial crops.

2. It provides the habitat for decomposition organisms. These have an essential role in the cycling of carbon and mineral nutrients.

3. It acts as a buffer for temperature change and for the flow of water between the atmosphere and ground water.

4. Because of its ion exchange properties it acts as a pH buffer, and retains nutrient and other elements against loss by leaching and volatilisation.

Turco et al. (1994) have defined a soil quality attribute or indicator as a measurable soil property that reflects the capacity of a soil to perform a specified function. Several indicators have been suggested that may be able to detect changes over various spatial and temporal scales. Examples of indicators most affected by soil degradation processes include topsoil depth, soil organic matter content, and electrical conductivity. Selection of indicators that are sensitive to management practices would also be desirable. Several biological attributes, including microbial biomass, respiration, amino acids, soil enzymes, and earthworm activity have also been suggested as soil quality indicators. Physical properties, which influence biological activity such as air-filled or water-filled pore space, have also been identified as important indicators. Water-filled pore space and many of the biological indicators, are much more temporary and perhaps spatially dependent than physical indicators such as bulk density, or chemical indicators such as cation exchange capacity (CEC), but they can be very responsive to soil and crop management practices.

Haynes et al. (1991) found that aggregate stability and size distribution may be useful indicators for evaluating the soil quality effects of agricultural practices, such as tillage, because these measurements often reflect resistance of soil to erosion. Soil dispersion in water has also been related to erosion and runoff. Soil organic matter influences soil quality, because decreases in this parameter can be directly related to decreased water stability of both macro-and micro-aggregates. Changes in microbial biomass carbon is especially important with regard to aggregate stability following various soil and crop management practices.

Karlen et al. (1994) considered that microbial biomass, respiration, and ergosterol, a sterol common to fungal tissue that can be used as an index of fungal biomass, are useful biological indicators for assessing long-term soil and crop management effects on soil quality. Periodic assessments of soil test properties have also been suggested as important chemical indicators of soil quality.

Several approaches for assessing soil quality are currently being evaluated. A common attribute among all these approaches is that soil quality is being assessed with respect to specific soil functions. The critical soil functions identified were the need to:

1. Accommodate water entry;
2. Facilitate water transfer, adsorption, and delivery;
3. Resist degradation;
4. Support crop growth;
5. Produce safe food and enhance human and animal health.

As mentioned above, the basis of soil quality is the capacity of the soil to function effectively at present and in the future. Doran and Parkin (1994) have defined soil quality as "The capacity of a soil to grow a crop in a sustained manner, to store water and to enhance environmental quality, and promote human and animal health".

2.4.2 *Soil Water Quality*

The soil is a reservoir for water and chemicals, including plant nutrients. Water is removed from the soil reservoir by evapotranspiration (evaporation plus transpiration). The rate at which water is removed from the soil by plants and the amount of water stored in the soil following rainfall or irrigation, partly determines the type of plants to be grown, plant spacing, yield, and general management criteria.

Mclaren and Cameron (1996) have described how water is added to the soil as precipitation (i.e. rainfall, hail, snow, dew) or as irrigation. When water is applied to a dry soil, a certain amount will be absorbed or stored before drainage starts. If the rate at which the soil is capable of infiltrating and transmitting is exceeded, then some water will either pond on the surface, or runoff downslope.

Water quality is determined by the biological, chemical and physical contaminants. Most water pollution is the result of human activities. Biological contaminants result from human and animal wastes plus some agricultural practices. Chemicals enter the water from the agricultural use of fertilisers and pesticides. Physical contaminants result from erosion and disposal of wastes from agriculture. Since all of these sources contribute to degradation of water quality, standards have been developed for drinking water (Eckenfelder, 1970; UNESCO/WHO, 1978; Vesilind et al., 1994, Schwab et al., 1996).

Eckenfelder (1970) found that agricultural runoff is a major contributor to eutrophication in lakes and rivers. Effective control measures have yet to be developed for this problem. Runoff of pesticides is also receiving increasing attention.

Lal (1994) found that erosion impacts on water quality through transport of sediments and sediment-borne pollutants. Soil erosion increases eutrophication of water and accentuates environmental pollution. In addition, chemical laden sediment may account for an equivalent, if not greater, quantity of chemicals transported in the world's rivers than that in solution. The impact on water quality is a major off-site effect of accelerated erosion.

Schwab et al. (1996) considered the standards of drinking water set to prevent health problems. They defined the quality of water considered safe for human consumption. They also indicated that in standard drinking water the maximum level of nitrate (expressed as N) should be less than 10.0 mg/l. The level of pH should be between 6.5 to 8.5, and there should be no coliform bacteria. Water temperature, colour, odour, and solids concentration are physical indicators of water quality. Suspended sediment is a common physical contaminant in irrigation and runoff water.

Bregman and Mackenthun (1992) noted water intended for human consumption must be free from organisms that are the causative agents of disease, and must not contain chemical substances at concentrations that may be hazardous to human health. In addition, drinking water should be aesthetically acceptable, and free from unpleasant or objectionable taste, odour, colour, and turbidity.

2.4.2.1 *Nonpoint source pollution*

Pollution sources include point (direct) and nonpoint (diffuse) sources. Corwin and Wagenet (1996) have described point sources that discharge from a point source such as a pipe or ditch at an identifiable location. A point source can be measured relatively easily, and therefore can be managed directly. Nonpoint source discharges, such as diffuse agricultural or urban runoff, are difficult to measure. Nonpoint source pollutions result from land based activities, such as crop production, and generally enter surface waters as land runoff.

If rain strikes the ground and ponds, a runoff process begins, and nonpoint source soil and water pollution is the unavoidable result. Even before people entered the picture, the rains came, raindrops picked up soil particles, muddy streams formed, and major water courses became clogged with sediment. This natural runoff is classified as "background" nonpoint source runoff and is not generally labelled as "pollution" (Loehr, 1984).

However, the world as it has been since the dawn of humankind, is a busy place where human activities including farming continue to influence our environment. Harvesting trees, constructing buildings and roadways, mining, and disposal of liquid and solid wastes all occur. Each activity has led to disruptions in the surface of the earth's soil, or has involved the application of chemicals to the soil. Increased transport of soil particles, with consequently increased sediment loading to watercourses, and the application of chemicals (e.g. pesticides and herbicides) to the soil, is generally labelled as pollution. So, agricultural practices are major activity causing soil and water pollution to increase above "natural" background levels.

The rates of erosion and resultant sediment have been accelerated by human activity and poor management of land, vegetation, and streams. The rates of erosion relate to how the land is being used and the characteristics of the soil. Land covered with permanent natural vegetation has lower erosion rates than does the land that is intensively used for agriculture. On cropland, the erosion can range from less than 3 to more than 50 tons/acre/year (Loehr, 1984).

Schwab et al. (1996) found that chemicals are a major source of water contamination. Some chemicals occur naturally in soil water, others are introduced naturally during water movement through geological materials. But most problems are caused by manufactured chemicals and agricultural pollution. Fertilisers and pesticides are the major contributors to water pollution by chemicals from agriculture. These chemicals are applied to soil or foliage over large areas, and hence become potential sources of nonpoint source pollution.

2.4.2.2 *Effects of nutrients*

Recently, there has been much concern about the effects of nutrients in agricultural drainage waters, because of their potential importance to the water quality of streams, lakes, rivers, and reservoirs (Schwab et al., 1996).

One of the most challenging problems is that of excessive nutrients and the conditions they can cause. Of particular concern are nitrogen and phosphorus compounds. Although these elements are needed in small amounts for all living matter, excessive amounts in surface waters can result in overfertilization and can accelerate the process of eutrophication. Other concerns include excessive amounts of nitrate in groundwaters and surface waters, ammonia toxicity to fish, altered effectiveness of chlorination by ammonia, and the oxygen demand of reduced nitrogen compounds in surface water (Loehr, 1984).

Robinson and Sharpley (1995) found that nitrogen and phosphorus have frequently been implicated as the cause of excessive growth of algae and other aquatic plants in surface waters. These nutrients enter a body of water, and through biological reactions driven by solar energy (photosynthesis), are fixed and utilised in the food chain. Increased concentrations of nitrogen and phosphorus in surface water increase eutrophication and debase water quality.

Baker (1987) noted that agriculture is a major source of phosphorus entering freshwater rivers and lakes. However, conservation tillage was identified as a potentially effective means of reducing erosion, and the associated suspended sediment and particulate phosphorus loading into freshwater rivers and lakes. He also found that, since conventional water treatment procedures do not remove nitrates, the nitrate concentrations present in the rivers are also present in the treated water supplies. The nitrate concentration in ground water frequently exceeds the World Health Organisation drinking water standard of 10 mg/l nitrate-nitrogen. The effects of watershed size on the nitrate concentration patterns in area streams and rivers are illustrated in the concentration-duration curves. As conservation tillage increases infiltration and, consequently, the proportion of stream water derived from tile effluents, it is likely that the percentage of time nitrates exceed the drinking water standard will increase.

2.4.2.3 *Water quality in New Zealand*

In New Zealand there are a variety of causes of poor water quality at farmland because some agricultural practices that have been used, have adverse effects on water quality. A survey carried out by the New Zealand Ministry of Agriculture and Fisheries showed that conservation problems associated with agriculture were the most important cause of water quality problems in New Zealand

(Turner, 1991). Many of lowland streams and lakes in New Zealand have been described as having "poor" water quality. These waters often have profuse aquatic plant growth and are turbid. Algal growth in lakes reduces clarity and produces unsightly scums. Nitrate and phosphorus concentrations in groundwater in some areas exceed drinking water standards (NZMFE, 1994). The most widespread problem is faecal contamination. Many lowland river reaches may often be unsuitable for contact recreation, and some may not be suitable for stock watering.

In New Zealand, phosphorus has commonly been regarded as the major nutrient involved in the eutrophication of surface water. By world standards the concentration of phosphorus in waters here is high, whereas that of nitrogen is low (NZMFE, 1994). Thus it is possible that nitrogen is more limiting in New Zealand waters and that additions of nitrogen could result in increased eutrophication. There has also been concern expressed overseas about the accumulation of nitrate in drinking water, because it has been established that excessive ingestion of NO_3 by young mammals including humans may lead to metabolic problems resulting from nitrate reduction to nitrite.

Agriculture is important for New Zealand economy, with gross production of $8.4 billion per year, It makes up 47 percent of our exports. However, agricultural production is not without environmental impacts, which are not surprising, given that pasture and arable land make up 52 percent of New Zealand's land area (NZMFE, 1994).

2.5 Tillage Effects on Soil and Water Quality

Usually when assessing soil and water quality, three kind of indicators may be used, viz. physical, chemical, and biological. Long-term tillage practices will affect all these three aspects.

2.5.1 *Physical Effects*

During tillage, soil is fractured and then turned over leading to rough surface conditions. The roughness of the surface after tillage depends upon the depth of tillage, type of tillage tool, texture, and pre-tillage soil physical conditions such as density and wetness (Marshall and Holmes, 1979; Acharya and Sharma, 1994). Tillage done with heavy machinery also produces a zone of compaction which is a function of the machinery weight (Mckyes, 1985). In addition, a compacted zone at the base of the manipulated soil may also form because of smearing by the tillage tool.

Soil physical properties are essential inputs to the models of soil physical processes and crop growth. In most existing models, soil physical properties correspond to those of untilled soil conditions. Alegre et al. (1991) found that tillage effects in these simulation models are generally accounted for by varying the bulk density of the soil. The usefulness of crop growth models can be greatly enhanced if physical models, are included as sub-models that describe the effects of tillage on soil physical properties.

The bulk density of the soil in the tilled zone is much lower than the density in the compacted zones. Lower density in the tilled zone results from the fracture of soil by tillage implements which leads to the formation of clods or aggregates. Gupta et al. (1991) used a packing model to show the differences in density for several aggregate size distributions of Webster clay loam soil. Input to the packing model included the proportion of various size fractions of aggregates in the soil, the bulk density of each aggregate fraction, and the bulk density of an aggregate within each fraction. The packing model, however needs further testing on other soil types but more importantly in the tilled zone under field conditions. There are three questions with the field testing: (a) can tilled soils be represented by an aggregate size distribution? (b) is the placement of aggregates after tillage random? (c) what is the variation in the aggregate size distribution within the till zone?

Soil hydraulic conductivity is very sensitive to changes in soil porosity, pore size distribution and bulk density. A small increase in bulk density often causes a very large decrease in hydraulic conductivity (Karlen et al., 1994; Choudhary, 1995). Thus, hydraulic conductivity has been recognised as a potentially sensitive measure of soil compaction. However, hydraulic conductivity measurements are very time consuming and highly variable.

Table 2.1. shows the effects of tillage on soil physical factors in central Ohio, USA. Increased tillage intensity decreased soil saturated hydraulic conductivity, penetration resistance, soil organic carbon and soil bulk density (Mahboubi et al., 1993). It is interesting to note that the organic carbon content, penetration resistance, and bulk density by no-tillage method is higher than with the chisel and mouldboard ploughing methods. On the other hand, saturated hhydraulic conductivity was much higher in the untilled soils than both the minimum tilled or conventionally tilled soil. These data suggest that continuous tillage reduces soil organic matter and destroys soil structure, whereas no-tillage generally conserves soil quality.

Table 2.1 Long-term (28 years) tillage effects on soil erodibility and water quality.

Factors	NT	CP	MP
Organic carbon (%) (original 1.4%)	2.3	1.5	1.0
Bulk density (mg/m^3)	1.34	1.32	1.31
Particle density (mg/m^3)	2.47	2.54	2.53
Porosity (%)	45.6	48.2	48.3
Penetrations resistance (MPa)	0.29	0.17	0.17
Saturated hydraulic conductivity (m/d)	13.0	0.9	0.2

NT: No-tillage, CP: Chisel ploughing, MP: Mouldboard ploughing.
Source: (Mahboubi et al., 1993)

Karlen et al. (1994) have collected soil property data showing tillage effects on soil gravimetric water content, water-filled pore space, particle size analysis, and pH in the top 50 mm of soils following 12 years of various tillage treatments (Table 2.2). They also reported that sediment concentrations and estimated soil loss from the long-term no-till treatment were significantly lower than those from the conventional tillage treatment (Table 2.3).

Table 2.2 Tillage effects on soil gravimetric water content, water-filled pore space, particle size analysis, and pH in the 50 mm of soil following 12 years of various tillage treatments.

Tillage treatment	Water content (%)	Water-filled pore space (%)	Clay (%)	Silt (%)	Sand (%)	pH
No-till	32.4	86.5	15.7	79.5	4.8	5.8
Chisel	25.5	58.6	16.8	77.9	6.2	6.2
Plough	23.1	64.5	17.4	78.2	4.5	6.2
$LSD_{(0.05)}$	5.9	15.3	NS	NS	NS	NS

(Karlen et al., 1994)

Karlen et al. (1994) also stated that the amount of surface cover such as crop residues may have affected simulated raindrop impact energy. But it also affected the water stability or soil aggregates, a predominant factor assumed to affect water entry.

Ward et al. (1994) found that conservation tillage systems reduced erosion by reducing surface runoff and soil detachment by raindrops and runoff. The impact of these processes on water quality depends on the water solubility and soil water partitioning behaviour of potential water pollutants. In the case of a non-partitioning, water-soluble pollutant like nitrate (NO_3), tillage practices which reduce runoff volume will reduce potential chemical loadings to surface waters.

Table 2.3 Runoff, sediment concentration, and calculated soil loss measured from historical plough and no-till treatments, 10 days after soil quality assessments were made.

Tillage treatment (date)	Runoff amount (mm)	Sediment concentration (g/l)	Estimated soil loss (Mg/ha)
Mouldboard plough (1/5/91)	33a[a]	3.8a	1.1a
No-till (1/5/91)	35a	1.5b	0.5b
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Mouldboard plough (23/5/91)	42a	5.0a	2.1a
No-till (23/5/91)	35a	1.4b	0.5b

[a]Means for each sampling date within a column followed by the same letter are not significantly different at $P \leq 0.10$ *(Karlen et al., 1994).*

2.5.1.1 *Surface water and sediment runoff*

Beasley et al. (1984) described surface runoff as precipitation that flows over the ground surface and through channels to larger streams. Another part of precipitation infiltrates into the soil and moves laterally to surface drainage ways. This is subsurface flow or interflow. In the design of structures for the control of erosion and conservation of water on small areas we are primarily concerned with surface runoff.

Before surface runoff can occur, precipitation must be in excess of that required for evaporation, interception, infiltration, and surface detention. The amount of water intercepted and evaporated during an intense rain of long duration is so small that it will have little effect in reducing surface runoff. On the other hand, a light rainfall may be almost entirely intercepted by dense vegetation.

Sediment is also of concern because it can reduce soil and water quality and degrade the areas in which it is deposited. Lal (1994) stated that on a mass basis sediment is major nonpoint source pollutant. Eroded soil fills irrigation canals and reservoirs reducing their capacity; and restrict drains, increasing flooding problems. Sediment directly damages fish and other wildlife habitats and their food supplies. Indirectly, sediment causes further damage by carrying nutrients and pesticides from agricultural land into bodies of surface water.

In Europe, reported soil loss rates by surface water and sediment runoff range from 10 to 20 t/ha/yr. Soil loss rates on cropland in Africa, Asia and South America range from 20 to 40 t/ha/yr (FAO, 1993). In New Zealand, soil loss rates on most cropland range from 15 to 30 t/ha/yr (NZMFE, 1994).

2.5.1.2 *Soil infiltration rate*

Beasley et al. (1984) have defined infiltration as the movement of water into soil. The higher the rate of infiltration, the lower the rate of surface runoff and erosion. During a rainstorm the maximum infiltration rate usually occurs at the beginning of the rain, and the rate may decrease very rapidly if structural changes in the surface soil occur. If the rain continues, the infiltration rate gradually approaches a minimum value. This value is determined by the rate at which water can enter the surface layer and can be transmitted through the soil profile.

Tillage practices such as cultivation have the effect of temporarily loosening the surface soil and increasing infiltration. However, if the surface is not protected by vegetation or mulches, rain and wind soon consolidate the surface and reduce the infiltration rate. So, special methods of cultivation such as conservation tillage systems may be used under certain conditions to increase infiltration and prevent surface sealing. So called "subsurface cultivation" stirs the ground beneath a surface mulch.

2.5.2 *Chemical Effects*

Alvarez et al. (1995) found that soils possess remarkable powers of breaking down synthetic organic pesticides. Soil micro-organisms such as bacteria and fungi need carbon for energy in much the same way as animals need carbohydrate. Normally they get carbon from plant and animal remains, but many types are able to adapt and use the carbon in pesticides. Often there is a time lag while the organisms adapt themselves to the new source of food. Some herbicides break down in a matter of days, while others are more persistent, particularly soil acting herbicides, some of which may take a year or more to disappear completely. Thus there may be a hazard to an autumn-sown crop following the crop to which a soil acting herbicide was applied in the spring. However, all the evidence indicates that there is no long-term hazard, either to crops or soil micro-organisms, provided the herbicides are used correctly and overdosing is avoided.

Karlen et al. (1994) stated that high quality soil must have a readily available supply of plant nutrients. Organic matter is a major soil component which is influenced by tillage. Their estimates of carbon inputs to soil from crops did not differ among tillage systems. Consequently, the accumulation of organic matter under no-tillage cannot be ascribed to higher carbon inputs to the soil . A lower mineralization rate for soil organic matter under no-till appeared to be the cause of the greater organic carbon accumulation.

Soil organic matter influences a wide range of soil chemical properties, and many experiments have shown that both the quantity and quality of the organic matter present is important. Angers and Carter (1996) reviewed the subject of soil aggregation and analysed the many effects of organic matter. They stressed the importance of maintaining a high level of microbial activity to maintain stable aggregation in soils, and this was best brought about by the regular addition of organic residues in the soil. According to Angers and Carter (1996) it is generally agreed that organic matter plays a key role in soil aggregation. Other researchers (Lal, 1991; Karlen et al., 1994; Choudhary, 1995) have confirmed that the main effect of organic matter is prevention of breakdown of aggregates. Clearly the binding action of living micro-organisms and of their products disappears when the food supply becomes exhausted and the number of micro-organisms declines; although some organic compounds or by-products remain and give some long-term soil structure stability.

Karlen et al. (1994) report that different tillage systems affect the total N concentration in the soil. At 0 to 25 mm depth there was almost twice as much N in the no-till treatment (3.0 mg/cm^3) as in the chisel (1.6 mg/cm^3) or plough (1.5 mg/cm^3) treatments. Significant differences at the 25 to 75 mm depth were due to the lower total N concentration in soil from the conventional tillage treatment, while at the 75 to 150 mm depth, the long-term chisel treatment had the highest total N concentration. They also found that the nitrate concentration in the soil was significantly different between conventional tillage systems and conservation tillage systems at the 0 to 25 mm and 75 to 150 mm depths. The total N values in the surface were higher for the long-term no-till treatment than for the conventional tillage treatment, so presumably this reflects more N being incorporated into microbial biomass near the soil surface and less available for mineralization and possible leachate.

Tillage practices may have effects on soil N, P, K concentration and soil pH. Choudhary et al. (1996) found long-term tillage effects on soil pH. Surface water runoff pH was higher in the mouldboard plough and chisel plough treatments than in the no-tillage treatment (Table 2.4). This suggested that soil pH decreased with increasing tillage intensity. But, other researchers (e.g. Karlen et al., 1994) found that soil pH was not affected by tillage practices. Over the normal field soil pH range from 5 to 7, most soils carry net negative charge. Long-term use of chemical fertilisers will generally decrease soil pH. Karlen et al. (1994)

have also reported that P and K concentration in soil were more stratified in the long-term no-till treatment than in the conventional tillage treatment.

Table 2.4 Surface water runoff and leachate pH as effected by tillage practices.

Treatment	pH in runoff	pH in leachate
MP	6.99a	-
CP	6.95a	6.80a
NT	6.62b	6.70a
LSD ($P = 0.05$)	0.22	0.20

NT: No-tillage, CP: Chisel ploughing, MP: Mouldboard ploughing (Choudhary et al., 1996).

2.5.3 *Biological Effects*

The exact role that the biological aspects of soil play in maintaining a high soil quality is unclear. This lack of clarity reflects two underlying problems:

1. a lack of a common set of biological indicators;
2. a recent realisation of the magnitude of diversity and interaction within the biotic portion of soil.

It is argued that the "tools" to address the structure and function of the soil microbial community are now available. Using these tools, there is now much greater potential to evaluate the role the soil microbial community plays in maintaining a healthy and productive soil environment. A better understanding of the role and function of soil micro-organisms and microbial processes in soil quality should be forthcoming (Alvarez et al., 1995) .

It is important to understand changes as a result of agriculture and to develop parameters for measuring soil quality. Karlen et al. (1994) found that decreases in soil organic N and net N mineralization rates under prolonged cropping with the burning of residues could indicate a decrease in the active pool of soil organic N . The evaluation of the absolute and relative size of the biologically active pool of soil organic N could contribute to a definition of soil quality. Generally, burning can control crop residue after harvest, but surface residue is not returned back to soil. If residue was left at the soil surface, it would increase organic matter in the soil. As long as annual burning occurs it results in lower levels of soil organic matter, and net N mineralization rate, higher levels of plant productivity compared with no burning. Thus burning affects N cycling and use in the soil.

Alvarez et al. (1995) noted the microbial biomass excretions and decay products are effective in creating or stabilising aggregates, and possibly blocking of soil pores, during various stages of residue decomposition, and thus affect the structure and biological properties of the soil. Furthermore, introduction of high C to N ratio organic material should result in some gradual changes in the surface residues.

Tillage reduces the earthworm population, which directly affects soil quality (Nuutinen, 1992; Kladivko, 1993; Karlen et al., 1994). Earthworm activity provides an indication of soil quality for several reasons. Earthworms can increase the water stability of soil through the production of casts, and by excreting materials from their bodies. They can also influence water infiltration, water transport, and plant root development, by creating macro-porosity. Earthworms create channels in the soil, which can aid water and air flow as well as root development. Also earthworms improve soil structure and tilth (Nuutinen, 1992). Their casts are an intimate mixture of organic matter and mineral soil, and are quite stable after initial drying. The mixing of organic matter and nutrients in the soil by earthworms may have an important benefit in reduced tillage systems, especially no-till. The earthworms may, in effect, partially replace the work of tillage implements in mixing materials and making them available for subsequent crops (Kladivko, 1993).

Table 2.5 shows that increased intensity of tillage practices reduced earthworm population both in continuous corn as well as in continuous soybeans rotation. Furthermore when fields were continuously under pasture, the earthworm numbers increased markedly. When manure was applied to the pastures, the earthworm number increased further.

In New Zealand, many pastoral, arable and agricultural soils are known to be deficient in earthworms (Stockdill and Cossens, 1966). Springett (1992) found that earthworm population was significantly different under various tillage systems. Tillage is a major factor affecting earthworm population (Janson, 1984). Earthworm population markedly decreased as tillage intensity increased, although the grassland still had twice as many earthworms as the direct drilled fields (Table 2.6).

Table 2.5 Tillage practices effect on earthworm population.

Crop[a]	Management[a]	Earthworms/m^2
Cont. corn	Plough	10
Cont. corn	No-till	20
Cont. soybeans	Plough	60
Cont. soybeans	No-till	140
Bluegrass-Clover	Alleyway	400
Dairy pasture	Manure	340
Dairy pasture	Manure (heavy)	1300

[a]Crop and management systems had been continuous for at least 10 years (Kladivko, 1993)

Table 2.6 Number of earthworms under different cultivation regimes.

Treatment	Earthworms/m^2
Cultivated	69
Direct drill	499
Grassland	1005

(Springett, 1992)

On the other hand, tillage destroys some insects pests, or at least destroys their habitat, and the absence of tillage may result in an increased risk of a pest problem (Baker, 1980). There are effective chemical remedies available for the pests, although clearly this adds to the cost of crop production, and adversely affected the environment.

2.6 Cropping Rotation Effects on Soil Quality

The effect of crop rotation on soil quality has been studied by many researchers. These studies have indicated that crop rotation is an important factor which effects soil quality. Various cropping rotations impact soil physical conditions. (Horne et al., 1992; Machado and Gerzabek, 1993; Campbell et al., 1996; Chan and Heenan, 1996).

