# *A Comparative Study of the Physical, Chemical and Microbiological Status of Soils, as influenced by Conventional and Reduced Tillage.*

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This Thesis is submitted in accordance with the academic
requirements for the
Degree of Master of Science
From
Research carried out at the School of Science,
Institute of Technology, Sligo.

Research conducted under the supervision of
Mr. E. Brady and Mr. P. Craddock

Submitted to the Higher education and Training Awards
Council 2004