Plants can modify soil structure by affecting the soil formation as well as the stabilisation processes and different plants can have differing abilities in affecting these processes. Reid and Goss (1981) reported that while growth of perennial ryegrass and lucerne increased soil aggregate stability, growth of maize, tomato and wheat under identical laboratory conditions decreased soil aggregate stability. Soybean has been shown to cause soil structure degradation and erosion problems (Bathke and Blake, 1984). Similarly, Angers and Mehuys (1988) reported increases in water stable aggregation under both barley

(*Hordeum Vulgare* L.) and alfalfa (*Medicago sativa* L.) but not under maize when compared with fallow control.

Horne et al. (1992) found that long term maize/oats rotation under three tillage systems on a silt loam in New Zealand affected selected soil properties. For example, after ten years of continuous cropping and compared with an adjacent pasture site, there were higher soil bulk densities, larger soil aggregates and lower total porosities in no-tillage as compared with full and minimum tillage. Continuous cropping caused a decline in aggregate stability, compared with pasture. They also found that organic carbon content and cation exchange capacities were lower in the cropped soil compared with those in adjacent pasture after ten years of cropping.

Campbell et al. (1996) indicated that tillage management and crop rotation may have an effect on soil organic matter such as organic C and N. Because generally organic C and N concentrations in surface 15 cm of no-tilled soils are greater than in tilled soils, especially when these are mouldboard ploughed. However, change in soil organic matter with time will depend on the initial level of the organic matter which may be affected by different cropping systems and crop rotation. Generally, organic matter content was higher in pasture than in the cropped land. But, after breaking grass sod (high in organic matter) organic matter levels initially decrease. However, if the land has been degraded by frequent summer fallow or erosion for many years, the opposite is likely to occur. Machado and Gerzabek (1993) found that crop rotation effected humic substances. The total amount of extractable humic substances was higher for forest soils than in the soybean/wheat rotation soils. Crop rotation such as soybean and wheat had an important influence on the quantity of the organic matter. Also they have high amount of extractable humic substances in the vestigated soils.

Chan and Heenan (1996) studied soil structure and other soil physical properties changes under four different winter crops in rotation with wheat in Australia. They found that at the end of four seasons (after two cycles of 1:1 wheat:altemate crop rotation), soils which had been under lupin (*Lupinus angustifolius* L.) and canola (*Brassica napus* L.) were more porous and had lower shear strength than those which had been under field pea (*Pisum sativum* L.) and barley (*Hordeum vulgare* L.). Soil bulk density and shear strength was highest under barley crop field, but water stability was similar to that of lupin and canola. Water stability was lowest under pea crop field. Such information is important for the long term maintenance of soil structure under continuous cropping. A challenge for sustainable agriculture is to identify those plants which are most efficient in forming stable soil structure and to incorporate them into economic rotational management systems.

2.7 Agricultural Sustainability

Good soil management and sustainable agriculture are a necessity to ensure maintenance of land productivity and human prosperity. Bed land management has the potential both to degrade and to enhance soil quality.

Meister (1991) argued that sustainable land management is a long-term concept. It is concemed with: (a) the rights of future generations to the services of natural and human-produced assets, (b) whether existing formal and informal institutions which affect the transfer of assets to future generations are adequate to assure the quality of life in the long-run, and (c) satisfying the needs of those currently living.

Lal (1991) commented that agricultural sustainability implies an increasing trend in per capita productivity to meet the present needs without jeopardising the future potential. Soil surface management, to alleviate soil-related constraints to crop production, is a basic and important aspect of both short-term and long-term sustainability. An important effect of soil tillage practices on sustainability is through their impact on the environment e.g. land degradation, soil and water quality, emission of greenhouse gases from soil-related processes, etc. The need to attain agricultural sustainability is particularly urgent in several tropical eco-regions and on soils of low-carrying capacity in the tropics.

Turkington (1991) has suggested that soil conservation and sustainable land management embrace:

1. the maintenance of the productive potential of the regional soil to retain sustainable land use options for present and future generations;

2. the maintenance of the land management in catchments to provide high quality water resources for downstream users;

3. the mitigation of the impacts of land related hazards, including flooding, subsidence and erosion; and

4. the maintenance of aesthetic, scientific and cultural values related to land and water.

Agricultural tillage practices influence agricultural sustainability through their effects on soil processes, soil properties, and crop growth (Bentley, 1991). However, there is no one blueprint of a universally applicable sustainable tillage system. Appropriate agricultural tillage systems are soil-specific and crop-specific, and their adaptation is governed by both biophysical and socio-economic factors. In addition to increasing crop yields, tillage methods must also facilitate soil and water conservation, improve root system development, maintain a favourable level of soil organic matter content, and reverse degradation trends in the soil's life-support processes.

Meister (1991) stated that sustainable management implies a change in the way land resources are used in New Zealand. Because leaving aside the almost total modification of the New Zealand landscape in less than 200 years, it is now widely believed that there should be a balanced, environmentally kind, sustainable agriculture or land use pattern. For sustainable land management, the New Zealand Government is now injecting more money into combating several threats to that sustainability - rabbits, opossums, erosion by water and soil loss through wind. Having addressed these degradation problems, New Zealand may have to do little more than keep on farming and keep on producing more of the foods and fibres which an increasingly polluted northern hemisphere wants.

Lal (1993) has suggested that long-term sustainability depends on soil quality rather than fertiliser derived sources of N. It is necessary, therefore, to adopt alternative farming systems such as surface residue-retention, minimum or no-tillage systems, and rotations with grain legumes to improve soil organic matter. By increasing soil organic matter levels, the nutrient supplying potential of soil will be improved, and long-term ecological sustainability may be economically achieved. While conservation tillage can reduce soil erosion, it may increase water pollution through increased use of pesticides, and surface application of fertiliser and other agricultural chemicals.

Basher et al. (1991) described a 'healthy' soil as one having desirable physical, chemical and biological attributes, including stable, well-developed structure and porosity, good nutrient supply, acid and base buffering capacity, organic matter decomposition, pathogen destruction, and toxic chemical inactivation and degradation. All these desirable characteristics can be affected by mismanagement. All soils differ in their properties and in their ability to respond to the cultivation pressures. So, sustainable use of soil resources aims to maintain the quantity and quality of the soil resource and to prevent and ameliorate all types of soil degradation. It may be viewed as the net result of a wide range of processes.

Sustainable agricultural land use is influenced by economic, financial and social factors interacting with the physical resource of soil and water (Steel, 1991). Sustainability implies limits to growth in activities such as agriculture which are dependent on natural resources, and suggests prompt reassessment of traditional value systems to incorporate natural resource accounting. However, environmental statistics, other than meteorological, are not normally so readily acquired as statistics on economic activity and population.

2.8 Summary

This review discusses tillage effects on soil and water quality in terms of biological, chemical, and physical aspects. The effects of agricultural practices often include soil degradation and reduced soil organic matter. The findings should encourage adoption of soil management practices that decrease tillage intensity, and lead to increased soil organic matter and improved soil quality. Also soil tillage plays an important role in agricultural sustainability. It influences crop yields through its effects on soil properties that regulate the nutrient and water supply, competition with pests, and crop-restrictive biophysical and socio-economic constraints. Appropriate tillage methods differ for various soils, crops, and climatic regions, and the choice depends on a range of interacting factors. There is an urgent need to attain agricultural sustainability in fragile eco-regions.

CHAPTER 3

EXPERIMENTAL METHODS AND MATERIALS

3.1 Introduction

As the problem of soil erosion grows, and soil conservation becomes more important, scientists are increasingly faced with the task of measuring or estimating soil erosion and water runoff. In New Zealand, sheet erosion is the most extensively mapped erosion type from agricultural and horticultural crop land (Eyles, 1985).

To gain a better understanding of soil erosion by sheet erosion processes, the Soil Science Department at Massey University has developed a laboratory rainfall simulator (Figure 3.1). This rainfall simulator was used to evaluate, in laboratory, the rates and amounts of surface runoff, leachate and sediment over two cropping seasons on a silt loam soil. The effects of tillage practices on soil erosion under a barley/oats rotation were investigated. Experiments were conducted comparing conventional tillage, no-tillage, and pasture (as a control treatment).

3.2 Experimental Site

The field experimental site was located at Massey University. Soil type was Ohakea silt loam with poor natural drainage (McLaren and Cameron, 1990). It was expected that this relatively heavy soil type would be sensitive to cultivation management systems and was therefore suitable for a comparison of tillage methods.

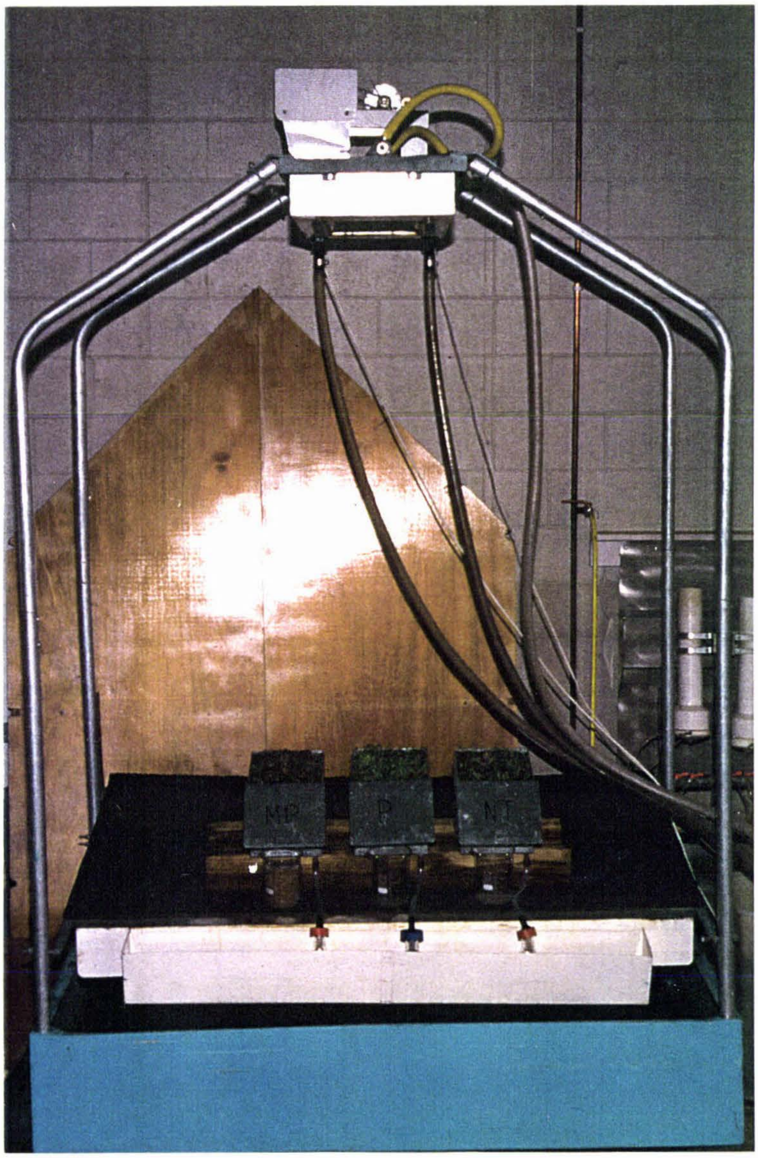

Figure 3.1 The Massey University Rainfall Simulator

3.3 Experimental Design

3.3.1 *Treatment Design*

Over 95% of crop establishment in New Zealand is done by conventional tillage systems. No-tillage practices, an extreme from of conservation tillage system, can help improve soil and environment quality. Overseas research suggests that minimising tillage intensity has an overwhelming effect on soil structure and erosion (Lal, 1991). There is little data available in New Zealand comparing interactions between tillage intensity and cropping patterns under long-term cropping. Thus, three different treatments were used in the field experiment. They were:

(a) conventional tillage with ploughing followed by secondary tillage and seedbed preparation (MP).

(b) no-tillage (NT).

(c) permanent pasture (P) (undisturbed soil as a control treatment).

The treatments were arranged in a randomised complete block (RCB) design with four blocks of three treatments in each trial. A minimum of four replications of each treatment were considered necessary to account for any data variation due to field conditions. Thus, a total of 12 plots were involved in the trial.

Each plot was 10 m long and 3.6 m wide (two drill widths) with a 5 m headland for machinery operation on both sides of the field. The plots were laid out as shown in Figure 3.2.

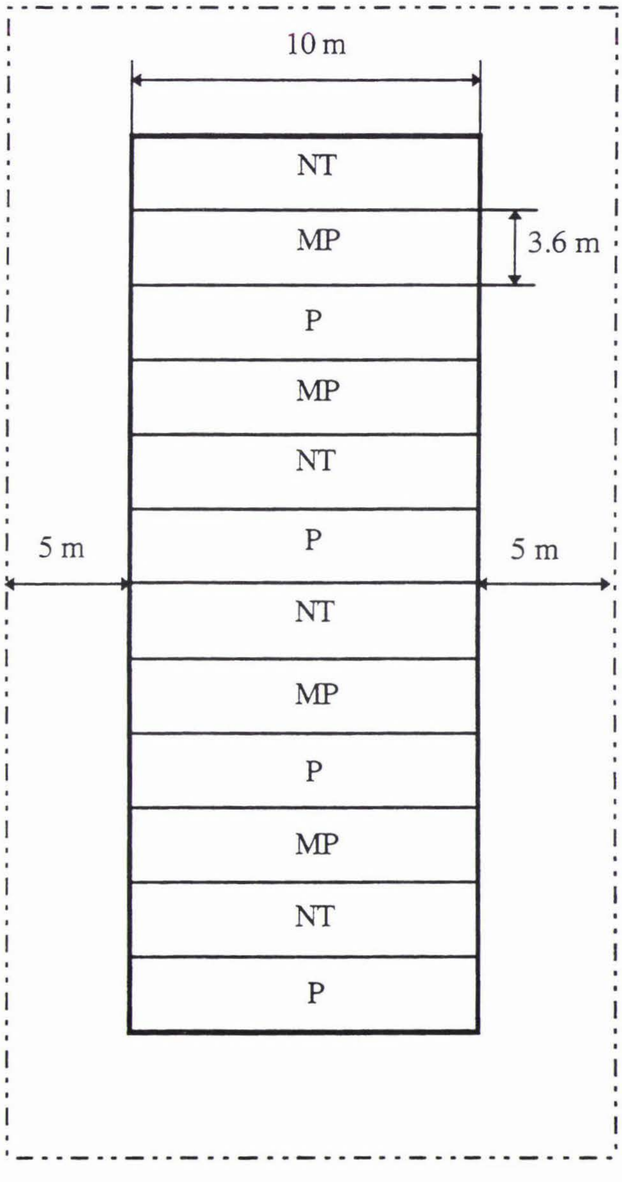

Figure 3.2 **Experiment treatments design (plots layout).**
(MP: Mouldboard plough, NT: No-tillage, P: Pasture)

3.3.2 *Tillage Operations*

In the no-tillage treatment weeds were controlled by herbicide spray with 4 l/ha of Roundup (*360 g/l glyphosate*) and with 1l/ha of Versatill (*300 g/l clopyralid*), followed by direct seeding with an Aitchison seed drill followed by chain harrowing. The conventional tillage treatment involved mouldboard ploughing and rolling, then two passes of a power harrow within intervals suitable, followed by seeding with an Aitchison seed drill.

Timing of operations depended on the weather, and working of the ground under wet soil conditions was avoided as much as possible. It could be reasonably assumed that tillage operations thus followed a "normal" pattern and are consistent with the limitations imposed by weather and human judgement.

3.3.3 *Sampling*

The method of soil sampling and size of the sample are very important for any field study. For a sample to be representative of the whole soil erosion problem, it must be large enough to reflect the variation within the whole area.

In this study, since considerable number of soil samples were to be taken repeatedly to the laboratory from the field for measurement, a choice had to be made as to the minimum size of the soil sample to be representative of soil condition which allowed ease of extraction and transportation to the laboratory without soil disturbance. Furthermore, the samples needed to be large enough to allow representative measurement of soil erosion rate, surface water runoff, leachate and soil sediment concentration in runoff water. Consequently, it was considered that an appropriate soil sample size of 300 mm long x 200 mm wide x 150 mm deep would be large enough for these experiments. Two samples for soil measurement were taken from each plot giving a total of 24 samples.

Before taking soil samples, crop residue was removed manually. This was considered important to ensure that there were no confounding effects from the previous crop residue on surface soil erosion.

A hand bottle-jack was used to penetrate the cores into the soil after carefully removing the crop residue from soil surface. A heavy tractor was used as a counter weight for core penetration (Figure 3.3). Soil cores were carefully transported and placed into a laboratory at Massey University. Bottom end of each soil cores was cut flush with the end of the core. A double layer of cheese cloth was tied in a way to prevent soil from falling off but allowing perforation and free drainage of water from the bottom end of the cores into the measuring tray placed beneath.

Special equipment was designed and constructed which allowed collection and measurement of soil and water runoff and leachate (Figure 3.4). At any one time three soil cores were placed under the rainfall simulator. The soil cores were inclined at 5% slope to simulate field conditions (Figure 3.5).

3.3.4 *Crop Rotation*

In spring 1995, an initial crop of barley (*Hordeum vulgare* L. cv. fleet) was grown on the conventional tillage and no-tillage treatments. Following the first crop, a winter crop oats (*Avena sativa*, L. cv. awapuni) were sown as a fodder crop in the MP and NT treatments (Figure 3.6). Standard practices for fertiliser were adopted, as described below. The barley was harvested at maturity, and oats were grazed by a mob of sheep. The pasture treatment was mown to 1000 kg/ha dry matter (DM), and kept grazed. Yearly data of pasture DM were accumulated to give total DM yield from this treatment.

Figure 3.3 Using a heavy tractor for soil core penetration in the field.

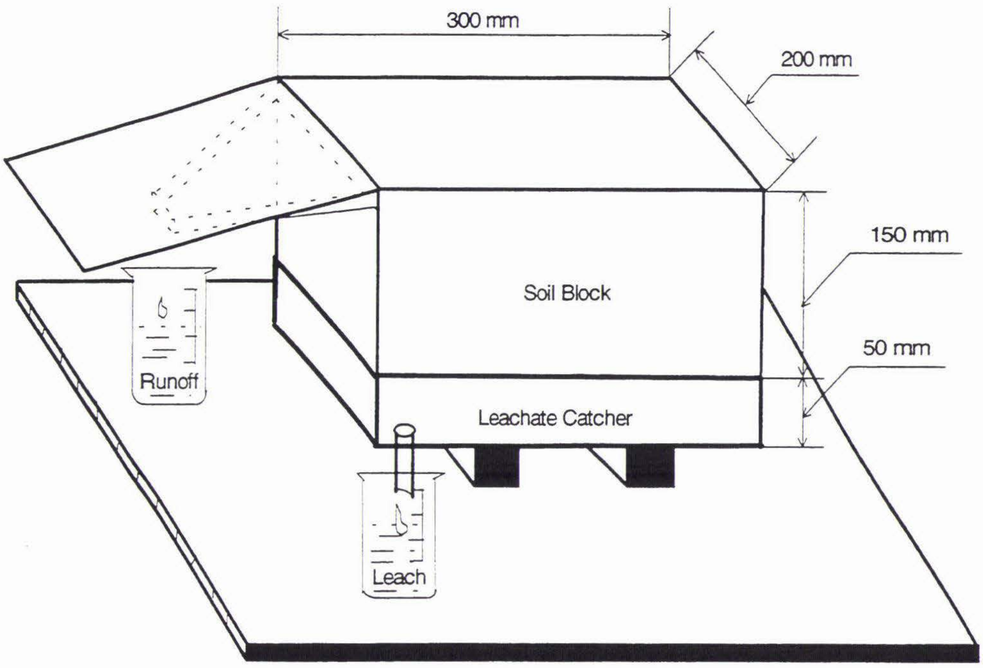

Figure 3.4 Schematic diagram of the apparatus used for laboratory measurement of surface water runoff and leachate using simulated rainfall.

Figure 3.5 Arrangement of soil cores receiving "rainfall" under the rainfall simulator.

Figure 3.6 A winter oats crop growing on the MP and NT plots.

3.3.4.1 *Summer crop (barley)*

The initial summer crop barley (*Hordeum vulgare* L. cv. fleet) was sown at a seed rate of 130 kg/ha on 5th December 1995. Fertiliser (Nitrophoska having 12% N, 10% P, 10% K, 1% S and 6% Ca) was applied to the plots at the planting time as a basal broadcast dressing of 130 kg/ha. An "Aitchison Seedamatic 1112" drill equipped with "Baker boot", set at 150 mm row spacing was used for drilling seed and basal application of fertiliser. Plant establishment was counted using quadrats. The barley was harvested by mowing at maturity, because barley grains were damaged by birds. The mode of harvesting was not important for this study.

3.3.4.2 *Winter crop (oats)*

Winter oats (*Avena sativa*, L. cv. awapuni) were sown at a seed rate of 120 kg/ha on 18th April 1996. Fertiliser (Nitrophoska with analysis as shown above) was applied to each plot with an Aitchison seed drill as a basal dressing of 200 kg/ha. On June 5th, 1996 all the plots (including the pasture plots) were supplied with 65 kg/ha of Urea by hand. Plant establishment numbers were counted by using a quadrat method, and calculated to obtain percentage establishment. The oats samples were harvested to take DM yield before grazing with sheep at maturity.

3.4 Soil Cores

Large steel soil corers 300 mm long x 200 mm wide x 150 mm deep (3 mm thickness of plate) were manufactured and used to extract soil core samples from the field soon after the barley and oats crops were harvested in March and July 1996 respectively (Figure 3.3). Selected soil properties were measured in the field and laboratory, as described in section 3.6.

3.5 Rainfall Simulator

A rainfall simulator is a research tool designed to apply water in a form similar to natural rainstorms. It is useful for many types of soil erosion and hydrologic experiments. However, rainstorm characteristics must be simulated closely.

Massey University has developed a laboratory rainfall simulator suitable for the investigation of soil erosion and hydrologic research. It was based on the design of USDA-ARS demonstration rainfall simulator developed by Laflen at Ohio State University (Keen, 1986). It consists of fan spray nozzles which oscillate across the soil bed. The rainfall simulator produces rainfall rates, drop sizes and drop velocities not dissimilar to natural rainfall. Varying the time between sweeps alters the rainfall intensity.

Rainfall intensities can be varied in the range of storms for which results are of interest. Intensities of natural rainfall vary from near zero to several millimetres per minute. Generally, very low intensities are not of major interest for erosion and hydrologic studies, and very high intensities are so rare that they may be of limited interest. Intensities between 0.2 and 2 mm/min are usually of greatest importance (Meyer, 1994).

The advantages of using a rainfall simulator for such studies are as follows:

(1) Soil erosion and hydrologic characteristics of newly developed cropping and tillage practices can be measured in a very short time, and in a controlled way.

(2) Simulated rainstorms can be applied for selected durations on selected treatment conditions, and measurements from a few such storms often can show conclusively a relative information about those treatments.

(3) Treatment plots preparation are very easy, and involve less time than field plot studies depending on natural rainstorms.

(4) Measurements and observations can be made during simulated storms that are difficult or impossible during natural rainstorms.

A rainfall simulator has some limitations and disadvantages. These include the difficulty of simulating natural rainfall characteristics, and the problems of interpreting data obtained from a rainfall simulator that fails to fully achieve such characteristics. Other problems are the relatively small area to which rain can be applied by most rainfall simulators and the compromise in rainfall characteristics that is necessary for large area rainfall simulators.

3.6 Measurements

There were two main aspects of measurement in these experiments e.g. the soil and runoff water. These were indicators used to assess the soil physical and chemical properties under conventional tillage and no-tillage treatments comparing with permanent pasture.

3.6.1 *Field Experiments*

Samples from top 150 mm of soil were taken on 21 March 1996 and 31 July 1996 from each plot, after the crops were harvested respectively. These samples were used to determine the soil erosion, water runoff, leachate, and selected soil physical and chemical properties in the laboratory.

The key soil physical indicators measured in the field were: (a) bulk density; (b) water content; (c) infiltrability; (d) penetration resistance; (e) earthworm population; and (f) pH.

3.6.1.1 *Bulk density*

Thin walled cylindrical aluminium samplers, 48 mm in internal 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 soil and material outside of the sample volume removed. The samples were weighed, oven-dried at 105°C overnight, and reweighed. Bulk density was calculated as the oven-dry mass of soil divided by the volume of the sample. Two soil samples from each plot were taken for soil bulk density measurement. Data were collected for each 50 mm layer.

3.6.1.2 *Water content*

Two soil samples (0 - 50 mm depth) from each plot were collected by using samples similar to those used for measuring soil bulk density. The samples were weighed, oven-dried at 105°C overnight, and reweighed. Volumetric water content was determined from the change of volume in oven drying.

3.6.1.3 *Infiltrability*

Infiltrability into the topsoil was determined by using large steel top and bottomless boxes (300 mm long x 200 mm wide and 150 mm deep) in the field (Figure 3.7). These were driven-in to a depth of about 100 mm. Water was ponded in them and Infiltrability was allowed to proceed for 30 minutes before measurements were taken. Readings were taken at regular intervals by recording the fall of the water level in the boxes. A sharpened bottom edge facilitated driving the boxes far enough into the soil to avoid leakage.

Figure 3.7 Soil infiltrability measurement in the field.

3.6.1.4 *Penetration resistance*

Measurements of soil penetration resistance were made to help characterise the soil found under the various tillage practices.

A Bush® recording soil penetrometer (Mark 1 model 1979) was used to measure soil penetration resistance in each plot at four different depths (Figure 3.8). The locations were chosen at random. The penetrometer was pushed into the soil by hand at a constant rate. The pressure on the cone was recorded at regular depth intervals by a data recorder.

3.6.1.5 *Earthworm population*

There are several methods for counting earthworm populations. One of these is chemical method, which involves applying formalin solution to bring the worms to surface, as described by Raw (1959). Earthworm activity was evaluated by saturating the soil within a 0.25 m^2 frame for 20 minutes with a formaldehyde solution (6 ml of a 40% solution l^{-1}) as suggested by Edwards and Lofty (1977). At the measurement site the weeds were cut and the soil surface cleared. Then 10 litres of formalin solution was applied to 0.25 m^2 area four times. Mature and immature earthworms coming to the surface within each frame were picked up and counted (Figure 3.9).

Earthworm counts were taken over the winter period. Two sets of measurements were taken from each plot.

Figure 3.8 A Bush® recording soil penetrometer used for soil penetration resistance measurement in the field.

Figure 3.9 Earthworm population measurement in the field.

3.6.1.6 *Soil pH*

Two soil samples from each plot were taken for soil pH measurement. Measurement were made by using 10 g of dry soil sample stirred in 25 ml of distilled water and left it over night. Soil pH was determined by using a pH electrode metre.

3.6.2 *Laboratory Experiments*

3.6.2.1 *Rainfall duration*

Ideally, if rainfall intensity-frequency-duration data are available for the area, they may be utilized in selecting the rainstorm duration for laboratory rainfall simulator studies (Meyer, 1994). On the other hand, most tests should be long enough that runoff is well established and leachate is somewhat constant before rainfall is stopped or its intensity is changed.

To estimate water runoff, soil sediment, and leachate under rainfall simulator, the rainfall intensity was set at 50 mm/hr and duration was established to be for one hour. Readings for runoff and leachate were taken at intervals of ten minutes each to understand intermittently the pattern and distribution of these parameters every ten minutes.

3.6.2.2 *Water runoff measurement*

A laboratory rainfall simulator was used for determining surface water runoff. Rainfall intensity was pulsed, with an average application rate of 50 mm/hr for one hour, simulating a rainstorm. The volume of water runoff was collected at every ten minutes interval (Figure 3.4). The total volumes of surface runoff were determined by adding all runoff samples thus collected.

3.6.2.3 *Sediment measurement*

The volume of the water-sediment mix for each sample was obtained from the surface water runoff under rainfall simulator as shown above in section 3.6.2.2. Half of the total water-sediment mix was used to determine the amounts of soil sediment in surface water runoff. The dry mass of sediment was determined after evaporating the water off in an oven at 105 °C for 24 hours. The sediment concentration in surface water runoff was determined by multiplying the mean mass of sediment by the mean volume of surface water runoff from each ten minutes interval.

3.6.2.4 *Leachate measurement*

The water leachate was collected by using a catching tray placed immediately below the soil cores (Figure 3.4). The volume of leachate sample was collected at ten minutes intervals. The total volumes of water leachate were determined by adding six collections over one hour.

3.6.2.5 *pH of runoff and leachate*

The pH of surface water runoff and leachate was measured by using a pH electrolytes meter (PHM 82 - STANDARD pH METER) by direct collection of surface runoff and leachate samples.

3.6.2.6 *Nutrient concentration*

The chemical measurements made of the surface water runoff, and leachate included total nitrogen (N), phosphorus (P), and potassium (K) concentrations. Total N and P were extracted and determined according to Kurmies (1972). Total K was measured, after dilution, by flame photometry (Athanasopoulos, 1989).

3.7 Statistical Analysis

The statistical package **SAS** (Statistical Analysis System) was used to assist with the analysis of all experimental data. An analysis of variance and coefficient of variation and other computations were completed with **SAS** programme (SAS Institute Inc., 1989).

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

Many studies have compared soil properties, runoff and leachate water quality under different tillage treatments. Conservation tillage such as no-tillage has been shown to improve soil properties as compared to conventional tillage by reducing surface water runoff volume and soil erosion. In contrast, soil erosion was significantly affected by conventional tillage practices impacting of soil moisture, soil loss from field, soil structure and soil nutrient levels.

In this chapter the results obtained from both the laboratory and the field experiments outlined in the preceding chapter are presented and discussed.

4.2 Experiment 1: Soil, Water Runoff and Leachate Properties Under Three Treatments Following Barley Crop Harvest

4.2.1 *Field Measurements*

4.2.1.1 *Bulk density*

An important soil physical property is bulk density. It is defined as the density of the whole soil, including the pores, but excluding the mass of water (Scotter, 1995).

Differences in bulk density reflect the fraction of pore space in the soil. Soils with a high proportion of pore space have lower bulk densities than those that are more compact and have less pore space. Fine-textured surface soils such as silt loams, clays, and clay loams usually have lower bulk densities than sandy soils. Generally, values of bulk density vary from 0.04 Mg/m^3 in some peat soils to 1.8 Mg/m^3 in some sands and compacted horizons such as fragipans. Soils containing a lot of humus and/or material of volcanic origin, often have bulk densities between 0.6 and 1.0 Mg/m^3. In general the denser the soil, the harder it is for roots to grow into it. As a rough guide, in fine-textured soils such as silt loams root penetration may be inhibited if the bulk density is greater than about 1.6 Mg/m^3.

In this study, bulk density was measured twice under the three treatments following barley and oats rotation, and in pasture.

Table 4.1 Effects of tillage practices and cropping regime on soil bulk density under the three treatments (following barley crop harvest on 14th March, 1996).

Treatment	Bulk density (Mg/m^3)
MP	1.27^a
NT	1.24^a
P	1.22^a
$LSD_{0.05}$	0.07

Values followed by the same letter are not significantly different ($P \leq 0.05$).

In March 1996, the topsoil (0 to 50 mm deep) was sampled from all twelve plots. The results (Table 4.1) showed that the bulk density of the three treatments was not significantly ($P \leq 0.05$) different. The reason may be that the experimental treatment were established only five months previously and there was not enough time for any differences to develop in soil bulk density levels. These data also suggested that this level of soil strength was not expected to be a hindrance to crop and pasture growth.

Detailed raw data and statistical analyses are shown in Appendix 1.1.

4.2.1.2 *Soil water content*

The water content of soil is important because it affects plant growth and influences soil properties such as aeration, temperature, and consistence. At low water contents the soil is hard and very coherent because of shrinkage and a cementation effect between the dried particles.

The soil water content measured in the first experiment after barley crop harvesting in March 1996 (Table 4.2) was significantly *($P \leq 0.05$)* higher in the no-tillage and pasture treatments than in the conventional tillage treatment. These soil water content differences may have been caused by differences in evaporation prior to sampling.

Table 4.2 Effects of tillage practices and cropping regime on soil volumetric water content (following barley crop harvest on 14th March, 1996).

Treatment	Water content (m^3/m^3)
MP	0.29^b
NT	0.31^a
P	0.32^a
$LSD_{0.05}$	0.02

Values followed by the unlike letter are significantly different ($P \leq 0.05$).

However, the experimental area was under permanent pasture prior to the tillage treatments were imposed. This means that tillage practices may have affected soil water evaporation and retention. Because evaporation is a major component of the water loss from the soil and has been shown by other researchers to be affected by tillage and the soil conditions resulting from tillage (Hillel, 1980; Lal, 1993). Tillage has been shown to increase evaporation rates and to decrease soil water content.

Detailed raw data and statistical analyses are shown in Appendix 1.2.

4.2.1.3 *Infiltrability*

Infiltrability of the soil at a particular site is defined as the maximum rate at which it can absorb rainfall or irrigation (Hillel, 1980). The higher the infiltrability, the less likely is surface runoff and erosion.

During a rainstorm the maximum infiltrability usually occurs at the beginning of the rain. Infiltrability can decrease very rapidly if structural changes in the surface soil occur. If the rain continues, the infiltrability usually approaches a steady value if soil structure is stable.

The infiltrability was measured both in autumn and winter after harvesting of barley and oats crops respectively. The results of experiment 1 showed significant $(P \leq 0.05)$ differences between the three treatments in autumn (Table 4.3). The infiltrability in the pasture plots was nearly twice that in the conventional tillage plots, and in the no-tillage plots was one and half times greater than that in the conventional tillage plots. This suggests decreased soil infiltrability with increased tillage intensity.

These data further indicated that under the conventional tillage practices soil surface was perhaps more compacted and the profile covered by a surface crust of lower conductivity. Because the surface crust acts as an hydraulic barrier, or bottleneck, impeding infiltrability, this effect, which becomes more pronounced with a thicker and denser crust, reduces soil infiltrability.

Detailed raw data and statistical analyses are shown in Appendix 1.3.

On the other hand, soil under low infiltrability conditions (high penetration resistance) may have an adverse effect on earthworm population. Conversely, earthworms can have significant impact on soil properties and processes through their feeding, casting, and burrowing activity. The earthworms create channels in the soil, which can aid water and air flow as well as root development, and increase soil infiltrability (Kladivko, 1993).

Table 4.3 Effects of tillage practices and cropping regime on infiltrability (following barley crop harvest on 14th March, 1996).

Treatment	Infiltrability (mm/h)
MP	22.5^c
NT	35.5^b
P	41.5^a
$LSD_{0.05}$	0.9

Values followed by the unlike letter are significantly different ($P \leq 0.05$).

4.2.1.4 *Penetration resistance*

In agricultural soils, penetrometers are used to quickly evaluate the parameters affecting the trafficability of soils. The penetrometer is a device designed to measure resistance to penetration. Some scientists have found relationships between penetrometer resistance and root growth, crop yields, and soil physical properties descriptive of tilth (Karlen et al., 1994; Unger, 1996).

Penetration resistance data were collected from all the plots and are presented in Table 4.4.

There were significant differences *($P \leq 0.05$)* in penetration resistance between the three treatments at all depths. The penetration resistance was significantly greater in the conventional tillage treatment (MP) than in the no-tillage (NT) and pasture (P) treatments at 0 to 5 cm depth. But, the soil penetration resistance was higher for NT and P treatments than for the MP treatment at 5 to 20 cm depth. This indicates that under the conventional tillage treatment (MP) soil was harder in the top 0 to 5 cm, while at 15 to 20 cm depth, the soil is slightly softer.

There is a significant variation in soil strength from 5 to 20 cm depth. Not unexpectedly, soil strength increased with depth. This was true for all treatments.

Further, it is also important to note that there were no differences between the values obtained from the pasture and no-tillage treatments. Perhaps under those two treatments, soil structure was undisturbed, and they have similar physical characteristics.

Detailed raw data and statistical analyses are shown in Appendix 1.4.

Table 4.4 Effects of tillage practices and cropping regime on soil penetration resistance (kPa).

Depth	Treatment			LSD
(cm)	P	NT	MP	(P=0.05)
0 - 5	530^d	516^d	592^d	MP > NT = P
5 - 10	698^c	677^c	605^c	P = NT > MP
10 -15	919^b	930^b	674^b	P = NT > MP
15 - 20	1292^a	1263^a	1082^a	P = NT > MP
LSD ($P \leq 0.05$)	12.7	8.5	12.2	

Values followed by the unlike letter in each column are significantly different ($P \leq 0.05$).

4.2.1.5 *Crop establishment*

Summer crop barley plant numbers were counted by using quadrats, and calculated to obtain percentage of plant establishment. Data showed that percentage of plant emergence was not significantly different between the no-tillage and the conventional tillage treatments (Table 4.5). These results suggested that tillage practices had no affect on crop establishment. This is not unexpected as at the time of sowing, field and climatic conditions were near "ideal" for crop establishment. Therefore, method of land preparation was not expected to impact seed germination and seedling emergence.

Detailed raw data and statistical analyses are shown in Appendix 1.5.

Table 4.5 Effects of tillage methods on barley crop establishment.

Treatment	Plant establishment (%)
MP	90.2[a]
NT	89.3[a]
$LSD_{0.05}$	7.88

Values followed by the same letter are not significantly different (P≤0.05).

4.2.2 *Laboratory Measurements*

4.2.2.1 *Introduction*

Tillage practices influence the hydrology of cultivated land by altering surface roughness, bulk density, and the porosity of the soil. These properties affect water storage, infiltrability, and surface runoff. This section discusses measurement of runoff and leachate water. It also discusses affects of tillage intensity on soil erosion.

The volumes of surface runoff and leachate under simulated rainfall were measured in autumn of 1996, following the harvest of barley crop. Soil cores (as described in chapter 3) were used for this purpose.

4.2.2.2 *Surface water runoff*

Soil cores were extracted from the field and transported to the laboratory, and immediately placed under the rainfall simulator (Figure 3.5). Experiment results showed .that surface water runoff was significantly higher for the conventional tillage treatment than for the no-tillage and pasture treatments. The volume of surface runoff from the conventional tillage treatment (MP) was nearly four times higher than that from the no-tillage treatment (NT) (Table 4.6). These results indicated that under the no-tillage and pasture treatments more of the applied water stayed in the soil.

Surface runoff data from the first experiment indicated that tillage intensity is a major factor affecting surface runoff. Because conventional tillage practices negatively impact soil structure and removed crop residue from soil surface, these assist in decreasing soil infiltrability, and increasing surface runoff as compared with no-tillage practices (Morgan, 1995).

The present findings confirm those obtained by other researchers elsewhere. For example, Choudhary et al. (1996) have studied long-term tillage effects on runoff and soil erosion under simulated rainfall for a silt loam soil in Ohio. They found that surface water runoff was significantly affected by the tillage method. There was high surface water runoff (four times) under the conventional method of cultivation using mouldboard plough than that under the no-tillage method. These results further confirmed that surface water runoff decreased markedly with the reduction in tillage intensity.

Detailed raw data and statistical analyses are shown in Appendix 1.6.

Table 4.6 Effects of tillage practices and cropping regime on surface water runoff under rainfall simulator (following barley crop harvest on 28th March, 1996)

Treatment	Surface runoff (mm)
MP	8.5[a]
NT	2.5[b]
P	3.6[b]
$LSD_{0.05}$	2.6

**Rainfall intensity of 48 ± 2 mm/hr.*
Values followed by the same letter are not significantly different ($P \leq 0.05$).

4.2.2.3 *Effects of rainstorm duration*

Data on the effects of rainstorm duration and tillage treatment on surface water runoff following barley crop harvest (Figure 4.1), suggested that a short duration (10 minute) rainstorm had a similar impact on surface water runoff irrespective of the previous tillage intensity or the type of vegetation cover. However, differences developed as the duration of the rainstorm increased. Runoff was significantly higher with the conventional tillage treatment than that with the no-tillage and pasture treatments, but was not significantly *($P \leq 0.05$)* different between the no-tillage and pasture.

This suggests a gradual collapse of the structure of the conventional tillage treated soil during the rainfall. Such a phenomenon have been earlier suggested

Figure 4.1 **Effect of rainstorm duration and tillage treatment on surface water runoff (following barley crop harvest on 28th March, 1996).**

by Morgan (1995) who concluded that Initial rapid wetting of the surface soil probably breaks down aggregates by raindrop impact and sometimes by slaking. If dispersion takes place, the detached fine materials then get washed into the macro pores and their volume is reduced. After aggregate breakdown, raindrop impact causes surface compaction, producing a thin skin or crust. Typically, the crust's bulk density is increased and its permeability is reduced relative to the underlying soil. Because the surface soil's permeability is reduced, excess water accumulates and runs off.

Statistical analysis has shown that the surface water runoff was highly ($P \leq 0.05$) correlated with rainfall duration. The regression equations for the three treatments are as below:

1. MP treatment:

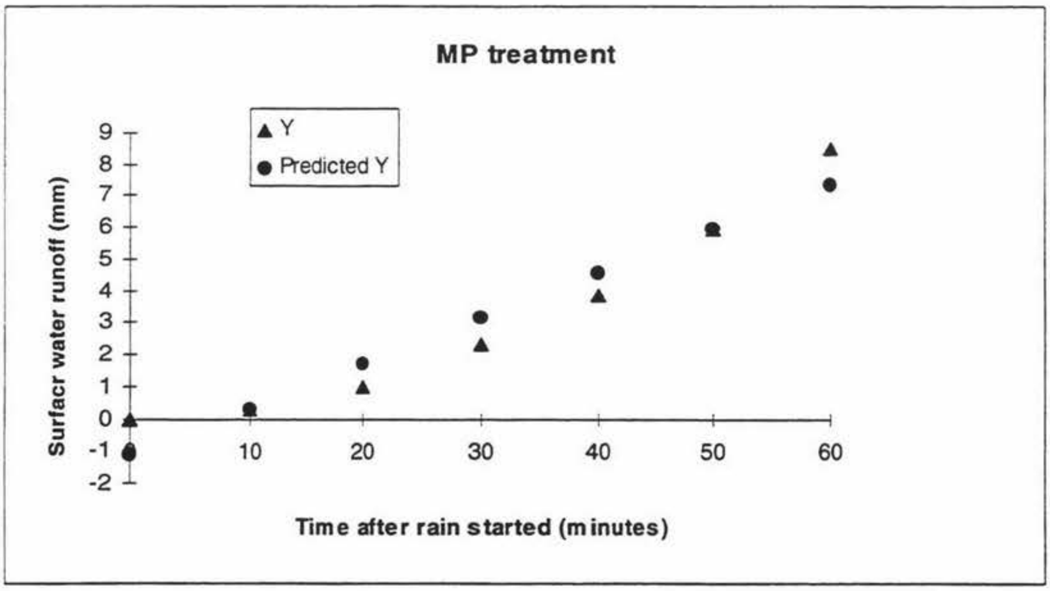

Figure 4.2 Regression analysis between surface water runoff and rainfall intervals under the conventional tillage treatment.

$$Y = -1.13 + 0.14\,X \qquad (R^2 = 0.93) \qquad (1)$$

Where, Y = volume of surface water runoff (mm);

X = rainfall duration (minutes);

Intercept = -1.13

Slope: $Y / X = o.14$ (2)

The mathematical model in equation (1) shows a best fit ($R^2 = 0.93$) and also that the water runoff from a Ohakea silt loam can be predicted by a simple linear regression equation (Figure 4.2).

2. NT treatment:

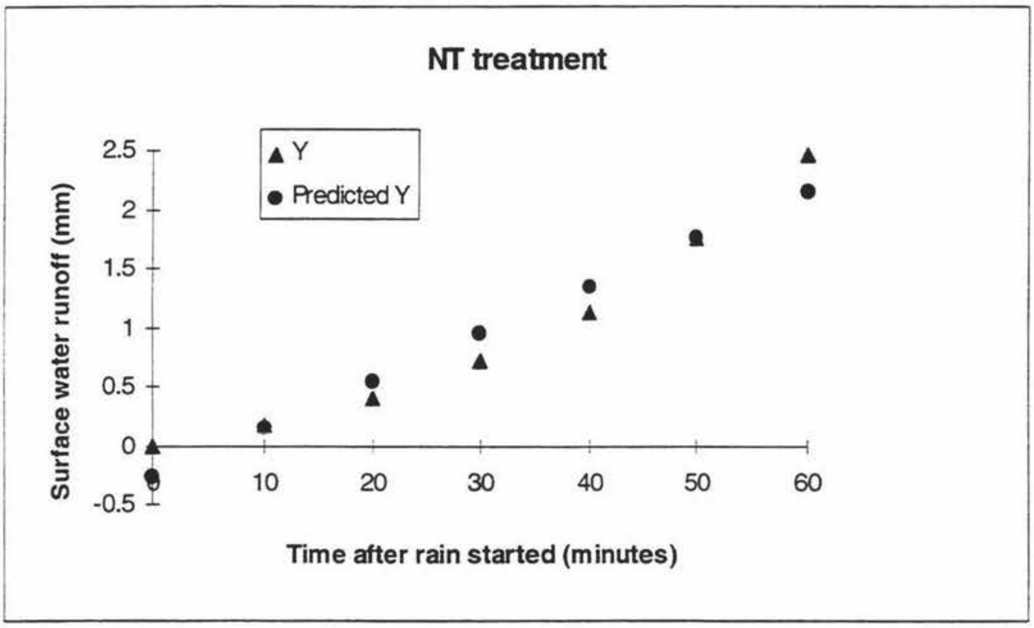

Figure 4.3 Regression analysis between surface water runoff and rainfall intervals under the no-tillage treatment.

$$Y = - 0.26 + 0.04 X \qquad (R^2 = 0.94) \qquad (3)$$

Where, Y = volume of surface water runoff (mm);
X = rainfall duration (minutes);
Intercept = - 0.26

Slope: $Y / X = 0.04$ (4)

The mathematical model in equation (3) shows a best fit ($R^2 = 0.94$) and also that the water runoff from a Ohakea silt loam can be predicted by a simple linear regression equation (Figure 4.3).

3. P treatment:

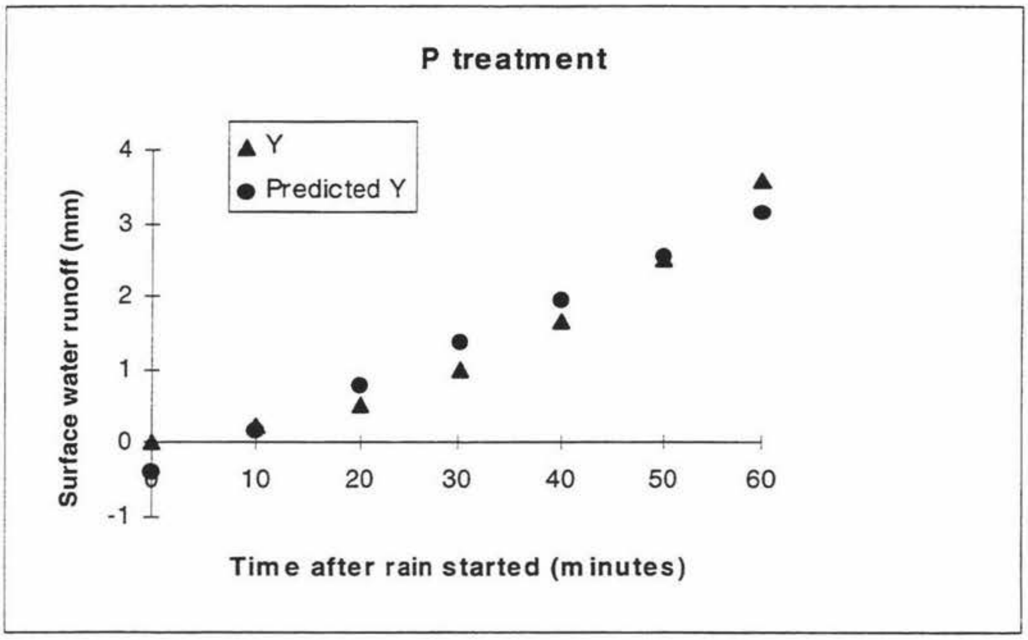

Figure 4.4 Regression analysis between surface water runoff and rainfall intervals under the pasture treatment.

$$Y = -0.41 + 0.06X \qquad (R^2 = 0.94) \qquad (5)$$

Where, Y = volume of surface water runoff (mm);
X = rainfall duration (minutes);
Intercept = - 0.41

Slope: $Y / X = 0.06$ (6)

The mathematical model in equation (5) shows a best fit ($R^2 = 0.94$) and also that the water runoff from a Ohakea silt loam can be predicted by a simple linear regression equation (Figure 4.4).

4.2.2.4 *Volume of water leachate*

The total volume of leachate during simulated rainfall was measured in autumn following barley crop harvest. The results of measurement showed significant differences between the conventional tillage treatment and the no-tillage treatment, but no differences were found between the pasture treatment and the no-tillage treatment (Table 4.7). These results showed that volume of water leachate increased markedly with the reduction in tillage intensity. This indicated that no-tillage practices improved soil aggregates which encouraged infiltrability (as shown in the field studies section 4.2.3) resulting in reduced soil erosion as compared with conventional tillage soil management.

Detailed raw data and statistical analyses are shown in Appendix 1.7.

Table 4.7 Effects of tillage practices and cropping regime on water leachate under rainfall simulator (following barley crop harvest on 28th March, 1996).

Treatment	Leachate (mm)
MP	14.6[b]
NT	24.8[a]
P	24.7[a]
$LSD_{0.05}$	5.9

**Rainfall intensity of 48 ± 2 mm/hr.*

Values followed by the same letter are not significantly different (P ≤ 0.05).

Figure 4.5 also showed that during a short duration rainstorm (10 minutes) there was no water leachate collected at 150 mm soil depth with the conventional tillage treatment, but some water leached in the no-tillage and pasture

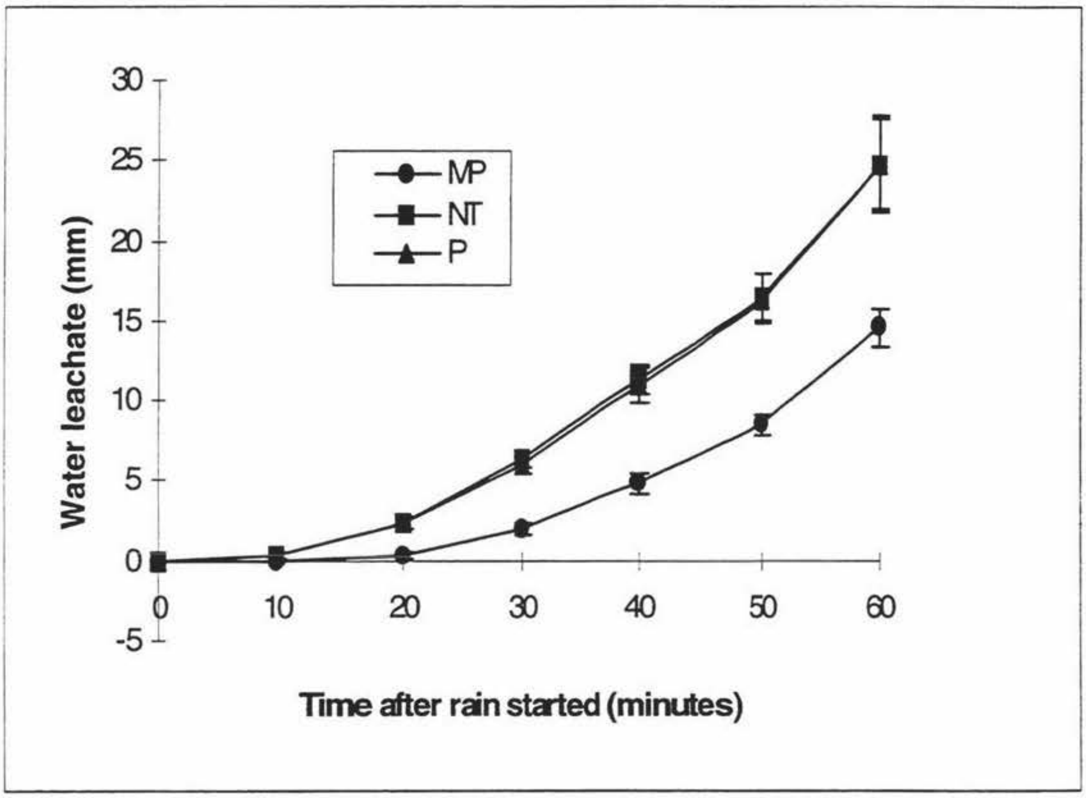

Figure 4.5 Effect of rainstorm duration and tillage treatment on water leachate (following barley crop harvest on 28th March, 1996)

treatments. The volumes of leachate with the conventional tillage treatment were significantly lower (about 15 mm) than those found in the no-tillage and pasture treatments, which were similar (about 25 mm).

4.2.2.5 *Soil sediment concentration in surface runoff*

Soil sediment is soil movement with flowing water; the main cause of raindrop and sheet erosion is the kinetic energy of falling raindrops. Under field conditions raindrop, sheet, and rill erosion are not independent of each other. They affect more acres and cause more soil loss than any other form of soil erosion (Beasley et al., 1984). Sediment is the biggest pollutant of surface water. The sediment itself can alter stream channel characteristics and adversely affect aquatic plant and animal life.

The soil sediment concentration in surface runoff was measured during autumn following barley crop harvest on 28th March 1996.

These data (Table 4.8) showed that the conventional tillage treatment gave approximately 100 times more sediment on an area basis (g/m^2) and 30 times higher sediment concentration in the runoff volume (kg/m^3) than the no-tillage treatment. There were similar volumes of sediment from the no-tillage and pasture treatments.

Soil sediment concentration in the surface runoff varied significantly with rainstorm duration, and was markedly different between the conventional tillage and no-tillage treatments (Figure 4.6). It was higher in the conventional tillage treatment (960 g/m^3 at first 30 minutes) at all times, whereas only small amounts of sediment were detected in surface runoff from the no-tillage (27 g/m^3) and pasture treatments (18 g/m^3) during the first 30 minutes. Also, It did not increase much as the rainstorm progressed over one hour.

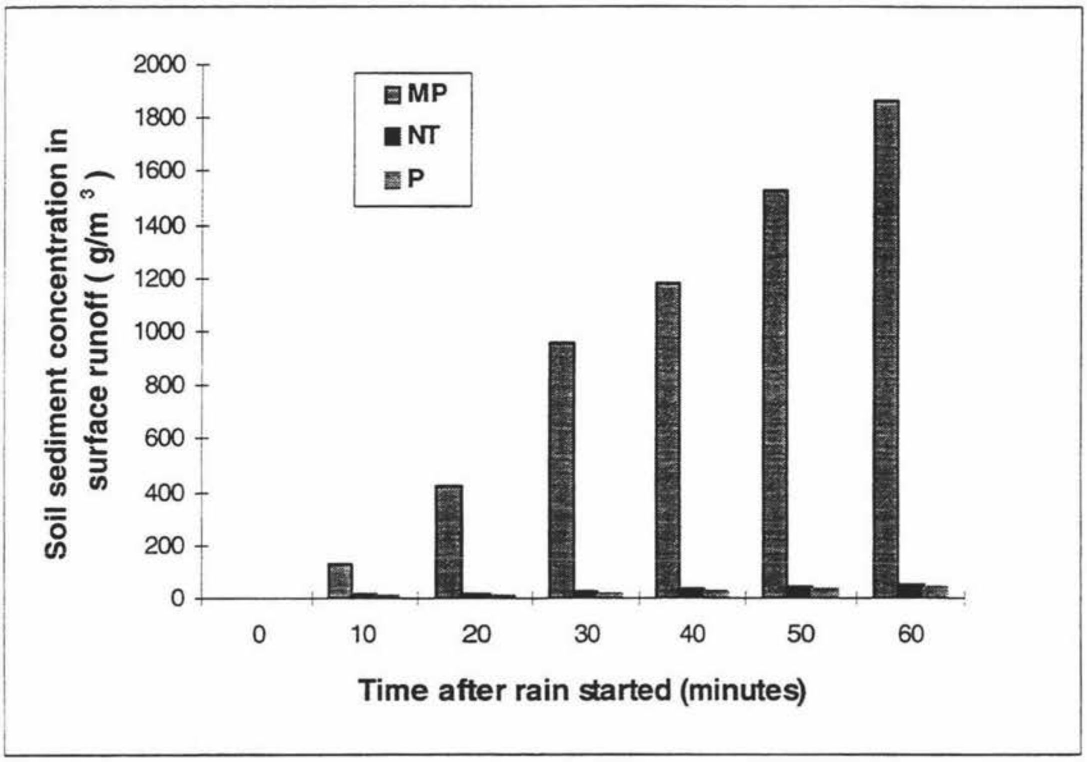

Figure 4.6 **Effect of rainstorm duration and tillage practices on soil sediment concentration (following barley crop harvest on 28th March, 1996).**

Detailed raw data and statistical analyses are shown in Appendix 1.8.

Table 4.8 Effects of tillage practices and cropping regime on soil sediment in runoff (following barley crop harvest on 28th March, 1996).

Treatment	Soil sediment in runoff	
	(g/m^2)	(kg/m^3)
MP	53.00[a]	6.28[a]
NT	0.47[b]	0.19[b]
P	0.50[b]	0.14[b]
$LSD_{0.05}$	2.96	0.52

Values followed by the same letter in each column are not significantly different ($P \leq 0.05$).

Further, statistical analysis has shown that the soil sediment concentration was highly *($P \leq 0.05$)* correlated with rainfall duration. The regression equations for three treatments are shown below:

1. MP treatment

$$Y = -109 + 32.64\,X \qquad (R^2 = 0.97) \qquad (7)$$

Where, Y = sediment concentration (g/m^3) in surface runoff water;
X = rainfall duration (minutes);
Intercept = - 109.61

Slope: $Y / X = 32.64$ (8)

The mathematical model in equation (7) shows a best fit ($R^2 = 0.97$) and also that the sediment concentration in surface runoff from a Ohakea silt loam can be predicated by a simple linear regression equation (Figure 4.7).

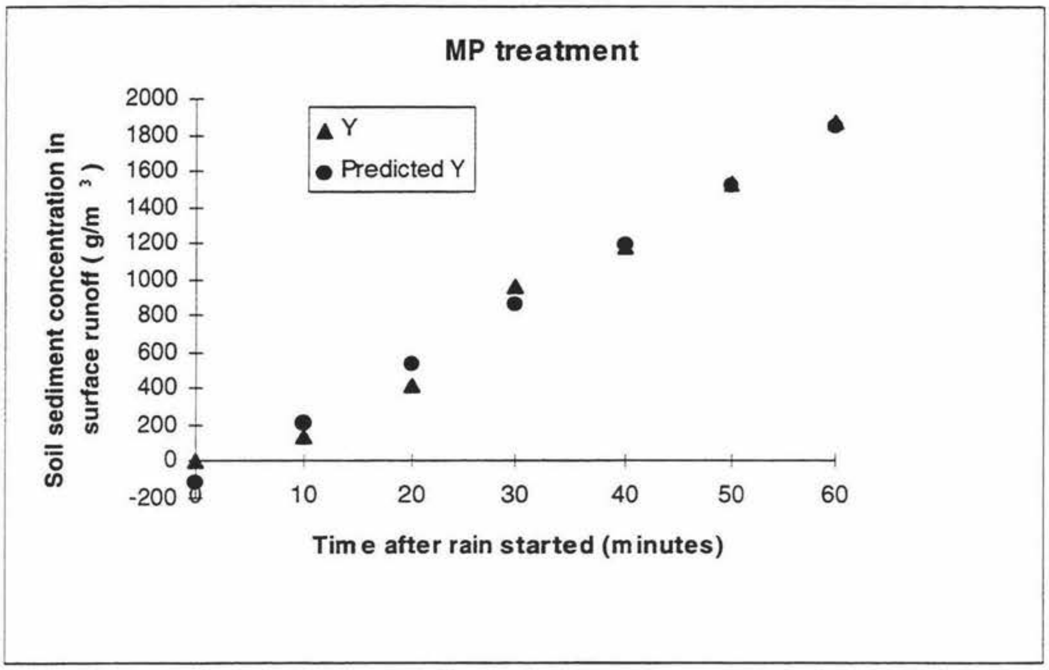

Figure 4.7 Regression analysis between sediment concentration in runoff and rainfall intervals under the conventional tillage treatment.

2 NT treatment

$$Y = 1.32 + 0.86\,X \qquad (R^2 = 0.99) \qquad (9)$$

Where, Y = sediment concentration (g/m^3) in surface runoff water;

X = rainfall duration (minutes);

Intercept = 1.32

Slope: $Y / X = 0.86$ (10)

The mathematical model in equation (9) shows a best fit ($R^2 = 0.99$) and also that the sediment concentration in surface runoff from a Ohakea silt loam can be predicated by a simple linear regression equation (Figure 4.8).

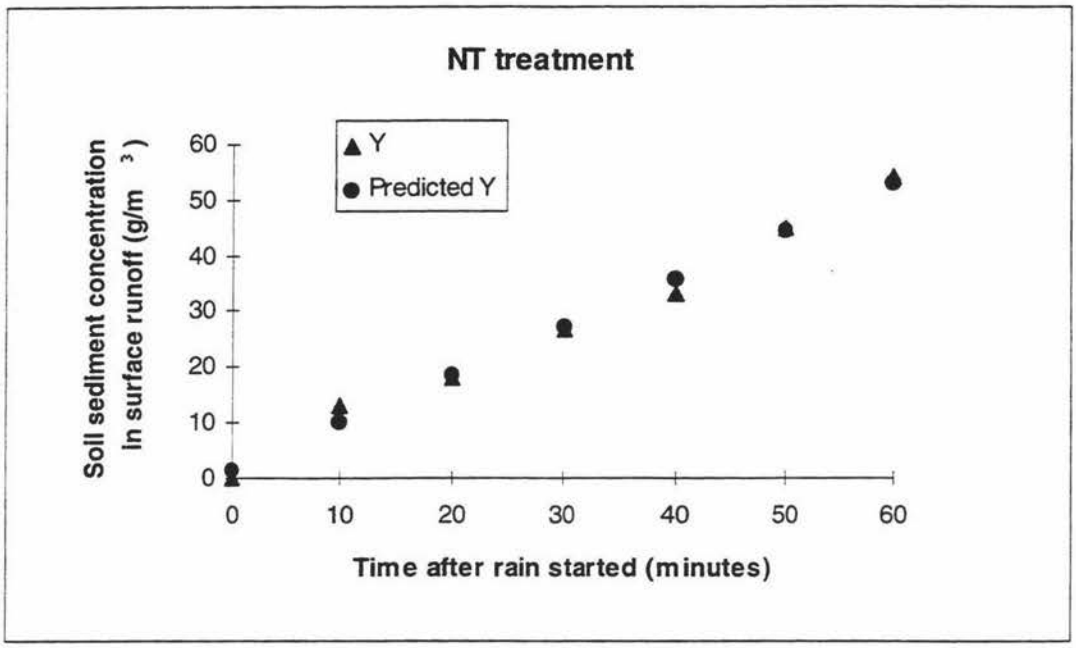

Figure 4.8 Regression analysis between sediment concentration in runoff and rainfall intervals under the no-tillage treatment.

3. P treatment

$$Y = -0.29 + 0.67\,X \qquad (R^2 = 0.99) \qquad (11)$$

Where, Y = sediment concentration (g/m^3) in surface runoff water;

X = rainfall duration (minutes);

Intercept = - 0.29

Slope: $Y / X = 0.67$ (12)

The mathematical model in equation (11) shows a best fit (R^2 = 0.99) and also that the sediment concentration in surface runoff from a Ohakea silt loam can be predicated by a simple linear regression equation (Figure 4.9).

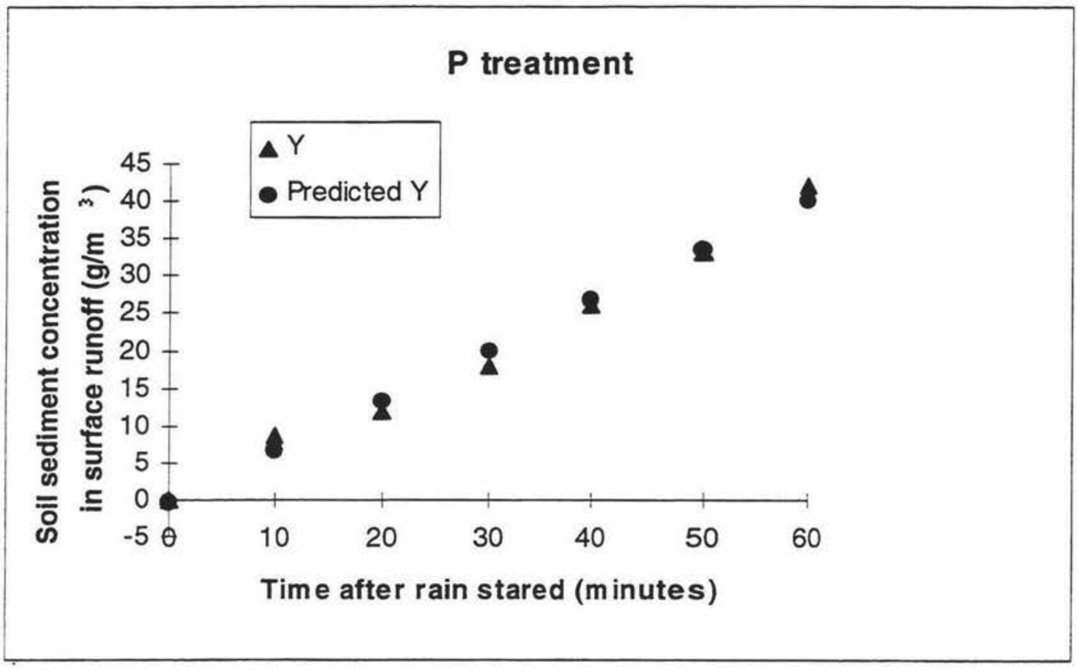

Figure 4.9 Regression analysis between sediment concentration in runoff and rainfall intervals under the pasture treatment.

4.2.2.6 *Nutrient concentration in surface runoff and leachate*

The concentration of the nutrient nitrogen (N), phosphorus (P), and potassium (K) in surface water and groundwater is of environmental and economic concern. Because the increase in nitrogen, phosphorus, and potassium concentrations in water has coincided with an increase in the use of fertilisers, it is often assumed that these fertilisers have been the major contributing factors (Steenvoorden, 1989). But a major source of nutrients in drainage water from agricultural land is often due to mineralization of organic N following cultivation, rather than from the fertiliser itself.

In the present studies the concentrations of nitrogen (N), phosphorus (P), and potassium (K) in runoff and leachate water were measured under the three treatments following barley crop harvest. The results from the experiments are as follows.

Nitrogen (N)

Fertilisers in agriculture play an important role in nitrogen pollution of surface waters and groundwater reservoirs (Loehr, 1984). Nitrogen losses to groundwater and surface waters from a certain field can be reduced by good water management and lower quantities of nitrogen applied to the soil surface and in the soil during the growing season. Agriculture is often singled out for contributing high levels of nitrogen to runoff. Nitrogen fertiliser can contaminate water supplies and, together with phosphorus, cause eutrophication of lakes and rivers (Follett and Walker, 1989).

The intensity and duration of rainfall can also greatly affect nitrogen concentrations in runoff water (Schwab et al., 1996).

The results (Table 4.9) show that average nitrogen concentrations in surface runoff water were lower with the conventional tillage treatment than those found in the no-tillage and pasture treatments. These results indicated that in no-tillage and pasture more nitrogen was stratified cease to the soil surface and thus eroded in rain water. Furthermore, experiment results indicated that amounts of metabolically active N in the surface layer of soils under no-tillage treatment should greatly promote the mineralization and immobilisation of fertiliser N placed on the surface of soils under no-tillage practices. Because of the nature of no-tillage operations, surface application of fertiliser N is currently the most common placement method used in crop production.

As the majority of soil nitrogen is bound in soil organic matter and is unavailable to plant, these organic compounds need to be broken down by natural soil biological processes to produce the plant available mineral form of NH_4^+ and NO_3^-.

However, since there is lower surface organic matter with the conventional tillage treatment than with the no-tillage and pasture treatment, this may have affected soil nitrogen cycling.

Table 4.9 also shows that the average nitrogen concentration in the leachate from the conventional tillage treatment was lower than that from the no-tillage and pasture treatments. This possibly reflected that residual mineral N in the top soil will be mainly subject to leaching from the no-tillage and pasture treatments. These results further indicated that the nitrogen concentration was significantly different between the different tillage treatments during crop growing seasons.

Table 4.9 Total nitrogen concentration (g/m^3) in surface runoff and leachate water as affected by tillage treatments and cropping regime (following barley crop harvest on 28th March, 1996).

Treatment	Nitrogen concentration in runoff water (g/m^3)	Nitrogen concentration in leachate water (g/m^3)
MP	0.17^c	0.11^c
NT	0.21^b	0.28^b
P	0.25^a	0.31^a
$LSD_{0.05}$	0.02	0.02

Values followed by the unlike letter in each column are significantly different ($P \leq 0.05$).

On the other hand, the total nitrogen loss in surface runoff from the conventionally tilled soil was two times greater than the untilled surface and the land under permanent pasture. This confirms earlier findings by Steenvoorden (1989) who suggested that total nitrogen loss is highly dependent on soil loss and can be greatly affected by seedbed preparation methods and the extent of residue cover. However, the amount of nitrogen loss in the leachate from the no-tillage and pasture treatments was approximate four-fold greater than that found in the conventional tillage treatment (Table 4.10). These data reflect the runoff and leachate volumes.

The combined nitrogen "loss" from both surface runoff and leachate water was found to be significantly different between the NT, P, and MP treatments at 7.70 mg/m², 8.29 mg/m², and 3.06 mg/m² respectively (Table 4.10). These data indicated that although total nitrogen losses due to leaching were greater in the no-tillage and pasture treatments than that found in the conventional tillage treatment, most of the soil nitrogen loss resulted due to high surface runoff in the latter treatment.

Detailed raw data and statistical analyses are shown in Appendix 1.9.

Table 4.10 Total nitrogen loss (mg/m^2) in surface runoff and leachate water as affected by tillage treatments and cropping regime (following barley crop harvest on 28th March, 1996).

Treatment	Nitrogen loss in runoff water (mg/m^2)	*Nitrogen loss in leachate water (mg/m^2)	*Total nitrogen loss (mg/m^2)
MP	1.45^a	1.61^c	3.06^c
NT	0.76^b	6.94^b	7.70^b
P	0.63^c	7.66^a	8.29^a
$LSD_{0.05}$	0.04	0.12	0.23

**These data include the downward movement of nitrogen in leachate from 0 to 150 mm soil deep. It is not real "loss" from the field.*

Values followed by the unlike letter in each column are significantly different ($P \leq 0.05$).

Phosphorus (P)

Phosphorus concentration in surface runoff

The phosphorus concentration in the runoff from the conventional tillage treatment was significantly *($P \leq 0.05$)* lower than from the no-tillage treatment. However, phosphorus concentration in the no-tillage and pasture treatments was similar(Table 4.11). The likely reason for these differences could be because of higher concentration of applied phosphorus fertilisers at the surface in the case of no-tillage and permanent pasture, whereas in the conventional tillage treatment the phosphorus fertiliser was mixed in the soil profile.

Table 4.11 Total phosphorus concentration (g/m^3) in surface runoff and leachate water as affected by tillage treatments and cropping regime (following barley crop harvest on 28th March, 1996).

Treatment	Phosphorus concentration in runoff water (g/m^3)	Phosphorus concentration in leachate water (g/m^3)
MP	0.12^c	0.60^c
NT	0.18^b	2.10^b
P	0.23^a	2.90^a
$LSD_{0.05}$	0.02	0.01

Values followed by the unlike letter in each column are significantly different ($P \leq 0.05$).

Phosphorus concentration in leachate

Similar to the phosphorus concentration in the runoff, the leached water displayed high concentration of phosphorus in the no-tillage and pasture plots as compared with conventional tillage plot. The likely reason for such phenomenon could be because of high phosphorus retention characteristics of the soil due to oxidation of FeO_2 to Fe_2O_3 in the conventionally tilled soil.

Phosphorus loss in runoff

Total phosphorus loss in surface runoff was higher from the conventional tillage treatment than from the no-tillage and pasture treatments (Table 4.12). Conversely, phosphorus loss in leachate water was much higher from the no-tillage and pasture treatments than that found in the conventional tillage treatment (Table 4.12). This was due to the greater amount of leachate from the no-tillage and pasture treatments.

Table 4.12 Total phosphorus loss (mg/m²) in surface runoff and leachate water as affected by tillage treatments and cropping regime (following barley crop harvest on 28th March, 1996).

Treatment	Phosphorus loss in runoff water (mg/m^2)	*Phosphorus loss in leachate water (mg/m^2)	*Total Phosphorus loss (mg/m^2)
MP	1.02^a	8.8^c	9.8^c
NT	0.65^b	52.1^b	52.7^b
P	0.58^c	71.6^a	72.2^a
$LSD_{0.05}$	0.02	1.6	2.8

**These data include the downward movement of phosphorus in leachate from 0 to 150 mm soil deep. It is not real "loss" from the field.*

Values followed by the unlike letter in each column are significantly different ($P \leq 0.05$).

These data showed that the phosphorus loss was significantly affected by the methods of tillage and cropping regime. This also indicated that tillage treatment had a major affect on soil phosphorus mineralization and availability for plant uptake as well as for potential leaching. Because phosphorus adsorption capacity of soils influences phosphorus movement, and since no-till soils are left practically undisturbed, there is a tendency for macropores to form. If macropores are continuous, these may cause preferential flow of water, and nutrients towards groundwater, thereby short-circuiting the retentive and biologically active soil zone. Thus allowing high water conductivity and consequent losses of nutrients including phosphorus in no-till cropped and pasture soils.

Tillage destroys macropores, thereby limiting their continuity from the soil surface through the profile. This decreases downward movement of water in the conventional tillage treatment, because of high soil density, penetration resistance, and low hydraulic conductivity, minimising phosphorus losses due to leaching.

Total phosphorus losses (including leachate carried in runoff and leachate) showed similar trends. As individual losses, the total losses in this case are not real losses because downward movement and catchment of water at 150 mm depth is considered as loss at that point.

Detailed raw data and statistical analysis are shown in Appendix 1.10.

Potassium (K)

The average concentration of potassium in surface runoff and leachate water was significantly affected by the three treatments (Table 4.13). No-tillage and pasture treatments had similar levels of potassium concentration, but higher than that found in the conventional tillage treatment. Similar trends were found in the levels of potassium concentration in the leachate water except that these potassium concentration were approximate ten-fold higher than those in the runoff.

Table 4.13 Total potassium concentration (g/m^3) in surface runoff and leachate water as affected by tillage treatments and cropping regime (following barley crop harvest on 28th March, 1996).

Treatment	Potassium concentration in runoff water (g/m^3)	Potassium concentration in leachate water (g/m^3)
MP	1.0^b	9.5^b
NT	1.9^a	23.3^a
P	2.2^a	26.9^a
$LSD_{0.05}$	0.1	0.2

Values followed by the unlike letter in each column are significantly different (P≤0.05).

Table 4.14 Total potassium loss (mg/m^2) from surface runoff and leachate water as affected by tillage treatments and cropping regime (following barley crop harvest on 28th March, 1996).

Treatment	Potassium loss in runoff water (mg/m^2)	*Potassium loss in leachate water (mg/m^2)	*Total potassium loss (mg/m^2)
MP	8.3^a	139^c	147^c
NT	6.8^b	578^b	585^b
P	5.5^c	644^a	650^a
$LSD_{0.05}$	0.1	8.6	9.1

**These data include the downward movement of potassium in leachate from 0 to 150 mm soil deep. It is not real "loss" from the field.*

Values followed by the unlike letter in each column are significantly different (P≤0.05).

Conversely, the total potassium loss in surface runoff was higher in the conventional tillage treatment than in the pasture and no-tillage treatments. This reflected the runoff trends in the treatments. But, total potassium loss in the leachate water was higher with the no-tillage and pasture treatments than with the conventional tillage treatment (Table 4.14). In this respect it is likely that the adoption of no-tillage, would lead to excessive downward movement of potassium and causing ground water pollution as earlier suggested by Beasley et al. (1984).

Detailed raw data and statistical analyses are shown in Appendix 1.11.

From the above experimental results of nutrient concentration in surface runoff and leachate water, it is clear that the type of tillage practices and their intensity is one of the major factors affecting soil and water quality. Adoption of conservation tillage such as no-tillage can be used effectively to reduce nutrient losses by controlling erosion and by improving quality of surface water runoff.

On the other hand, because of the likelihood of higher rates of downward movement of phosphorus and potassium dissolved in water might affect ground water quality when no-tillage was adopted. To assess it the downward movement of phosphorus and potassium would affect ground water, there is a need to measure the concentration of these nutrients close to ground water. This should perhaps be undertaken as a separate study. However, such a concern is unlikely because of gentle nature of rainfall patterns particularly in the low permeability finer soils in New Zealand.

4.2.2.7 *pH of runoff and leachate*

The experimental results after one crop season suggested that pH for both surface runoff and leachate water was not significantly *($P \leq 0.05$)* different among the three treatments, indicating that tillage methods and cropping pattern perhaps had no impact on soil pH. (Table 4.15). The rather high pH values obtained in this experiment reflect the pH of water used for rainfall. In hindsight, deionised water should have been used for this purpose.

Table 4.15 Soil pH of surface water runoff and leachate as affected by tillage treatments (following barley crop harvest on 28th March, 1996).

Treatment	Runoff	Leachate
MP	7.45[a]	7.15[a]
NT	7.40[a]	7.07[a]
P	7.38[a]	7.02[a]
$LSD_{0.05}$	0.26	0.21

Values followed by the same letter in each column are not significantly different ($P \leq 0.05$).

These data are in contrast to those found by Choudhary et al. (1996) who reported that in a central Ohio silt loam after 32 years of continuous no-tillage cropping, surface pH decreased significantly. These authors related this phenomenon to continuous stratification of soil surface due to surface application of nitrogen fertilisers. However, such differences were not visible in the present study. This may have been due to lack of longevity of present experiments.

Detailed raw data and statistical analysis are shown in Appendix 1.12.

4.3 Experiment 2: Soil, Water Runoff and Leachate Properties Under Three Treatments Following Winter Oats Harvest

4.3.1 *Field Measurements*

4.3.1.1 *Bulk density*

These results were collected in August 1996, during the second season after oats crop harvest. The results (Table 4.16) showed that the soil bulk density in the no-tillage, pasture and conventional tillage treatments was significantly different. Soil bulk density increased as the tillage intensity increased. These data indicated that the soil became most compact under the conventional tillage practices. This confirms the view that the system of crop and soil management employed on a given soil can influence the bulk density of the surface layers as earlier suggested by Brady (1984).

Table 4.16 Effects of tillage practices and cropping regime on soil bulk density (following oats crop harvest on 1st August, 1996).

Treatment	Bulk density (Mg/m^3)
MP	1.21^a
NT	1.10^b
P	1.02^c
$LSD_{0.05}$	0.012

Values followed by the unlike letter are significantly different ($P \leq 0.05$).

Interestingly the present results were contrasting to those found by Horne et al. (1992) who reported that in Tokomoru silt loam after ten years of continuous maize and oats rotation, soil bulk density increased with the adoption of zero-tillage. On the other hand, Unger (1996) found that soil bulk density was not significantly effected by tillage practices. These differing results possibly reflected the location and site specificity, and cropping systems adopted. Also experiment longevity and time of measurement during the year may have effected the soil strength results in various locations.

Detailed raw data and statistical analyses are shown in Appendix 2.1.

4.3.1.2 *Soil water content*

After the oats crop harvest in the winter 1996, soil water contents was measured in all three treatment plots (Table 4.17). Soil water content was significantly higher in pasture, followed by no-tillage and the conventional treatment. This could have been caused by a lower humus content in the topsoil under conventional tillage. More importantly, this could be due to damaged soil structure (high bulk density) (Table 4.16) and reduced soil moisture infiltration in the conventional tillage treatment (Table 4.17). On the other hand, no-tillage practices have been found to retain topsoil organic matter, which allows retention of more soil moisture, and maintains soil structure, and infiltrability.

Table 4.17 Effects of tillage practices and cropping regime on soil volumetric water content (following oats crop harvest on 1st August, 1996).

Treatment	Water content (m^3/m^3)
MP	0.40^c
NT	0.48^b
P	0.55^a
$LSD_{0.05}$	0.012

Values followed by the unlike letter are significantly different ($P \leq 0.05$).

These results are contrasting to those found in experiment 1, which suggested no differences in bulk density between three treatments. These findings are, however, similar to other data shown by Karlen et al. (1994).

Detailed raw data and statistical analyses are shown in Appendix 2.2.

4.3.1.3 *Infiltrability*

The infiltrability results showed no significant differences between the pasture plots and no-tillage plots, but these treatments had higher values than the conventional tillage plots (Table 4.18).

Table 4.18 Effects of tillage practices and cropping regime on soil infiltrability (following oats crop harvest on 28 August, 1996).

Treatment	Infiltrability (mm/h)
MP	10.5^{b}
NT	16.7^{a}
P	17.2^{a}
$LSD_{0.05}$	0.5

Values followed by the same letter are not significantly different ($P \leq 0.05$).

An important factor affecting the infiltrability is the crop residue and vegetative cover on the soil surface. Because crop residue had not been removed from the no-tillage treatment in the field, this allowed high water penetration. In contrast, since there was no or little crop residue cover and low organic matter on MP treatment, and when intense rain comes the soil is not protected by a vegetative cover or by a mulch, it often packs and seals the surface layer, reducing infiltrability. On the other hand, the vegetative cover breaks the impact of the rain drops, and the soil remains permeable and has a much higher infiltrability. The great value of soil conservation practices in erosion control comes from the ability of the improved soil to produce and maintain a more effective vegetative cover.

Detailed raw data and statistical analyses are shown in Appendix 2.3.

4.3.1.4 *Earthworm population*

Earthworms improve soil structure by making macropores, and by ingesting soil and in doing so binding particles together to produce stable earthworm casts. Earthworms need an organic food source. They dislike soil cultivation, which can be directly fatal for them, and degrades their environment.

The results of earthworm counts showed that earthworm populations were significantly higher in the pasture and no-tillage treatments than in the conventional tillage treatment (Table 4.19). The degree of disturbance and the amount of surface residue cover are the key factors to consider when assessing the effect different tillage practices have on plant establishment which encourage earthworm populations.

Table 4.19 Effects of tillage practices and cropping regime on earthworm population (July, 1996).

Treatment	Earthworm population (numbers/m^2)
MP	159^c
NT	254^b
P	313^a
LSD$_{0.05}$	41

Values followed by the unlike letter are significantly different ($P \leq 0.05$).

These findings are similar to other researcher's reports e.g. by House (1985) and Karlen et al. (1994). This further confirmed that tillage practices and soil management are major factors affecting soil earthworm populations. Therefore, to improve soil quality adoption of no-tillage or minimum tillage practices management for agricultural crop production should be encouraged.

Detailed raw data and statistical analyses are shown in Appendix 2.4.

4.3.1.5 *Soil pH*

The soil pH was measured in winter 1996 at two different depth (0-5, and 5-15 cm). At the time of measurement no significant differences were found. The average soil pH was around 5.3 (Table 4.20). Clearly the tillage methods and cropping pattern had no impact on soil pH in the early years of this long-term experiment. Further, these low pH values are not unexpected in pastoral lands. In such soils, the pasture which have high clover contents, fix nitrogen giving high ionic activity and hence low pH. This is in contrast to other continuously cropped calcarious soils where average soil pH ranged from 7 to 8 (Choudhary et al., 1996).

Table 4.20 Effects of tillage practices and cropping regimes on topsoil (0-15 cm depth) pH (on 31st July, 1996).

Treatment	0 - 5 cm	5 - 15 cm
MP	5.38[a]	5.36[a]
NT	5.35[a]	5.32[a]
P	5.33[a]	5.31[a]
$LSD_{0.05}$	0.06	0.11

Values followed by the same letter in each column are not significantly different ($P \leq 0.05$).

Detailed raw data and statistical analyses are shown in Appendix 2.5.

4.3.1.6 *Crop establishment*

Winter oats seedling numbers were counted by using a quadrat method, and calculated to obtain percentage of plant establishment. Data showed that plant percentage emergence was significantly different between the no-tillage and the conventional tillage treatments (Table 4.21). These results indicated that crop establishment is only moderately affected by tillage method.

This is not unexpected as at the time of sowing, field and climatic conditions were near "ideal" for establishment. Therefore, method of land preparation was expected to have minimal impact on seed germination and seedling emergence.

These results are somewhat dissimilar to those found by Hughes (1985), who suggested that after three years of oats crop sown in rotation with summer maize in Manawatu, crop establishment was not different between no-tillage and conventional tillage.

Detailed raw data and statistical analyses are shown in Appendix 2.6.

Table 4.21 Effects of tillage methods on oats establishment.

Treatment	Plant establishment (%)
MP	97.1^{a}
NT	94.3^{b}
$LSD_{0.05}$	2.01

Values followed by the unlike letter are significantly different ($P \leq 0.05$).

4.3.1.7 *Dry matter yield*

The dry matter (DM) of pasture was accumulated to give total DM yield from pasture treatment which was 7.58 t/ha/yr from December 1995 to November 1996.

Dry matter yield of oats in the present experiments were measured at maturity. Data showed that total DM of oats were not significantly *($P \leq 0.05$)* different between the conventional tillage and no-tillage treatments (Table 4.22). However, DM of oats was significantly higher than the pasture DM. The results further confirmed that no-tillage practices and soil management not only improved soil quality and reduced the input for crop production, but also gave sustainable crop yield as compared with conventional tillage systems.

Table 4.22 Oats dry matter yield (t/ha) as affected by tillage treatments (before oats crop grazing on 1st August, 1996).

Treatment	Dry matter yield (t/ha)
MP	3.37^{a}
NT	3.33^{a}
*P	2.60^{b}
$LSD_{0.05}$	0.07

Values followed by the same letter are not significantly different ($P > 0.05$).
**DM of pasture was accumulated to give total yield during oats crop growth from 18/04/1996 to 01/08/1996.*

These results are contrasting to earlier results which suggested that after ten years of continuous maize and oats double cropping rotation under three tillage systems in Manawatu (Hughes et al., 1992), crops yield had no significant difference between no-tillage and conventional tillage. Janson (1984) found similar establishment results in Canterbury.

Detailed raw data and statistical analyses are shown in Appendix 2.7.

4.3.2 *Laboratory Measurements*

4.3.2.1 *Surface water runoff*

The volumes of surface runoff and leachate under simulated rainfall were again measured in winter 1996, following oats crop harvest. Significant differences were found between the three treatments.

Table 4.23 Effects of tillage practices and cropping regime on surface water runoff under rainfall simulator (following oats crop harvest on 6th August, 1996)

Treatment	Surface runoff (mm)
MP	15.4[a]
NT	3.3[b]
P	2.5[b]
$LSD_{0.05}$	0.6

Values followed by the same letter are not significantly different ($P \leq 0.05$).

**Rainfall intensity of 48 ± 2 mm/hr*

The volume of surface runoff from the conventional tillage treatment was nearly five times higher than from the no-tillage treatment (Table 4.23). There are similarities between the results of surface runoff in winter following oats crop harvest and in autumn 1996. These results indicated that the least tillage operation used for crop production have been recognised as important

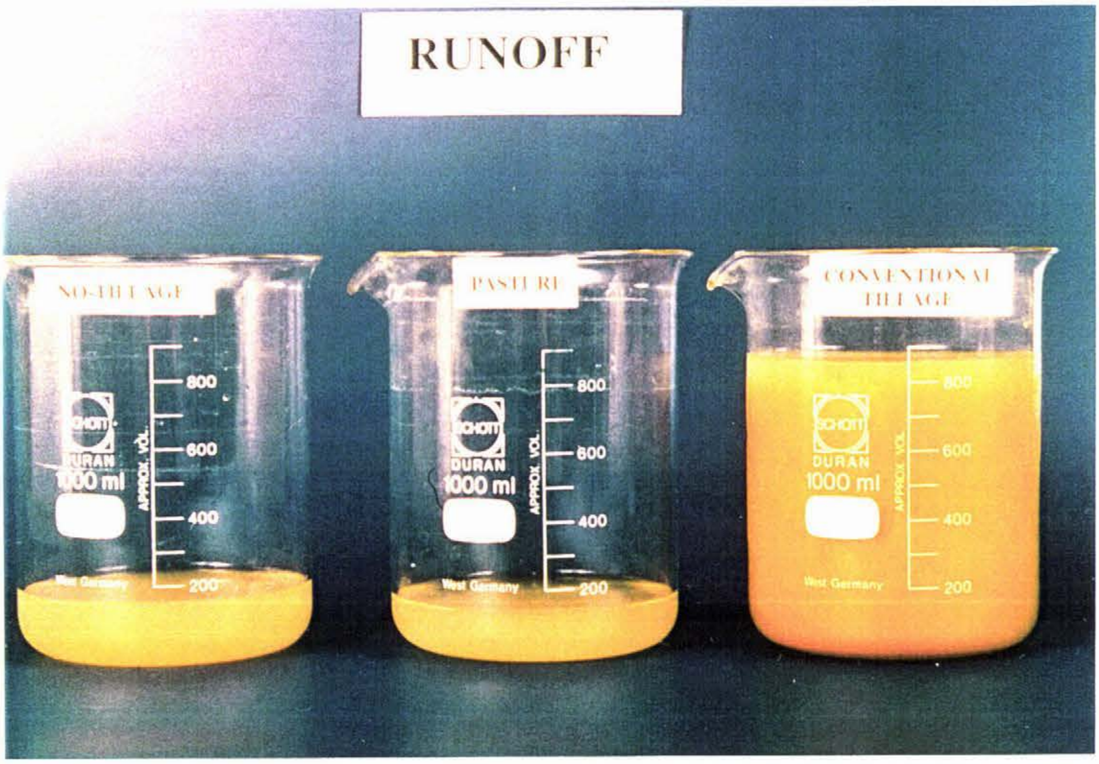

Figure 4.10 Volume of surface water runoff for the three treatments under rainfall simulator (following oats crop harvest on 6th August, 1996).

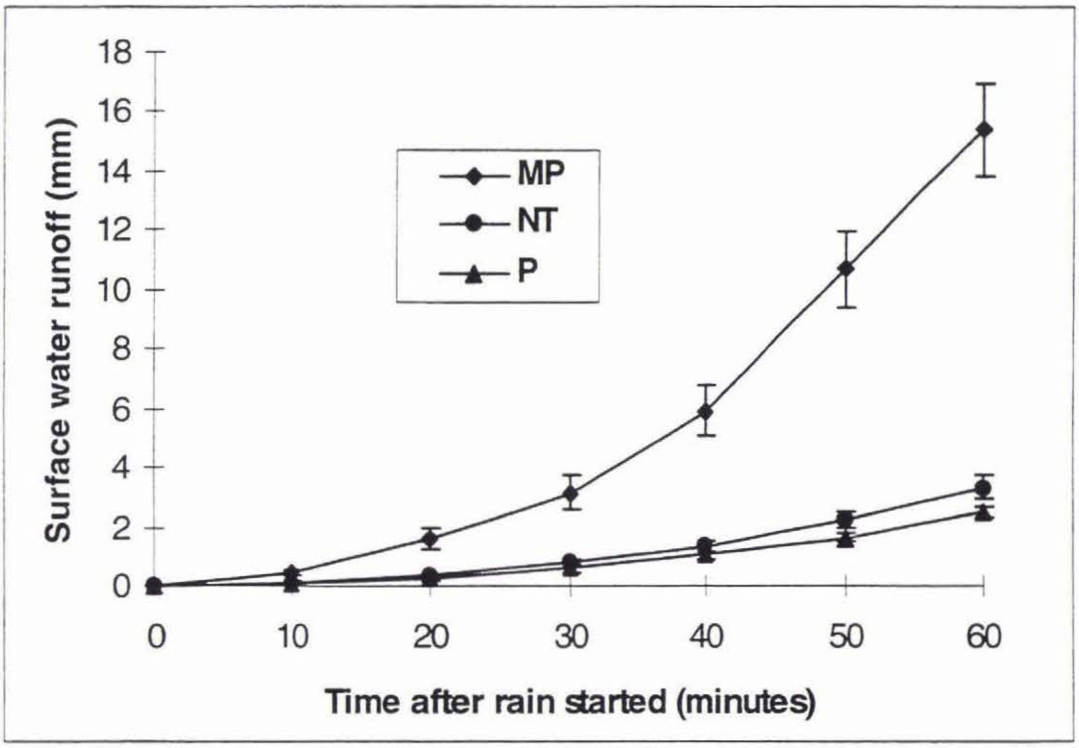

Figure 4.11 **Effect of rainstorm duration and tillage practices on surface water runoff (following oats crop harvest on 6th August, 1996).**

determinants of the infiltration-runoff relationship, and have an effect on land management and soil hydrology.

Figure 4.10 also clearly show that volume of surface runoff under rainfall simulator was significantly different between three treatments.

Detailed raw data and statistical analyses are shown in Appendix 2.8.

4.3.2.2 *Effects of rainstorm duration*

Data on the effects of rainstorm duration (Figure 4.11) showed that a short duration (10 minute) rainstorm had no significant impact on surface water runoff irrespective of the previous tillage intensity or the type of vegetation. But, a difference developed as the duration of the rainstorm increased. This indicated that soil structure under the conventional tillage treatment easily allowed runoff to occur as the rainstorm progressed. Such a phenomenon indirectly also reflected low infiltrability of conventionally tilled soils. Volume of water runoff from no-tillage plots was similar to that from pasture plots.

Statistical analysis has shown that the surface water runoff was highly ($P \leq 0.05$) correlated with rainfall duration (Figures 4.12, 4.13 and 4.14). The regression equations for the three treatments are as below:

1. MP treatment

$$Y = -2.29 + 0.25 X \qquad (R^2 = 0.89) \qquad (13)$$

Where, Y = volume of surface water runoff (mm);
X = rainfall duration (minutes);
Intercept = - 2.29

Slope: $$Y / X = 0.25 \qquad (14)$$

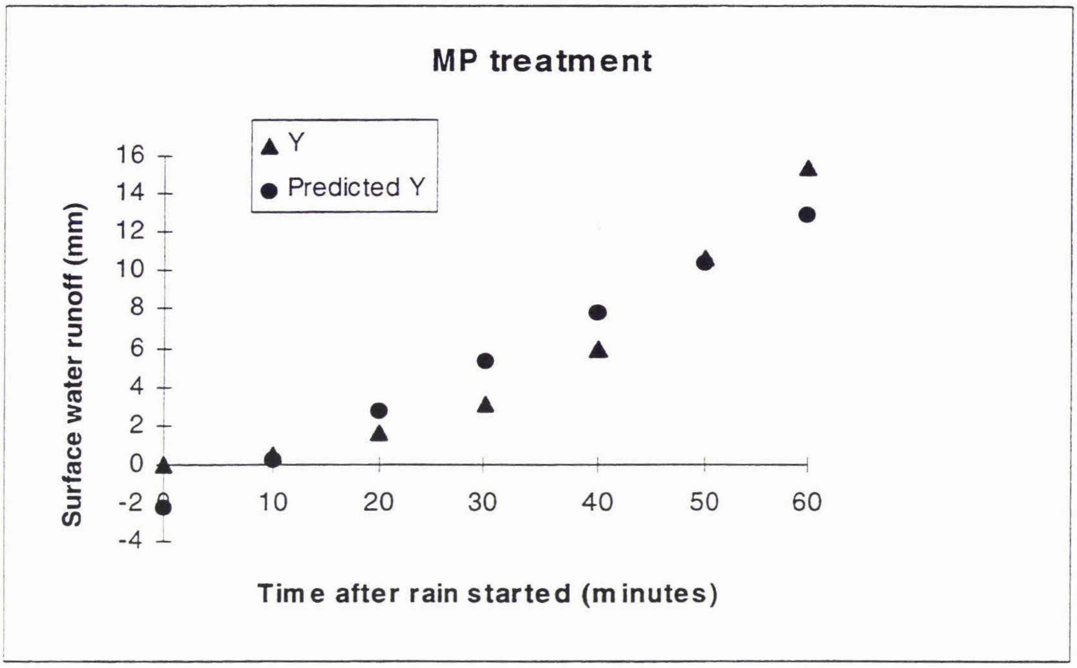

Figure 4.12 Regression analysis between surface runoff and rainfall intervals under the conventional tillage treatment.

2. NT treatment

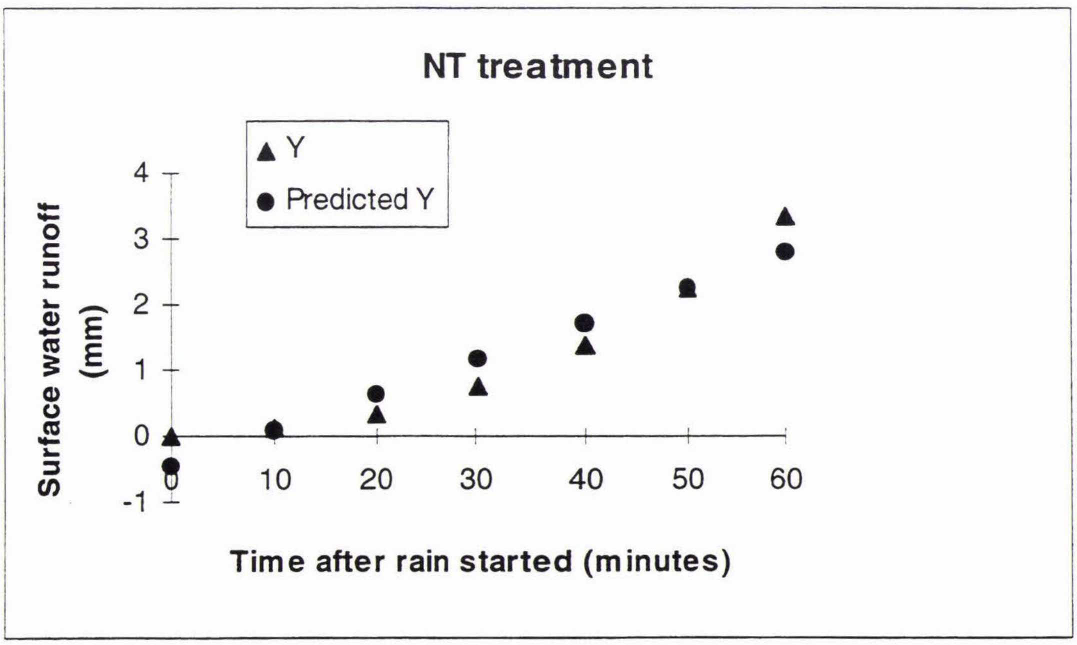

Figure 4.13 Regression analysis between surface runoff and rainfall intervals under the no-tillage treatment.

$$Y = -0.47 + 0.05X \qquad (R^2 = 0.91) \qquad (15)$$

Where, Y = volume of surface water runoff (mm);

X = rainfall duration (minutes);

Intercept = - 0.47

Slope: $Y / X = 0.05$ (16)

3. P treatment

$$Y = -.0.35 = 0.04X \qquad (R^2 = 0.91) \qquad (17)$$

Where, Y = volume of surface water runoff (mm);

X = rainfall duration (minutes);

Intercept = - 0.35

Slope: $Y / X = 0.04$ (18)

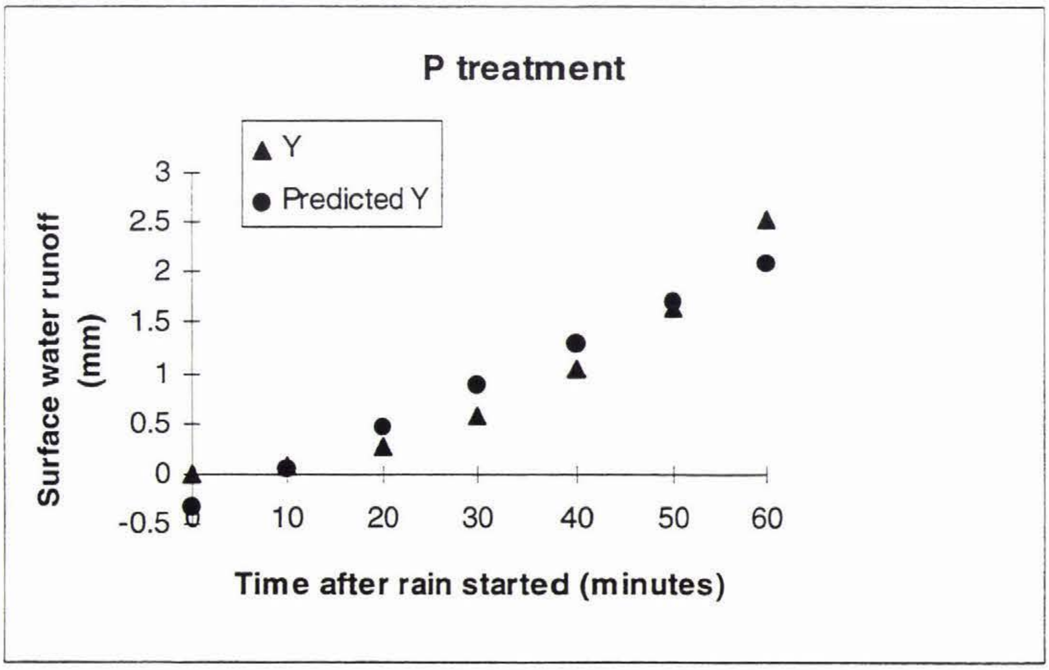

Figure 4.14 Regression analysis between surface runoff and rainfall intervals under the pasture treatment.

The mathematical model in above equations (13, 15 and 17) show the best fit (R^2 = 0.89, 0.91 and 0.91 respectively) and also the water runoff from Ohakea silt loam can probably be predicated by the simple linear regression equations.

4.3.2.3 *Volume of water leachate*

The total volume of leachate during simulated rainfall was also measured in winter 1996 (following oats crop harvest). The results of measurements showed significant differences between the conventional tillage treatment and the no-tillage treatment, but no differences in the leachate volume were found between the pasture treatment and the no-tillage treatment (Table 4.24).

Detailed raw data and statistical analyses are shown in Appendix 2.9.

Table 4.24 Effects of tillage practices and cropping regime on water leachate under rainfall simulator (following oats crop harvest on 6th August, 1996).

Treatment	Leachate (mm)
MP	2.7^b
NT	11.5^a
P	13.2^a
$LSD_{0.05}$	2.5

Values followed by the same letter are not significantly different ($P \leq 0.05$).
**Rainfall intensity of 48 ± 2 mm/hr.*

Figure 4.15 also clearly shows that overall volume of leachate water was significantly different between three treatments.

During the first twenty minutes there was no water leachate with conventional tillage treatment, but similar volumes of water leached from the no-tillage and pasture treatments (Figure 4.16).

The total water leachate volumes with the conventional tillage treatment were significantly lower (2.7 mm) than those from the no-tillage and pasture treatments. The volumes of water leachate with these two latter treatments were statistically similar to each other with no-tillage at 11.5 mm and pasture at 13.2 mm.

These results indicated that continuously tilled soil increased the immediately available pore space near the surface, but decreased the amount of infiltrating water moving deeper into the soil profile as earlier suggested by Hillel (1980).

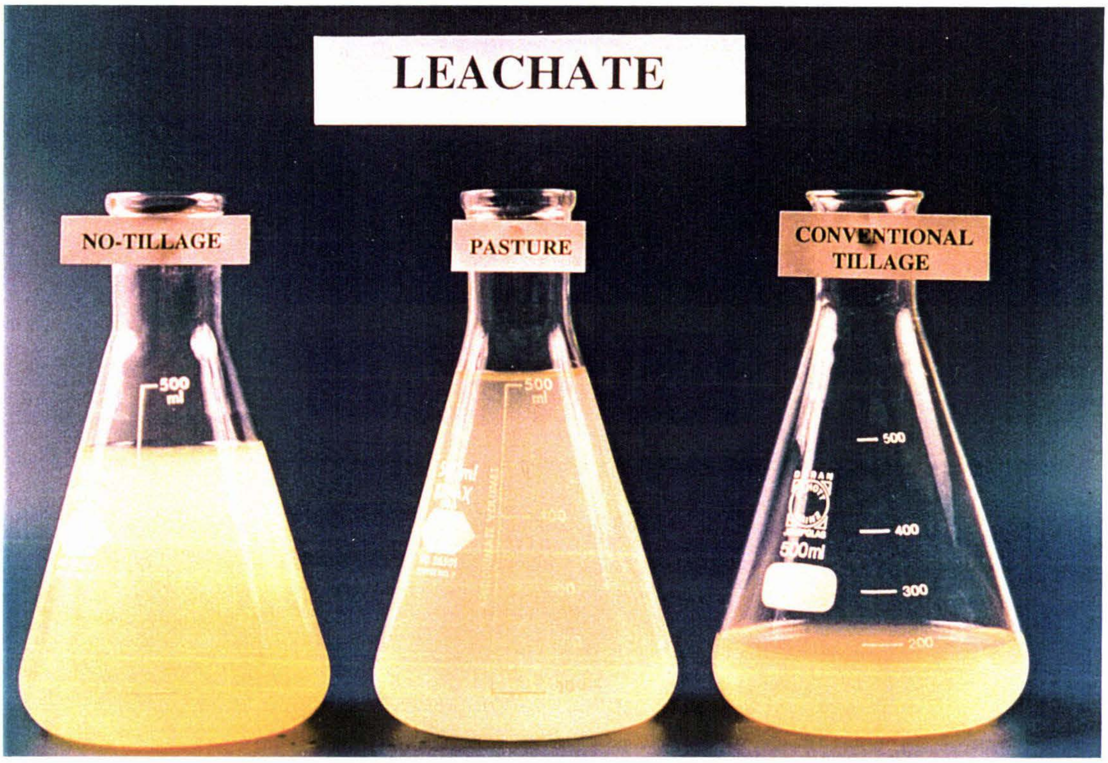

Figure 4.15 Volume of water leachate as affected three treatments under rainfall simulator (following oats crop harvest on 6th August, 1996).

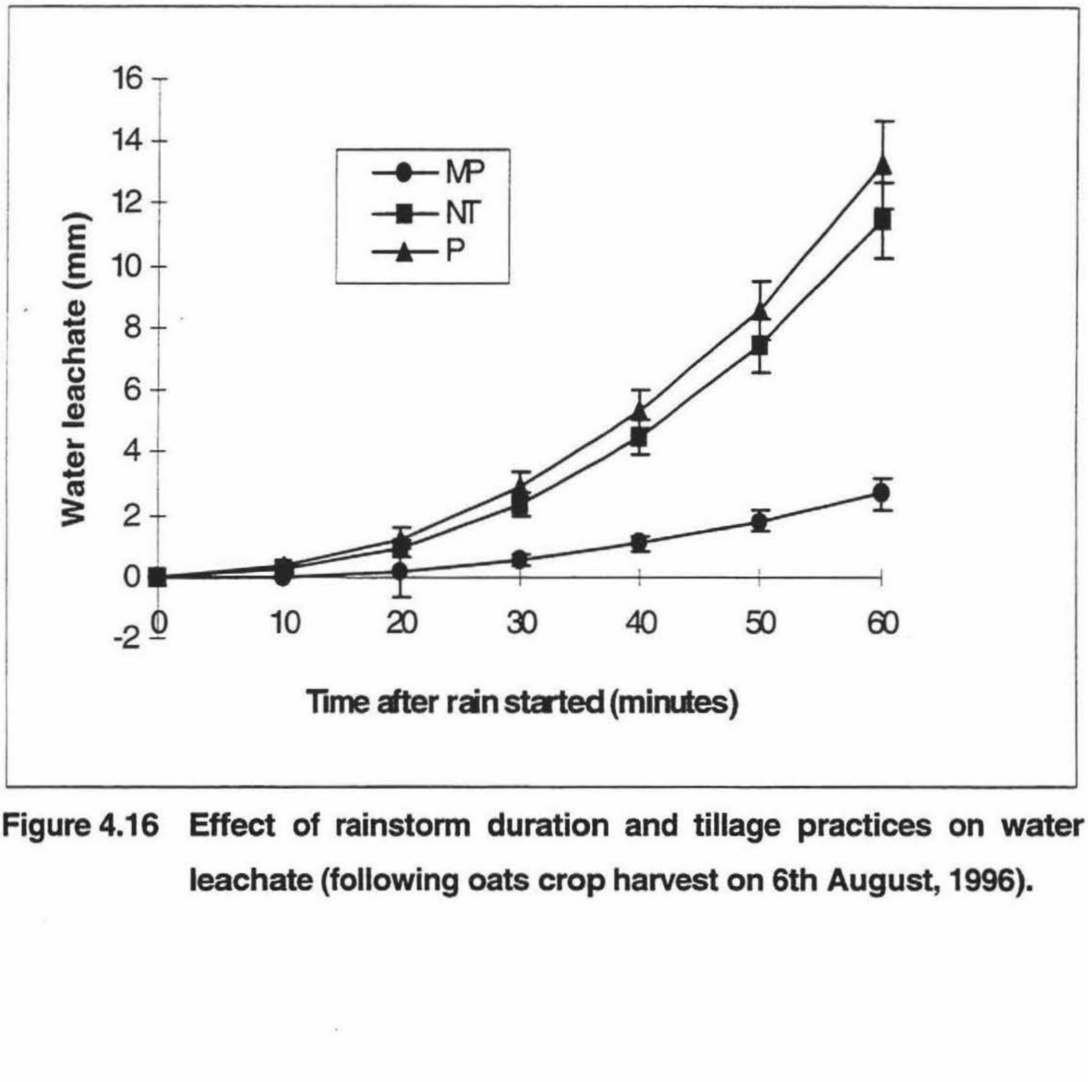

Figure 4.16 Effect of rainstorm duration and tillage practices on water leachate (following oats crop harvest on 6th August, 1996).

4.3.2.4 *Soil sediment concentration in surface runoff*

The soil sediment concentration in surface runoff was measured in winter following oats crop harvest on 6th August 1996.

The amount of sediment from the ploughed soil (MP) was 17 times greater compared to the no-tillage (NT) treatment on an area basis (g/m^2), and four times the sediment concentration (kg/m^3) in the runoff. Again there were no significant differences between the pasture and no-tillage treatments (Table 4.25). These trends again reflect the data obtained in experiment 1.

Detailed raw data and statistical analyses are shown in appendix 2.10.

Table 4.25 Effects of tillage practices and cropping regime on soil sediment in runoff (following oats crop harvest on 6th August, 1996).

Treatment	Soil sediment in runoff	
	(g/m^2)	(kg/m^3)
MP	51.67[a]	3.95[a]
NT	2.94[b]	0.93[b]
P	1.25[b]	0.50[b]
$LSD_{0.05}$	5.34	0.88

Values followed by the same letter in each column are not significantly different ($P \leq 0.05$).

Figure 4.17 shows that the rate of detachment and transport of soil sediment in the surface runoff is much higher over a period of one hour from the conventional tillage treatment than from the no-tillage and pasture treatments. This means that

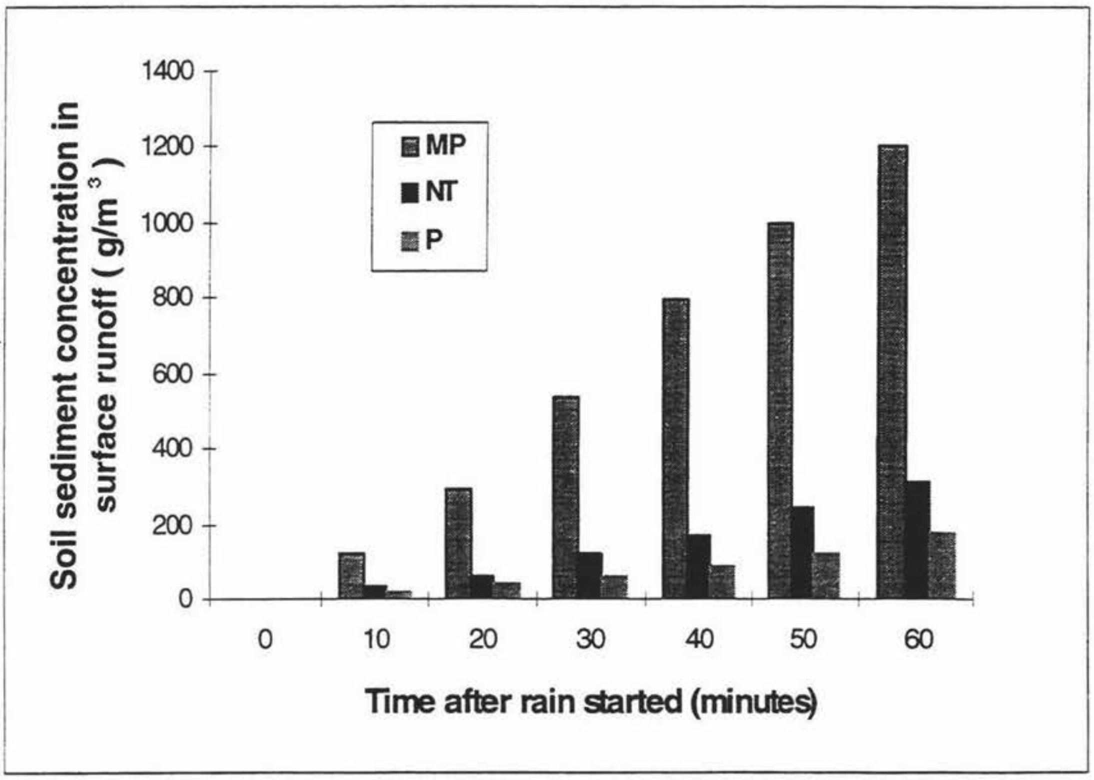

Figure 4.17 Effect of rainstorm duration and tillage practices on soil sediment concentration (following oats crop harvest on 6th August, 1996).

the tillage intensity and the amount of vegetation on the soil surface appear to be the main factors controlling the amount of soil sediment detachment and runoff.

Statistical analysis were shown that the soil sediment was highly *($P \leq 0.05$)* correlated to with rainfall duration (Figures 4.18, 4.19 and 4.20). The regression equations for three treatments are shown below:

1. MP treatment

$$Y = -66.29 + 21.01\,X \qquad (R^2 = 0.99) \qquad (19)$$

Where, Y = sediment concentration (g/m^3) in surface runoff water;
X = rainfall duration (minutes);
Intercept = - 66.29

Slope: $Y / X = 21.01$ (20)

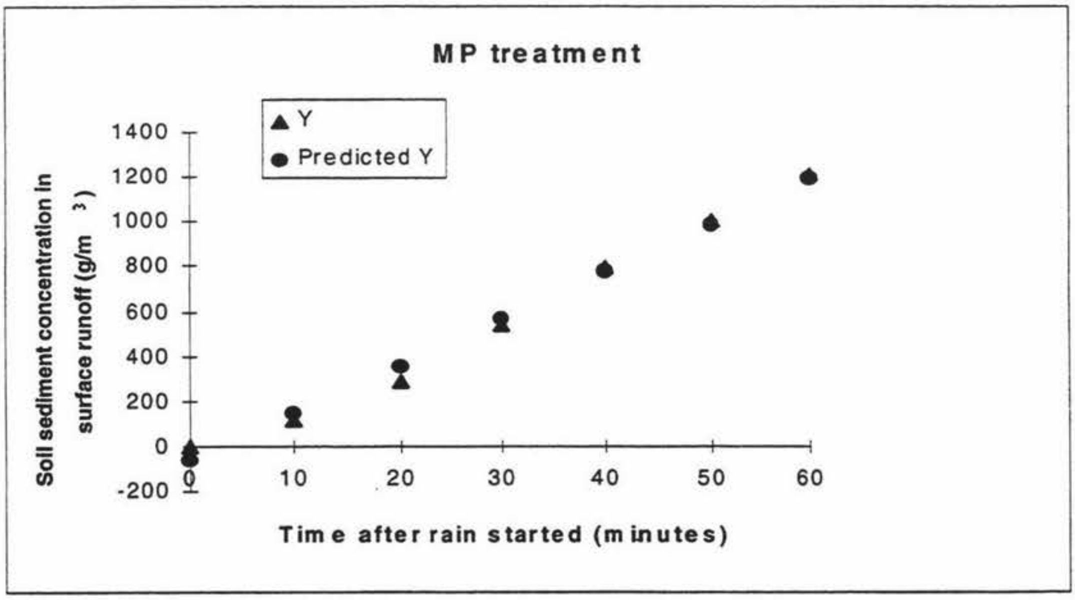

Figure 4.18 Regression analysis between sediment concentration in runoff and rainfall intervals under the conventional tillage treatment.

2. NT treatment

$$Y = -22.21 + 5.22\,X \qquad (R^2 = 0.98) \qquad (21)$$

Where, Y = sediment concentration (g/m^3) in surface runoff water;
X = rainfall duration (minutes);
Intercept = - 22.21

Slope: Y / X = 5.22 (22)

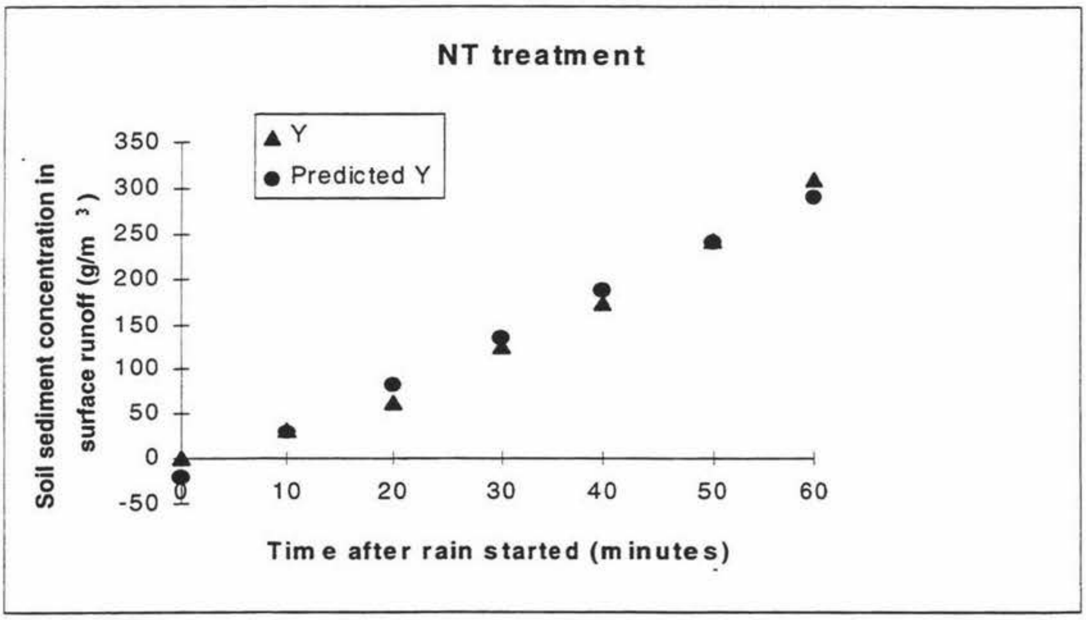

Figure 4.19 Regression analysis between sediment concentration in runoff and rainfall intervals under the no-tillage treatment.

3. P treatment

$$Y = -12\ 79 + 2.84\,X \qquad (R^2 = 0.96) \qquad (23)$$

Where, Y = sediment concentration (g/m^3) in surface runoff water;
X = rainfall duration (minutes);
Intercept = - 12.79

Slope: $Y / X = 2.84$ (24)

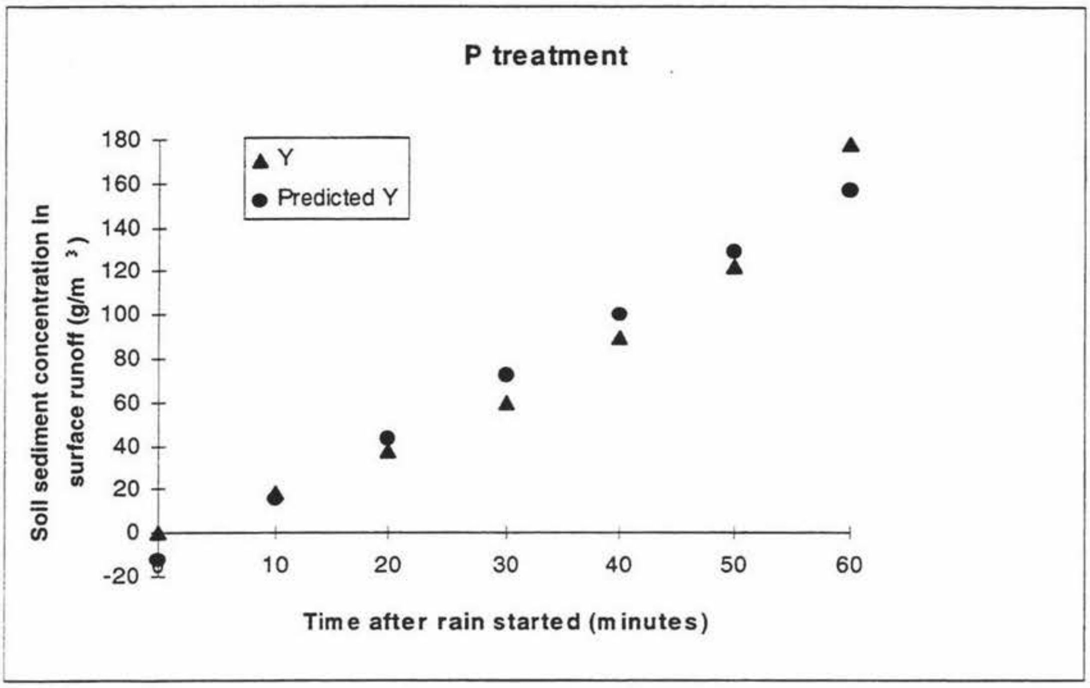

Figure 4.20 Regression analysis between sediment concentration in ronoff and rainfall intervals under the pasture treatment.

The mathematical model in above equations (19, 21 and 23) show the best fit (R^2 = 0.99, 0.98 and 0.96 respectively) and also that the sediment concentration in runoff water from Ohakea silt loam can probably be predicated by the simple linear regression equations.

4.3.2.5 *Nutrient concentration in surface runoff and leachate*

The nutrient concentrations e.g. nitrogen (N), phosphorus (P), and potassium (K) in runoff and leachate water for the three treatments were measured as in experiment 1. However, these results were not clear, because winter being rainy season in New Zealand there was excessive water impacting soil surface, and most surface nutrients were probably wasted off before measurements were made. The N, P, and K concentration in topsoil cores brought in the laboratory showed only traces of these elements. Therefore, measurement of total N, P, and K concentration in surface water runoff and leachate was unavailable. Hence, experiment data has not been shown in this section.

4.3.2.6 *pH of runoff and leachate*

pH of runoff and leachate was measured in laboratory after oats crop harvest in winter on 8th August 1996. No significant differences were found between three treatments (Table 4.26). This phenomenon is similar to autumn data. Somewhat higher value of pH reflect pH of water (8.25) used in the rainfall simulator. In hind right, deionised water should have been used for pH measurement. Nonetheless, this data further indicated that soil pH was not affected by tillage practices and cropping pattern.

Detailed raw data and statistical analyses are shown in Appendix 2.11.

Table 4.26 Soil pH of surface water and leachate as affected by tillage treatments (following oats crop harvest on 8th August, 1996).

Treatment	Runoff	Leachate
MP	7.38[a]	7.26[a]
NT	7.35[a]	7.25[a]
P	7.33[a]	7.22[a]
$LSD_{0.05}$	0.04	0.03

Values followed by the same letter in each column are not significantly different ($P \leq 0.05$).

CHAPTER 5

SUMMARY AND CONCLUSIONS

5.1 Summary

Soil erosion caused land and water quality degradation are serious problems in the world. In New Zealand, the conditions most conducive to erosion are found on sloping soil which lack a vegetative cover and have been cultivated (Eyles, 1985).

Results from both the field and laboratory experiments indicated that tillage practices are an important factor affecting soil erosion and runoff water quality. These suggested that no-tillage systems reduce soil erosion and improve water quality. If adopted, no-tillage practices would not only improve soil physical characteristics, but also such improvements would enable the soil to resist degradation due to water and wind erosion, and accept and retain more water. These findings should encourage adoption of soil management practices that decrease tillage intensity.

5.1.1 *Field Studies*

Conventional agricultural practices in cropping regions generally aim to modify the soil environment to provide a suitable seedbed and to control weed growth in the prospect of better crop yield. But, this technique degrades the soil environment through reducing soil water content and infiltrability, increasing bulk density, reducing soil nutrients, and increasing soil erosion. This, combined with relatively low levels of productivity of much of the extensive cropping lands and the physical impact of cultivation machinery, has generally been reflected in a decrease in the physical attributes of the soil. However, these soil attributes can be improved under either continuous pasture regime or by adopting reduced tillage practices of various forms, if crops were grown.

A summary of results from field experiment is shown in Table 5.1.

Table 5.1 Summary of mean data from field experiments under the tillage practices and cropping pattern.

Factors	Treatment (Experiment 1)			Treatment (Experiment 2)		
	MP	NT	P	MP	NT	P
Bulk density (Mg/m^3)	1.22	1.24	1.27	1.21	1.10	1.02
Water content (m^3/m^3)	0.29	0.31	0.32	0.40	0.48	0.55
Infiltrability (mm/h)	22.5	35.6	41.3	10.5	16.7	17.2
Penetration resistance						
0 - 5 cm depth (kPa)	592	516	530	-	-	-
15-20 cm depth (kPa)	1292	1263	1082	-	-	-
Earthworm population (No./m^2)	-	-	-	159	254	313
Soil pH (0 - 5 cm depth)	-	-	-	5.38	5.35	5.33
Soil pH (5-15 cm depth)	-	-	-	5.36	5.32	5.31

MP = Mouldboard ploughing followed by secondary tillage and seedbed preparation.

NT = No-tillage followed by direct seeding.

P = Permanent pasture.

5.1.2 *Laboratory Studies*

5.1.2.1 *Surface water runoff and leachate*

Over the one hour period, 50 mm of rainfall was applied to all soil samples. During each rainstorm simulation, the volumes of runoff and leachate were collected from different tillage treatments. Applied water either infiltrated into the soil or became runoff. On average surface runoff was in the order of NT = P < MP whereas leachate were in the order of NT = P > MP.

5.1.2.2 *Effect of rainstorm duration*

The runoff volume generated increased over time during the initial stage of the "storm" in all three treatments. However, runoff volume progressively increased in the conventional tillage treatment than that found in the no-tillage and pasture treatments. This indicates that surface runoff is affected by tillage practices and rainfall intensity, and is directly proportional to the intensity of tillage and perhaps the ground cover.

5.1.2.3 *Sediment loss*

The total soil sediment in surface runoff eroded over the one hour rainfall was greatly different among three treatments. It seems the runoff volume generated over time, and the soil sediment eroded progressively increased during the initial stages of the "storm". The sediment concentration in surface runoff was greater for the conventional tillage treatment than that found in the no-tillage and pasture treatments. This evidence suggests that soil sediment detachment, transport, and loss increased as the amount of surface vegetative cover decreased, and increased by soil cultivation.

5.1.2.4 *Nutrient losses*

Soil erosion cause nutrient loss from crop land particularly with respect to nitrogen (N), phosphorus (P), and potassium (K) losses. There is considerable consistency in total N, P, K losses from surface runoff and those leached to groundwater. Total nutrient loss from surface runoff was found higher in the conventional tillage treatment than that in the no-tillage and pasture treatments. Experimental data showed that losses of nutrients tend to reflect soil erosion rates.

A summary of results from laboratory experimental is shown in Table 5.2.

5.2 Conclusions

These studies demonstrated that no-tillage practices improve soil physical parameters which enable the soil to resist soil degradation, accept and retain more water, and support crop production comparable to permanent pasture, but better than those attained with conventional tillage practices. Continuous crop production with no-tillage practices may also result in better soils and environment management than with conventional cultivation. The present data supports the following specific conclusions:

1. Tillage can have significant effect on soil physical properties such as bulk density, water content, and penetration resistance, which were found to be significantly different between the three treatments. Under conventional tillage practices, soil bulk density was greater than that found with the no-tillage and pasture soils. Also, soil water content was markedly reduced as tillage intensity increased. These results demonstrated that the surface soil became more compact under the conventional tillage treatment as compared with the no-tillage and pasture treatments.

Table 5.2 Summary of mean data from laboratory experiments under the tillage practices and cropping pattern .

Factors	Treatment (Experiment 1)			Treatment (Experiment 2)		
	MP	NT	P	MP	NT	P
Surface water runoff (mm)	8.5	2.5	3.6	15.4	3.3	2.5
Soil sediment in runoff (g/m^2)	53.00	0.47	0.50	51.67	2.94	1.25
Soil sediment in runoff (kg/m^3)	6.28	0.19	0.14	3.95	0.93	0.50
Nutrient concentration in runoff water (g/m^3)						
N	0.17	0.21	0.25	-	-	-
P	0.12	0.18	0.23	-	-	-
K	1.0	1.9	2.2	-	-	-
Nutrient losses in runoff (mg/m^2)						
N	1.45	0.76	0.63	-	-	-
P	1.02	0.65	0.58	-	-	-
K	8.3	6.8	5.5	-	-	-
pH of runoff	7.45	7.40	7.38	7.38	7.35	7.33
Water leachate (mm)	14.6	24.8	24.7	2.7	11.5	13.2
Nutrient concentration in leachate water (g/m^3)						
N	0.11	0.28	0.31	-	-	-
P	0.60	2.10	2.90	-	-	-
K	9.5	23.3	26.9	-	-	-
Nutrient losses in leachate water (mg/m^2)						
N	1.61	6.94	7.66	-	-	-
P	8.8	52.1	71.6	-	-	-
K	139	578	644	-	-	-
pH of leachate	7.15	7.07	7.02	7.26	7.25	7.22

MP = Mouldboard ploughing followed by secondary tillage and seedbed preparation.

NT = No-tillage followed by direct seeding.

P = Permanent pasture.

2. Tillage also affects soil fauna such as earthworm population. This study found, not unexpectedly, that earthworm populations decreased with the increasing tillage intensity. This evidence suggests that better understanding of the ecology of earthworms could enable their activities to be manipulated to improve soil fertility, and adoption of no-tillage soil management would certainly help this.

3. Water leachate volumes (laboratory experimental data) measured at 150 mm soil depth and soil infiltrability (field study data) were higher in the no-tillage fields (and similar to permanent pasture) as compared with the conventional tillage practices. This clearly reflected high intact surface residue and high earthworm biochannels of the continuously cropped soil using no-tillage, and in pasture.

4. Surface water runoff and sediment concentration were significantly impacted by crop establishment techniques used and by cropping regimes adopted. Conventional tillage gave highest runoff and sediment concentrations as compared with no-tillage and pasture.

5. The duration of "rainstorm" has significant impact on the quantity of surface water and sediment runoff. A rainstorm of high intensity and duration e.g. 50 mm / hr for an hour is likely to decrease surface water runoff and associated sediment detachment and transport if no-tillage practices are adopted, or if soil is covered with growing pasture.

6. Surface soil pH was found to be similar in all three treatments. This suggested that different tillage practices and cropping pattern would probably have no impact on soil pH in early stages of conversion from intensive tillage to reduced tillage for crop establishment.

7. Soil nutrient concentration and losses due to soil erosion was found higher under the conventional tillage practices as compared with the no-tillage practices, and permanent pasture. This suggested that soil management should encourage use of conservation tillage technology which may give sustainable crop yield and have significant positive impact on soil and surface water quality.

8. Nutrient concentration in the leachate (with a potential to reach ground water) were in the order of P > NT > MP respectively. This may be due to no-tillage crop production and permanent pasture field having significantly high water infiltration, due to high soil permeability, as compared with conventional tillage.

9. Overall, quantitatively comparing the soil erodibility of the three treatments tested in this study, it was found that no-tillage markedly decreased surface runoff and sediment detachment, and transport as compared with the conventional tillage practices, but was not dissimilar to permanent pasture. If adopted no-tillage practices can improve soil physical characteristics. Such improvements can reduce soil degradation due to erosion, accept and retain more water, and support crop production at levels comparable to those attained using conventional tillage practices.

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APPENDIX 1

1.1 Detailed data on bulk density (Mg/m^3) (following barley crop harvest on 14th March, 1996).

Treatment	Plot 1	Plot 2	Plot 3	Plot 4
MP sample 1	1.39	1.20	1.28	1.18
sample 2	1.30	1.24	1.32	1.23
NT sample 1	1.26	1.26	1.26	1.20
sample 2	1.25	1.19	1.17	1.32
P sample 1	1.27	1.21	1.18	1.25
sample 2	1.28	1.18	1.18	1.18

Statistical analysis of above using GLM.

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General Linear Models Procedure

Dependent Variable: BULK DENSITY
                                    Sum of             Mean
Source                   DF        Squares           Square    F Value       Pr > F

Model                    11     0.05038333       0.00458030       2.33       0.0810

Error                    12     0.02360000       0.00196667

Corrected Total          23     0.07398333

                   R-Square           C.V.         Root MSE         BULK DENSITY Mean

                   0.681009       3.573978         0.044347                  1.240833


Source                   DF    Type II SS      Mean Square    F Value       Pr > F

REPS                      3     0.02175000      0.00725000       3.69       0.0433
TREAT                     2     0.01055833      0.00527917       2.68       0.1088
REPS*TREAT                6     0.01807500      0.00301250       1.53       0.2491

Tests of Hypotheses using the Type II MS for REPS*TREAT as an error term

Source                   DF    Type II SS      Mean Square    F Value       Pr > F

REPS                      3     0.02175000      0.00725000       2.41       0.1657
TREAT                     2     0.01055833      0.00527917       1.75       0.2515
```

1.2 Detailed data on volumetric water content (m^3/m^3) (following barley crop harvest on 14th March, 1996).

Treatment	Plot 1	Plot 2	Plot 3	Plot 4
MP sample 1	0.31	0.28	0.28	0.27
sample 2	0.29	0.27	0.30	0.28
NT sample 1	0.31	0.33	0.35	0.30
sample 2	0.31	0.33	0.33	0.33
P sample 1	0.32	0.30	0.30	0.32
sample 2	0.30	0.31	0.31	0.30

Statistical analysis of above data using GLM.

```
General Linear Models Procedure

Dependent Variable: WATER CONTENT
                                      Sum of              Mean
Source                    DF         Squares            Square    F Value      Pr > F

Model                     11      0.00814583        0.00074053       5.39      0.0036

Error                     12      0.00165000        0.00013750

Corrected Total           23      0.00979583

                    R-Square            C.V.        Root MSE Mean     WATER CONTENT mean

                    0.831561        3.839358         0.011726                0.305417


Source                    DF     Type I SS       Mean Square    F Value      Pr > F

REPS                       3      0.00044583      0.00014861       1.08      0.3942
TREAT                      2      0.00605833      0.00302917      22.03      0.0001
REPS*TREAT                 6      0.00164167      0.00027361       1.99      0.1462

Source                    DF    Type III SS      Mean Square    F Value      Pr > F

REPS                       3      0.00044583      0.00014861       1.08      0.3942
TREAT                      2      0.00605833      0.00302917      22.03      0.0001
REPS*TREAT                 6      0.00164167      0.00027361       1.99      0.1462

Tests of Hypotheses using the Type III MS for REPS*TREAT as an error term

Source                    DF    Type III SS      Mean Square    F Value      Pr > F

REPS                       3      0.00044583      0.00014861       0.54      0.6704
TREAT                      2      0.00605833      0.00302917      11.07      0.0097
```

1.3 Detailed data on infiltrability (mm/h) (following barley crop harvest on 14th March, 1996).

Treatment	Plot 1	Plot 2	Plot 3	Plot 4
MP sample 1	21.5	22.5	23.5	22.5
sample 2	23.5	21.5	22.5	22.5
NT sample 1	34.5	36.0	35.5	36.5
sample 2	36.0	35.0	35.5	35.5
P sample 1	40.5	42.0	41.5	42.0
sample 2	41.0	40.5	42.0	42.5

Statistical analysis of above data using GLM.

General Linear Models Procedure

Dependent Variable: INFILTRABILITY

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	1493.051250	135.731932	283.51	0.0001
Error	12	5.745000	0.478750		
Corrected Total	23	1498.796250			

R-Square	C.V.	Root MSE	INFILTRABILITY Mean
0.996167	2.088020	0.691918	33.13750

Source	DF	Type I SS	Mean Square	F Value	Pr > F
REPS	3	1.774583	0.591528	1.24	0.3398
TREAT	2	1488.407500	744.203750	1554.47	0.0001
REPS*TREAT	6	2.869167	0.478194	1.00	0.4689

Source	DF	Type III SS	Mean Square	F Value	Pr > F
REPS	3	1.774583	0.591528	1.24	0.3398
TREAT	2	1488.407500	744.203750	1554.47	0.0001
REPS*TREAT	6	2.869167	0.478194	1.00	0.4689

Tests of Hypotheses using the Type III MS for REPS*TREAT as an error term

Source	DF	Type III SS	Mean Square	F Value	Pr > F
REPS	3	1.774583	0.591528	1.24	0.3757
TREAT	2	1488.407500	744.203750	1556.28	0.0001

1.4 Detailed data on soil penetration resistance (kPa).

Treatment										
MP 0 -5 cm	595	588	605	580	585	610	562	585	620	593
5 - 10 cm	610	595	605	635	592	602	618	585	615	595
10 - 15 cm	670	685	675	688	695	660	675	662	663	668
15 - 20 cm	1090	1085	1088	1095	1072	1075	1078	1065	1105	1068
NT 0 -5 cm	518	525	516	515	520	508	523	512	510	525
5 - 10 cm	670	673	675	665	675	710	688	675	670	672
10 - 15 cm	935	941	925	934	925	920	932	925	933	928
15 - 20 cm	1250	1273	1260	1265	1252	1265	1255	1270	1268	1275
P 0 -5 cm	535	538	535	536	525	527	528	523	522	531
5 - 10 cm	690	712	695	685	715	710	688	725	670	692
10 - 15 cm	915	911	925	918	925	920	922	925	913	918
15 - 20 cm	1310	1293	1290	1300	1292	1295	1235	1325	1278	1305

Statistical analysis of above data using GLM.

General Linear Models Procedure for **MP**

Dependent Variable: PENETRATION RESISTANCE

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	12	3184357.800	265363.150	3070.67	0.0001
Error	27	2333.300	86.419		
Corrected Total	39	3186691.100			

R-Square	C.V.	Root MSE	penetration resistance Mean
0.999268	1.097993	9.296156	846.6500

Source	DF	Type II SS	Mean Square	F Value	Pr > F
REPS	9	480.100	53.344	0.62	0.7718
DEPTH	3	3183877.700	1061292.567	12280.85	0.0001

General Linear Models Procedure for **NT**

Dependent Variable: **PENETRATION RESISTANCE**

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	12	1615905.800	134658.817	764.47	0.0001
Error	27	4755.975	176.147		
Corrected Total	39	1620661.775			

R-Square	C.V.	Root MSE	Mean
0.997065	1.797345	13.27205	738.4250

Source	DF	Type II SS	Mean Square	F Value	Pr > F
REPS	9	2389.525	265.503	1.51	0.1956
DEPTH	3	1613516.275	537838.758	3053.35	0.0001

General Linear Models Procedure for **P**

Dependent Variable: **PENETRATION RESISTANCE**

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	12	3257644.500	271470.375	1412.74	0.0001
Error	27	5188.275	192.158		
Corrected Total	39	3262832.775			

R-Square	C.V.	Root MSE	Mean
0.998410	1.612015	13.86212	859.9250

Source	DF	Type II SS	Mean Square	F Value	Pr > F
REPS	9	2973.025	330.336	1.72	0.1331
DEPTH	3	3254671.475	1084890.492	5645.82	0.0001

1.5 Detailed data on effects of tillage methods on barley establishment (%).

Treatment	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
MP plot 1	93.9	87.0	93.9	90.4	95.7
plot 2	87.0	88.7	92.2	85.2	90.4
plot 3	90.4	83.5	93.9	95.7	88.7
plot 4	81.7	92.2	90.4	87.0	95.7
NT plot 1	80.0	90.4	93.9	87.0	85.2
plot 2	93.9	92.2	78.3	83.5	85.2
plot 3	87.0	93.9	97.4	88.7	90.4
plot 4	92.2	95.7	87.0	90.4	93.9

Statistical analysis of above data using GLM.

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General Linear Models Procedure

Dependent Variable: BARLEY
                                     Sum of          Mean
Source                   DF         Squares        Square    F Value       Pr > F

Model                     7     55.51500000    7.93071429       0.33       0.9351

Error                    32    772.02400000   24.12575000

Corrected Total          39    827.53900000

                   R-Square            C.V.      Root MSE             BARLEY Mean

                   0.067084        5.473059      4.911797                89.74500

Source                   DF       Type I SS   Mean Square    F Value       Pr > F

REPS                      3     13.19700000    4.39900000       0.18       0.9076
TREAT                     1      7.56900000    7.56900000       0.31       0.5793
REPS*TREAT                3     34.74900000   11.58300000       0.48       0.6984

Source                   DF     Type III SS   Mean Square    F Value       Pr > F

REPS                      3     13.19700000    4.39900000       0.18       0.9076
TREAT                     1      7.56900000    7.56900000       0.31       0.5793
REPS*TREAT                3     34.74900000   11.58300000       0.48       0.6984

Tests of Hypotheses using the Type III MS for REPS*TREAT as an error term

Source                   DF     Type III SS   Mean Square    F Value       Pr > F

REPS                      3     13.19700000    4.39900000       0.38       0.7762
TREAT                     1      7.56900000    7.56900000       0.65       0.4780
```

1.6 Detailed data on surface water runoff (mm) under rainfall simulator (following barley crop harvest on 28th March, 1996).

Treatment	Plot 1	Plot 2	Plot 3	Plot 4
MP sample 1	10.5	7.8	8.2	7.8
sample 2	9.6	8.4	8.0	7.4
NT sample 1	2.6	3.1	1.9	2.8
sample 2	2.3	2.5	2.9	2.2
P sample 1	4.2	3.5	3.2	3.5
sample 2	4.1	3.1	3.6	3.7

Statistical analysis of above data using GLM.

General Linear Models Procedure

Dependent Variable: RUNOFF

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	167.5345833	15.2304167	102.97	0.0001
Error	12	1.7750000	0.1479167		
Corrected Total	23	169.3095833			

R-Square	C.V.	Root MSE	RUNOFF Mean
0.989516	7.895966	0.384599	4.870833

Source	DF	Type I SS	Mean Square	F Value	Pr > F
REPS	3	3.7745833	1.2581944	8.51	0.0027
TREAT	2	159.4233333	79.7116667	538.90	0.0001
REPS*TREAT	6	4.3366667	0.7227778	4.89	0.0095

Source	DF	Type III SS	Mean Square	F Value	Pr > F
REPS	3	3.7745833	1.2581944	8.51	0.0027
TREAT	2	159.4233333	79.7116667	538.90	0.0001
REPS*TREAT	6	4.3366667	0.7227778	4.89	0.0095

Tests of Hypotheses using the Type III MS for REPS*TREAT as an error term

Source	DF	Type III SS	Mean Square	F Value	Pr > F
REPS	3	3.7745833	1.2581944	1.74	0.2578
TREAT	2	159.4233333	79.7116667	110.29	0.0001

1.7 Detailed data on water leachate (mm) for the three treatments under rainfall simulator (following barley crop harvest on 28th March, 1996).

Treatment	Plot 1	Plot 2	Plot 3	Plot 4
MP sample 1	11.6	15.5	18.4	11.2
sample 2	13.8	15.7	17.6	12.8
NT sample 1	19.6	25.9	30.1	28.1
sample 2	21.4	28.6	21.8	22.9
P sample 1	23.4	29.7	23.1	27.2
sample 2	20.8	25.7	22.8	25.1

Statistical analysis of above data using GLM.

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General Linear Models Procedure

Dependent Variable: LEACHATE
                                      Sum of            Mean
Source                     DF        Squares          Square    F Value       Pr > F

Model                      11    693.8533333      63.0775758      10.68       0.0001

Error                      12     70.9000000       5.9083333

Corrected Total            23    764.7533333

                     R-Square           C.V.        Root MSE            LEACHATE Mean

                     0.907290       11.37616        2.430706                 21.36667


Source                     DF      Type I SS     Mean Square    F Value       Pr > F

REPS                        3     84.7233333      28.2411111       4.78       0.0205
TREAT                       2    553.5433333     276.7716667      46.84       0.0001
REPS*TREAT                  6     55.5866667       9.2644444       1.57       0.2386

Source                     DF    Type III SS     Mean Square    F Value       Pr > F

REPS                        3     84.7233333      28.2411111       4.78       0.0205
TREAT                       2    553.5433333     276.7716667      46.84       0.0001
REPS*TREAT                  6     55.5866667       9.2644444       1.57       0.2386

Tests of Hypotheses using the Type III MS for REPS*TREAT as an error term

Source                     DF    Type III SS     Mean Square    F Value       Pr > F

REPS                        3     84.7233333      28.2411111       3.05       0.1139
TREAT                       2    553.5433333     276.7716667      29.87       0.0008
```

1.8 Detailed data on soil sediment in runoff for the three treatments (following barley crop harvest on 28th March, 1996).

Treatment	g/m^2				kg/m^3			
	Plot 1	Plot 2	Plot 3	Plot 4	Plot 1	Plot 2	Plot 3	Plot 4
MP sample 1	47.7	56.0	58.0	47.7	5.64	6.62	6.86	5.64
sample 2	51.0	55.0	54.0	56.0	6.03	6.50	6.39	6.62
NT sample 1	0.67	0.33	0.33	0.67	0.27	0.14	0.14	0.27
sample 2	0.33	0.33	0.67	0.67	0.14	0.14	0.27	0.27
P sample 1	0.67	0.33	0.33	0.67	0.14	0.14	0.14	0.14
sample 2	0.33	0.67	0.33	0.67	0.14	0.14	0.14	0.14

Statistical analysis of above data using GLM.

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General Linear Models Procedure

Dependent Variable: SEDIMENT (g/m²)
                                      Sum of           Mean
Source                    DF         Squares         Square    F Value       Pr > F

Model                     11     14822.71300     1347.51936     295.43       0.0001

Error                     12        54.73400        4.56117

Corrected Total           23     14877.44700

                    R-Square            C.V.       Root MSE          SEDIMENT Mean

                    0.996321        11.85506       2.135689               18.01500

Source                    DF       Type I SS    Mean Square    F Value       Pr > F
REPS                       3        19.01407        6.33802       1.39       0.2935
TREAT                      2     14760.97030     7380.48515    1618.11       0.0001
REPS*TREAT                 6        42.72863        7.12144       1.56       0.2405

Source                    DF     Type III SS    Mean Square    F Value       Pr > F

REPS                       3        19.01407        6.33802       1.39       0.2935
TREAT                      2     14760.97030     7380.48515    1618.11       0.0001
REPS*TREAT                 6        42.72863        7.12144       1.56       0.2405

Tests of Hypotheses using the Type III MS for REPS*TREAT as an error term

Source                    DF     Type III SS    Mean Square    F Value       Pr > F

REPS                       3        19.01407        6.33802       0.89       0.4982
TREAT                      2     14760.97030     7380.48515    1036.38       0.0001
```

General Linear Models Procedure

Dependent Variable: **SEDIMENT** (kg/m^3)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	113.4946967	10.3176997	1.62	0.1840
Error	16	101.7721380	6.3607586		
Corrected Total	27	215.2668347			

	R-Square	C.V.	Root MSE	SEDIMENT Mean
	0.527228	131.3717	2.522054	1.919786

Source	DF	Type I SS	Mean Square	F Value	Pr > F
REPS	3	0.1626153	0.0542051	0.01	0.9989
TREAT	2	112.8900465	56.4450233	8.87	0.0026
REPS*TREAT	6	0.4420349	0.0736725	0.01	1.0000

Source	DF	Type III SS	Mean Square	F Value	Pr > F
REPS	3	0.0817642	0.0272547	0.00	0.9996
TREAT	2	112.8900465	56.4450233	8.87	0.0026
REPS*TREAT	6	0.4420349	0.0736725	0.01	1.0000

Tests of Hypotheses using the Type III MS for REPS*TREAT as an error term

Source	DF	Type III SS	Mean Square	F Value	Pr > F
REPS	3	0.0817642	0.0272547	0.37	0.7779
TREAT	2	112.8900465	56.4450233	766.16	0.0001

1.9 Detailed data on total nitrogen concentration (g/m^3) in surface runoff and leachate water under the three treatments (following barley crop harvest on 28th March 1996).

Treatment	Total N in runoff water				Total N in leachate water			
	Plot 1	Plot 2	Plot 3	Plot 4	Plot 1	Plot 2	Plot 3	Plot 4
MP sample 1	0.15	0.18	0.17	0.15	0.09	0.13	0.11	0.12
sample 2	0.19	0.17	0.16	0.19	0.14	0.09	0.12	0.10
NT sample 1	0.20	0.23	0.19	0.20	0.26	0.28	0.25	0.27
sample 2	0.22	0.21	0.21	0.23	0.31	0.29	0.30	0.31
P sample 1	0.24	0.25	0.23	0.28	0.30	0.31	0.29	0.32
sample 2	0.26	0.27	0.26	0.24	0.31	0.32	0.33	0.31

Statistical analysis of above data using GLM.

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General Linear Models Procedure

Dependent Variable: NITROGEN (IN RUNOFF)
                                        Sum of            Mean
Source                     DF          Squares          Square   F Value      Pr > F

Model                      11       0.02893333      0.00263030      7.17      0.0010

Error                      12       0.00440000      0.00036667

Corrected Total            23       0.03333333

                     R-Square             C.V.        Root MSE          NITROGEN Mean

                     0.868000         9.046555        0.019149               0.211667


Source                     DF        Type I SS     Mean Square   F Value      Pr > F

REPS                        3       0.00076667      0.00025556      0.70      0.5716
TREAT                       2       0.02805833      0.01402917     38.26      0.0001
REPS*TREAT                  6       0.00010833      0.00001806      0.05      0.9993

Tests of Hypotheses using the Type I MS for REPS*TREAT as an error term

Source                     DF        Type I SS     Mean Square   F Value      Pr > F

REPS                        3       0.00076667      0.00025556     14.15      0.0040
TREAT                       2       0.02805833      0.01402917    777.00      0.0001
```

General Linear Models Procedure

Dependent Variable: **NITROGEN (IN LEACHATE)**

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	0.18598333	0.01690758	30.74	0.0001
Error	12	0.00660000	0.00055000		
Corrected Total	23	0.19258333			

R-Square	C.V.	Root MSE	NITROGEN Mean
0.965729	9.944344	0.023452	0.235833

Source	DF	Type I SS	Mean Square	F Value	Pr > F
REPS	3	0.00008333	0.00002778	0.05	0.9843
TREAT	2	0.18555833	0.09277917	168.69	0.0001
REPS*TREAT	6	0.00034167	0.00005694	0.10	0.9945

Tests of Hypotheses using the Type I MS for REPS*TREAT as an error term

Source	DF	Type I SS	Mean Square	F Value	Pr > F
REPS	3	0.00008333	0.00002778	0.49	0.7033
TREAT	2	0.18555833	0.09277917	1629.29	0.0001

1.10 Detailed data on total phosphorus measured as concentration (g/m^3) in surface runoff and leachate water under the three treatments (following barley crop harvest on 28th March, 1996).

Treatment	Total P in runoff water				Total P in leachate water			
	Plot 1	Plot 2	Plot 3	Plot 4	Plot 1	Plot 2	Plot 3	Plot 4
MP sample 1	0.10	0.13	0.11	0.14	0.58	0.60	0.58	0.56
sample 2	0.12	0.11	0.14	0.10	0.62	0.59	0.63	0.65
NT sample 1	0.18	0.19	0.20	0.16	2.11	2.13	2.06	2.05
sample 2	0.19	0.17	0.18	0.19	2.08	2.10	2.15	2.16
P sample 1	0.23	0.24	0.25	0.22	2.85	2.90	2.88	2.94
sample 2	0.22	0.23	0.21	0.24	2.92	2.93	2.91	2.88

Statistical analysis of above data using GLM.

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General Linear Models Procedure

Dependent Variable: PHOSPHORUS (IN RUNOFF)
                                         Sum of              Mean
Source                    DF            Squares            Square    F Value      Pr > F

Model                     11         0.05044583        0.00458598      15.08      0.0001

Error                     12         0.00365000        0.00030417

Corrected Total           23         0.05409583

                    R-Square               C.V.          Root MSE          PHOSPHOR Mean

                    0.932527           9.848682          0.017440               0.177083


Source                    DF        Type I SS      Mean Square    F Value      Pr > F

REPS                       3       0.00024583       0.00008194       0.27      0.8462
TREAT                      2       0.04985833       0.02492917      81.96      0.0001
REPS*TREAT                 6       0.00034167       0.00005694       0.19      0.9747

Tests of Hypotheses using the Type I MS for REPS*TREAT as an error term

Source                    DF        Type I SS      Mean Square    F Value      Pr > F

REPS                       3       0.00024583       0.00008194       1.44      0.3216
TREAT                      2       0.04985833       0.02492917     437.78      0.0001
```

General Linear Models Procedure

Dependent Variable: **PHOSPHORUS (IN LEACHATE)**

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	21.82908333	1.98446212	1067.87	0.0001
Error	12	0.02230000	0.00185833		
Corrected Total	23	21.85138333			

R-Square	C.V.	Root MSE	PHOSPHOR Mean
0.998979	2.306289	0.043108	1.869167

Source	DF	Type I SS	Mean Square	F Value	Pr > F
REPS	3	0.00081667	0.00027222	0.15	0.9300
TREAT	2	21.82740833	10.91370417	5872.85	0.0001
REPS*TREAT	6	0.00085833	0.00014306	0.08	0.9975

Tests of Hypotheses using the Type I MS for REPS*TREAT as an error term

Source	DF	Type I SS	Mean Square	F Value	Pr > F
REPS	3	0.00081667	0.00027222	1.90	0.2303
TREAT	2	21.82740833	10.91370417	76289.97	0.0001

1.11 Detailed data on total potassium measured as concentration (g/m^3) in surface runoff and leachate water under the three treatments (following barley crop harvest on 28th March, 1996).

Treatment	Total K in runoff water				Total K in leachate water			
	Plot 1	Plot 2	Plot 3	Plot 4	Plot 1	Plot 2	Plot 3	Plot 4
MP sample 1	0.9	1.0	1.2	0.8	9.0	9.4	9.7	10.1
sample 2	1.2	1.1	1.0	1.1	9.6	9.8	9.3	9.2
NT sample 1	1.8	1.9	2.1	2.0	23.5	22.1	25.3	24.2
sample 2	2.0	1.8	1.9	1.7	23.8	24.0	20.4	23.2
P sample 1	2.3	2.1	2.0	2.2	27.1	26.8	28.3	25.7
sample 2	2.2	2.4	2.1	2.5	27.8	27.0	25.4	27.4

Statistical analysis of above data using GLM.

```
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General Linear Models Procedure

Dependent Variable: POTASSIUM (IN RUNOFF)
                                        Sum of             Mean
Source                       DF        Squares           Square    F Value      Pr > F

Model                        11     6.17458333       0.56132576      22.08      0.0001

Error                        12     0.30500000       0.02541667

Corrected Total              23     6.47958333

                       R-Square           C.V.         Root MSE          POTASSIUM Mean

                       0.952929       9.264468         0.159426                1.720833


Source                       DF      Type I SS      Mean Square    F Value      Pr > F

REPS                          3     0.00125000       0.00041667       0.02      0.9970
TREAT                         2     6.02583333       3.01291667     118.54      0.0001
REPS*TREAT                    6     0.14750000       0.02458333       0.97      0.4864

Tests of Hypotheses using the Type I MS for REPS*TREAT as an error term

Source                       DF      Type I SS      Mean Square    F Value      Pr > F

REPS                          3     0.00125000       0.00041667       0.02      0.9967
TREAT                         2     6.02583333       3.01291667     122.56      0.0001
```

General Linear Models Procedure

Dependent Variable: **POTASSIUM (IN LEACHATE)**

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	1354.644583	123.149508	70.32	0.0001
Error	12	21.015000	1.751250		
Corrected Total	23	1375.659583			

R-Square	C.V.	Root MSE	POTASSIUM Mean
0.984724	6.643035	1.323348	19.92083

Source	DF	Type I SS	Mean Square	F Value	Pr > F
REPS	3	0.524583	0.174861	0.10	0.9586
TREAT	2	1352.563333	676.281667	386.17	0.0001
REPS*TREAT	6	1.556667	0.259444	0.15	0.9859

Tests of Hypotheses using the Type I MS for REPS*TREAT as an error term

Source	DF	Type I SS	Mean Square	F Value	Pr > F
REPS	3	0.524583	0.174861	0.67	0.5988
TREAT	2	1352.563333	676.281667	2606.65	0.0001

1.12 Detailed data on soil pH from surface runoff and leachate (following barley crop harvest on 28th March, 1996).

Treatment	pH of runoff				pH of leachate			
	Plot 1	Plot 2	Plot 3	Plot 4	Plot 1	Plot 2	Plot 3	Plot 4
MP sample 1	7.42	7.48	7.44	7.38	7.10	7.16	7.14	7.23
sample 2	7.46	7.45	7.47	7.49	7.15	7.20	7.11	7.14
NT sample 1	7.42	7.38	7.36	7.41	7.05	7.02	7.07	7.06
sample 2	7.40	7.43	7.45	7.34	7.10	7.11	7.08	7.10
P sample 1	7.35	7.41	7.39	7.38	6.95	7.03	7.05	7.11
sample 2	7.40	7.38	7.36	7.37	7.02	7.01	6.98	7.04

Statistical analysis of above data using GLM.

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General Linear Models Procedure

Dependent Variable: pH (RUNOFF)
                                      Sum of              Mean
Source                    DF         Squares            Square    F Value       Pr > F

Model                     11      0.02348333        0.00213485       1.43       0.2733

Error                     12      0.01790000        0.00149167

Corrected Total           23      0.04138333

                    R-Square            C.V.          Root MSE                 pH Mean

                    0.567459        0.521275          0.038622                7.409167


Source                    DF       Type I SS       Mean Square    F Value       Pr > F

REPS                       3      0.00218333        0.00072778       0.49       0.6971
TREAT                      2      0.02020833        0.01010417       6.77       0.0107
REPS*TREAT                 6      0.00109167        0.00018194       0.12       0.9915

Tests of Hypotheses using the Type I MS for REPS*TREAT as an error term

Source                    DF       Type I SS       Mean Square    F Value       Pr > F

REPS                       3      0.00218333        0.00072778       4.00       0.0701
TREAT                      2      0.02020833        0.01010417      55.53       0.0001
```

General Linear Models Procedure

Dependent Variable: pH (LEACHATE)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	0.08411250	0.00764659	4.53	0.0075
Error	12	0.02025000	0.00168750		
Corrected Total	23	0.10436250			

	R-Square	C.V.	Root MSE		pH Mean
	0.805965	0.579907	0.041079		7.083750

Source	DF	Type I SS	Mean Square	F Value	Pr > F
REPS	3	0.00917917	0.00305972	1.81	0.1984
TREAT	2	0.06880000	0.03440000	20.39	0.0001
REPS*TREAT	6	0.00613333	0.00102222	0.61	0.7216

Tests of Hypotheses using the Type I MS for REPS*TREAT as an error term

Source	DF	Type I SS	Mean Square	F Value	Pr > F
REPS	3	0.00917917	0.00305972	2.99	0.1174
TREAT	2	0.06880000	0.03440000	33.65	0.0005

APPENDIX 2

2.1 Detailed data on bulk density (Mg/m^3) (following oats crop harvest on 1st August 1996).

Treatment	Plot 1	Plot 2	Plot 3	Plot 4
MP sample 1	1.22	1.21	1.23	1.20
sample 2	1.21	1.20	1.22	1.21
NT sample 1	1.08	1.09	1.10	1.10
sample 2	1.09	1.10	1.11	1.08
P sample 1	1.01	1.03	1.02	1.02
sample 2	1.02	1.01	1.02	1.03

Statistical analysis of above data using GLM.

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-------------------------------------------------------------------------
                         General Linear Models Procedure

Dependent Variable: BULK DENSITY
                                      Sum of            Mean
Source                    DF         Squares          Square    F Value      Pr > F

Model                     11      0.15201250      0.01381932     195.10      0.0001

Error                     12      0.00085000      0.00007083

Corrected Total           23      0.15286250

                    R-Square            C.V.        Root MSE          BULK DENSITY Mean

                    0.994439        0.759076        0.008416                   1.108750


Source                    DF       Type I SS     Mean Square    F Value      Pr > F

REPS                       3      0.00051250      0.00017083       2.41      0.1175
TREAT                      2      0.15092500      0.07546250    1065.35      0.0001
REPS*TREAT                 6      0.00057500      0.00009583       1.35      0.3081

Tests of Hypotheses using the Type I MS for REPS*TREAT as an error term

Source                    DF       Type I SS     Mean Square    F Value      Pr > F

REPS                       3      0.00051250      0.00017083       1.78      0.2503
TREAT                      2      0.15092500      0.07546250     787.43      0.0001
```

2.2: Detailed data on volumetric water content (m^3/m^3) (following oats crop harvest on 1st August, 1996).

Treatment	Plot 1	Plot 2	Plot 3	Plot 4
MP sample 1	0.39	0.41	0.40	0.42
sample 2	0.38	0.39	0.41	0.43
NT sample 1	0.47	0.50	0.47	0.51
sample 2	0.48	0.46	0.49	0.48
P sample 1	0.55	0.54	0.56	0.55
sample 2	0.54	0.56	0.55	0.56

Statistical analysis of above data using GLM.

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General Linear Models Procedure

Dependent Variable: Water Content
                                    Sum of              Mean
Source                  DF         Squares            Square    F Value       Pr > F

Model                   11      0.08938333        0.00812576      44.32       0.0001

Error                   12      0.00220000        0.00018333

Corrected Total         23      0.09158333

                  R-Square            C.V.          Root MSE          MOISTURE Mean

                  0.975978        2.825752          0.013540               0.479167


Source                  DF       Type I SS       Mean Square    F Value       Pr > F

REPS                     3      0.00168333        0.00056111       3.06       0.0694
TREAT                    2      0.08715833        0.04357917     237.70       0.0001
REPS*TREAT               6      0.00054167        0.00009028       0.49       0.8022

Source                  DF     Type III SS       Mean Square    F Value       Pr > F

REPS                     3      0.00168333        0.00056111       3.06       0.0694
TREAT                    2      0.08715833        0.04357917     237.70       0.0001
REPS*TREAT               6      0.00054167        0.00009028       0.49       0.8022

Tests of Hypotheses using the Type III MS for REPS*TREAT as an error term

Source                  DF     Type III SS       Mean Square    F Value       Pr > F

REPS                     3      0.00168333        0.00056111       6.22       0.0285
TREAT                    2      0.08715833        0.04357917     482.72       0.0001
```

2.3 Detailed data on infiltrability (mm/h) (following oats crop harvest on 28th August, 1996).

Treatment	Plot 1	Plot 2	Plot 3	Plot 4
MP sample 1	9.5	10.5	10.0	11.0
sample 2	10.0	10.5	11.0	11.5
NT sample 1	16.0	16.5	17.0	17.5
sample 2	15.5	16.0	18.0	17.0
P sample 1	16.0	16.5	17.0	19.0
sample 2	16.0	17.0	18.0	18.0

Statistical analysis of above data using GLM.

```
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General Linear Models Procedure

Dependent Variable: INFILTRABILITY
                                      Sum of            Mean
Source                  DF           Squares          Square    F Value        Pr > F

Model                   11       232.2033333      21.1093939     170.01        0.0001

Error                   12         1.4900000       0.1241667

Corrected Total         23       233.6933333

                  R-Square              C.V.        Root MSE           INFILTRABILITY Mean

                  0.993624          2.378220        0.352373                      14.81667


Source                  DF        Type I SS     Mean Square    F Value        Pr > F

REPS                     3       10.5933333       3.5311111      28.44        0.0001
TREAT                    2      220.5008333     110.2504167     887.92        0.0001
REPS*TREAT               6        1.1091667       0.1848611       1.49        0.2621

Source                  DF      Type III SS     Mean Square    F Value        Pr > F

REPS                     3       10.5933333       3.5311111      28.44        0.0001
TREAT                    2      220.5008333     110.2504167     887.92        0.0001
REPS*TREAT               6        1.1091667       0.1848611       1.49        0.2621

Tests of Hypotheses using the Type III MS for REPS*TREAT as an error term

Source                  DF      Type III SS     Mean Square    F Value        Pr > F

REPS                     3       10.5933333       3.5311111      19.10        0.0018
TREAT                    2      220.5008333     110.2504167     596.40        0.0001
```

2.4 Detailed data on earthworm population (No./m^2) under three treatments (July, 1996).

Treatment	Plot 1	Plot 2	Plot 3	Plot 4
MP sample 1	144	186	184	124
sample 2	151	175	178	132
NT sample 1	252	248	260	256
sample 2	262	237	275	245
P sample 1	284	292	340	336
sample 2	291	283	352	327

Statistical analysis of above data using GLM.

General Linear Models Procedure

Dependent Variable: EARTHWORM POPULATIONS

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	106686.5000	9698.7727	195.28	0.0001
Error	12	596.0000	49.6667		
Corrected Total	23	107282.5000			

R-Square	C.V.	Root MSE	EARTHWORM Mean
0.994445	2.909167	7.047458	242.2500

Source	DF	Type I SS	Mean Square	F Value	Pr > F
REPS	3	4228.16667	1409.38889	28.38	0.0001
TREAT	2	96474.25000	48237.12500	971.22	0.0001
REPS*TREAT	6	5984.08333	997.34722	20.08	0.0001

Tests of Hypotheses using the Type I MS for REPS*TREAT as an error term

Source	DF	Type I SS	Mean Square	F Value	Pr > F
REPS	3	4228.16667	1409.38889	1.41	0.3279
TREAT	2	96474.25000	48237.12500	48.37	0.0002

2.5 Detailed data on topsoil pH (o - 15 cm deep) under three treatment (on 31st July, 1996).

Treatment	pH (0 - 5 cm)				pH (5 - 15 cm)			
	Plot 1	Plot 2	Plot 3	Plot 4	Plot 1	Plot 2	Plot 3	Plot 4
MP sample 1	5.23	5.38	5.45	5.48	5.22	5.36	5.42	5.44
sample 2	5.25	5.36	5.44	5.49	5.23	5.35	5.41	5.45
NT sample 1	5.22	5.36	5.42	5.44	5.35	5.33	5.28	5.33
sample 2	5.23	5.35	5.42	5.46	5.32	5.36	5.29	5.32
P sample 1	5.33	5.36	5.42	5.44	5.27	5.28	5.33	5.36
sample 2	5.34	5.35	5.41	5.45	5.28	5.26	5.34	5.35

Statistical analysis of above data using GLM.

```
----------------------------------------------------------------------------------------------------
General Linear Models Procedure

Dependent Variable: SOIL pH (0 - 5 cm depth)
                                    Sum of            Mean
Source                  DF         Squares          Square    F Value      Pr > F

Model                   11      0.14685000      0.01335000     133.50      0.0001

Error                   12      0.00120000      0.00010000

Corrected Total         23      0.14805000

                  R-Square            C.V.        Root MSE          SOIL pH Mean

                  0.991895        0.185960        0.010000              5.377500


Source                  DF       Type I SS     Mean Square    F Value      Pr > F

REPS                     3      0.12898333      0.04299444     429.94      0.0001
TREAT                    2      0.00370000      0.00185000      18.50      0.0002
REPS*TREAT               6      0.01416667      0.00236111      23.61      0.0001

Tests of Hypotheses using the Type I MS for REPS*TREAT as an error term

Source                  DF       Type I SS     Mean Square    F Value      Pr > F

REPS                     3      0.12898333      0.04299444      18.21      0.0020
TREAT                    2      0.00370000      0.00185000       0.78      0.4985
```

General Linear Models Procedure

Dependent Variable: **SOIL pH (5 - 15 cm depth)**

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	0.08290000	0.00753636	53.20	0.0001
Error	12	0.00170000	0.00014167		
Corrected Total	23	0.08460000			

R-Square	C.V.	Root MSE	SOIL pH Mean
0.979905	0.223309	0.011902	5.330000

Source	DF	Type I SS	Mean Square	F Value	Pr > F
REPS	3	0.02890000	0.00963333	68.00	0.0001
TREAT	2	0.01170000	0.00585000	41.29	0.0001
REPS*TREAT	6	0.04230000	0.00705000	49.76	0.0001

Tests of Hypotheses using the Type I MS for REPS*TREAT as an error term

Source	DF	Type I SS	Mean Square	F Value	Pr > F
REPS	3	0.02890000	0.00963333	1.37	0.3398
TREAT	2	0.01170000	0.00585000	0.83	0.4807

2.6 Detailed data on effects of tillage methods on oats establishment (%).

Treatment	Plot 1	Plot 2	Plot 3	Plot 4
MP sample 1	95.7	96.5	97.3	98.2
sample 2	95.8	96.5	98.2	97.3
sample 3	97.3	98.5	97.6	96.8
NT sample 1	91.5	92.3	95.1	97.4
sample 2	93.5	94.1	95.2	94.7
sample 3	92.8	93.3	94.5	96.8

Statistical analysis of above data using GLM.

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-----------------------------------------------------------------------
General Linear Models Procedure

Dependent Variable: OATS
                                     Sum of            Mean
Source                   DF         Squares          Square   F Value      Pr > F

Model                     7     78.35625000     11.19375000     13.08      0.0001

Error                    16     13.69333333      0.85583333

Corrected Total          23     92.04958333

                   R-Square            C.V.        Root MSE               OATS Mean

                   0.851240        0.966638        0.925113                95.70417


Source                   DF       Type I SS     Mean Square   F Value      Pr > F

REPS                      3     21.57458333      7.19152778      8.40      0.0014
TREAT                     1     49.59375000     49.59375000     57.95      0.0001
REPS*TREAT                3      7.18791667      2.39597222      2.80      0.0735

Source                   DF     Type III SS     Mean Square   F Value      Pr > F

REPS                      3     21.57458333      7.19152778      8.40      0.0014
TREAT                     1     49.59375000     49.59375000     57.95      0.0001
REPS*TREAT                3      7.18791667      2.39597222      2.80      0.0735

Tests of Hypotheses using the Type III MS for REPS*TREAT as an error term

Source                   DF     Type III SS     Mean Square   F Value      Pr > F

REPS                      3     21.57458333      7.19152778      3.00      0.1954
TREAT                     1     49.59375000     49.59375000     20.70      0.0199
```

2.7 Detailed data on oats dry matter yield (t/ha) (following oats crop at maturity on 1st August, 1996)

Treatment	Plot 1	Plot 2	Plot 3	Plot 4
MP sample 1	3.29	3.32	3.43	3.45
sample 2	3.31	3.34	3.38	3.42
NT sample 1	3.22	3.31	3.33	3.46
sample 2	3.15	3.28	3.43	3.44
P sample 1	2.55	2.56	2.68	2.85
sample 2	2.43	2.58	2.46	2.67

Statistical analysis of above data using GLM.

```
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General Linear Models Procedure

Dependent Variable: DM
                                     Sum of            Mean
Source                   DF         Squares          Square    F Value        Pr > F

Model                    11      3.18745000      0.28976818      59.95        0.0001

Error                    12      0.05800000      0.00483333

Corrected Total          23      3.24545000

                   R-Square            C.V.        Root MSE                  DM Mean

                   0.982129        2.244461        0.069522                 3.097500


Source                   DF       Type I SS     Mean Square    F Value        Pr > F

REPS                      3      0.15898333      0.05299444      10.96        0.0009
TREAT                     2      3.00640000      1.50320000     311.01        0.0001
REPS*TREAT                6      0.02206667      0.00367778       0.76        0.6139

Source                   DF     Type III SS     Mean Square    F Value        Pr > F

REPS                      3      0.15898333      0.05299444      10.96        0.0009
TREAT                     2      3.00640000      1.50320000     311.01        0.0001
REPS*TREAT                6      0.02206667      0.00367778       0.76        0.6139

Tests of Hypotheses using the Type III MS for REPS*TREAT as an error term

Source                   DF     Type III SS     Mean Square    F Value        Pr > F

REPS                      3      0.15898333      0.05299444      14.41        0.0038
TREAT                     2      3.00640000      1.50320000     408.73        0.0001
```

2.8 Detailed data on surface water runoff (mm) under rainfall simulator (following oats crop harvest on 6th August, 1996).

Treatment	Plot 1	Plot 2	Plot 3	Plot 4
MP sample 1	14.83	13.17	17.25	14.17
sample 2	13.53	17.08	15.83	17.17
NT sample 1	2.62	3.17	3.75	3.50
sample 2	2.42	4.13	3.83	3.25
P sample 1	1.83	2.33	2.58	3.08
sample 2	1.58	3.45	3.17	2.17

Statistical analysis of above data using GLM.

General Linear Models Procedure

Dependent Variable: RUNOFF

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	838.9942125	76.2722011	58.08	0.0001
Error	12	15.7590500	1.3132542		
Corrected Total	23	854.7532625			

R-Square	C.V.	Root MSE	RUNOFF Mean
0.981563	16.18892	1.145973	7.078750

Source	DF	Type I SS	Mean Square	F Value	Pr > F
REPS	3	8.1759458	2.7253153	2.08	0.1571
TREAT	2	829.3044000	414.6522000	315.74	0.0001
REPS*TREAT	6	1.5138667	0.2523111	0.19	0.9731

Source	DF	Type III SS	Mean Square	F Value	Pr > F
REPS	3	8.1759458	2.7253153	2.08	0.1571
TREAT	2	829.3044000	414.6522000	315.74	0.0001
REPS*TREAT	6	1.5138667	0.2523111	0.19	0.9731

Tests of Hypotheses using the Type III MS for REPS*TREAT as an error term

Source	DF	Type III SS	Mean Square	F Value	Pr > F
REPS	3	8.1759458	2.7253153	10.80	0.0078
TREAT	2	829.3044000	414.6522000	1643.42	0.0001

2.9 Detailed data on water leachate (mm) for the three treatments under rainfall simulator (following oats crop harvest on 6th August, 1996).

Treatment	Plot 1	Plot 2	Plot 3	Plot 4
MP sample 1	2.95	3.08	2.75	2.25
sample 2	3.08	2.58	2.75	2.08
NT sample 1	6.72	9.75	12.08	12.17
sample 2	9.75	14.42	12.25	14.75
P sample 1	9.33	12.00	14.33	13.58
sample 2	12.33	13.58	13.25	17.50

Statistical analysis of above data using GLM.

```
General Linear Models Procedure

Dependent Variable: LEACHATE
                                    Sum of            Mean
Source                  DF         Squares          Square   F Value      Pr > F

Model                   11     565.7611458      51.4328314     18.70      0.0001

Error                   12      33.0000500       2.7500042

Corrected Total         23     598.7611958

                  R-Square            C.V.        Root MSE          LEACHATE Mean

                  0.944886        18.14761        1.658314               9.137917


Source                  DF       Type I SS     Mean Square   F Value      Pr > F

REPS                     3      29.5152792       9.8384264      3.58      0.0469
TREAT                    2     511.1750583     255.5875292     92.94      0.0001
REPS*TREAT               6      25.0708083       4.1784681      1.52      0.2527

Source                  DF     Type III SS     Mean Square   F Value      Pr > F

REPS                     3      29.5152792       9.8384264      3.58      0.0469
TREAT                    2     511.1750583     255.5875292     92.94      0.0001
REPS*TREAT               6      25.0708083       4.1784681      1.52      0.2527

Tests of Hypotheses using the Type III MS for REPS*TREAT as an error term

Source                  DF     Type III SS     Mean Square   F Value      Pr > F

REPS                     3      29.5152792       9.8384264      2.35      0.1712
TREAT                    2     511.1750583     255.5875292     61.17      0.0001
```

2.10 Detailed data on soil sediment (total loss and concentration) in runoff for the three treatments (following oats crop harvest on 6th August, 1996).

Treatment	g/m²				kg/m³			
	Plot 1	Plot 2	Plot 3	Plot 4	Plot 1	Plot 2	Plot 3	Plot 4
MP sample 1	50.50	42.17	59.83	54.17	3.40	3.20	5.40	5.00
sample 2	46.00	51.33	57.00	52.33	3.40	3.00	3.60	4.60
NT sample 1	2.67	2.50	3.00	3.50	1.00	0.80	0.80	1.00
sample 2	2.00	3.67	2.33	3.83	0.80	1.00	0.80	1.20
P sample 1	1.17	1.50	1.00	1.33	0.60	0.60	0.40	0.40
sample 2	1.33	1.33	1.33	1.00	0.80	0.40	0.40	0.40

Statistical analysis of above data using GLM.

General Linear Models Procedure

Dependent Variable: SEDIMENT (g/m²)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	13287.89425	1207.99039	245.28	0.0001
Error	12	59.09900	4.92492		
Corrected Total	23	13346.99325			

	R-Square	C.V.	Root MSE	SEDIMENT Mean
	0.995572	11.92005	2.219215	18.61750

Source	DF	Type I SS	Mean Square	F Value	Pr > F
REPS	3	55.43275	18.47758	3.75	0.0413
TREAT	2	13118.04602	6559.02301	1331.80	0.0001
REPS*TREAT	6	114.41547	19.06925	3.87	0.0220

Source	DF	Type III SS	Mean Square	F Value	Pr > F
REPS	3	55.43275	18.47758	3.75	0.0413
TREAT	2	13118.04602	6559.02301	1331.80	0.0001
REPS*TREAT	6	114.41547	19.06925	3.87	0.0220

Tests of Hypotheses using the Type III MS for REPS*TREAT as an error term

Source	DF	Type III SS	Mean Square	F Value	Pr > F
REPS	3	55.43275	18.47758	0.97	0.4665
TREAT	2	13118.04602	6559.02301	343.96	0.0001

General Linear Models Procedure

Dependent Variable: **SEDIMENT** **(kg/m^3)**

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	60.93833333	5.53984848	36.53	0.0001
Error	12	1.82000000	0.15166667		
Corrected Total	23	62.75833333			

R-Square	C.V.	Root MSE	SEDIMENT Mean
0.971000	21.73641	0.389444	1.791667

Source	DF	Type I SS	Mean Square	F Value	Pr > F
REPS	3	1.24500000	0.41500000	2.74	0.0899
TREAT	2	56.62333333	28.31166667	186.67	0.0001
REPS*TREAT	6	3.07000000	0.51166667	3.37	0.0347

Source	DF	Type III SS	Mean Square	F Value	Pr > F
REPS	3	1.24500000	0.41500000	2.74	0.0899
TREAT	2	56.62333333	28.31166667	186.67	0.0001
REPS*TREAT	6	3.07000000	0.51166667	3.37	0.0347

Tests of Hypotheses using the Type III MS for REPS*TREAT as an error term

Source	DF	Type III SS	Mean Square	F Value	Pr > F
REPS	3	1.24500000	0.41500000	0.81	0.5325
TREAT	2	56.62333333	28.31166667	55.33	0.0001

2.11 Detailed data on soil pH from surface runoff and leachate (following oats crop harvest on 8th August, 1996).

Treatment	pH of runoff				pH of leachate			
	Plot 1	Plot 2	Plot 3	Plot 4	Plot 1	Plot 2	Plot 3	Plot 4
MP sample 1	7.42	7.30	7.38	7.36	7.23	7.26	7.34	7.23
sample 2	7.33	7.34	7.43	7.40	7.25	7.20	7.31	7.24
NT sample 1	7.38	7.25	7.32	7.29	7.25	7.22	7.27	7.26
sample 2	7.40	7.33	7.42	7.30	7.23	7.21	7.28	7.20
P sample 1	7.35	7.31	7.34	7.36	7.22	7.23	7.20	7.21
sample 2	7.33	7.38	7.31	7.32	7.21	7.26	7.25	7.24

Statistical analysis of above data using GLM.

General Linear Models Procedure

Dependent Variable: pH (RUNOFF)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	0.02974583	0.00270417	1.69	0.1914
Error	12	0.01925000	0.00160417		
Corrected Total	23	0.04899583			

R-Square	C.V.	Root MSE	pH Mean
0.607109	0.545080	0.040052	7.347917

Source	DF	Type I SS	Mean Square	F Value	Pr > F
REPS	3	0.01041250	0.00347083	2.16	0.1454
TREAT	2	0.00585833	0.00292917	1.83	0.2031
REPS*TREAT	6	0.01347500	0.00224583	1.40	0.2913

Tests of Hypotheses using the Type I MS for REPS*TREAT as an error term

Source	DF	Type I SS	Mean Square	F Value	Pr > F
REPS	3	0.01041250	0.00347083	1.55	0.2970
TREAT	2	0.00585833	0.00292917	1.30	0.3386

General Linear Models Procedure

Dependent Variable: pH (LEACHATE)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	0.02073333	0.00188485	3.33	0.0249
Error	12	0.00680000	0.00056667		
Corrected Total	23	0.02753333			

R-Square	C.V.	Root MSE	pH Mean
0.753027	0.328719	0.023805	7.241667

Source	DF	Type I SS	Mean Square	F Value	Pr > F
REPS	3	0.00890000	0.00296667	5.24	0.0153
TREAT	2	0.00363333	0.00181667	3.21	0.0767
REPS*TREAT	6	0.00820000	0.00136667	2.41	0.0916

Tests of Hypotheses using the Type I MS for REPS*TREAT as an error term

Source	DF	Type I SS	Mean Square	F Value	Pr > F
REPS	3	0.00890000	0.00296667	2.17	0.1925
TREAT	2	0.00363333	0.00181667	1.33	0.3328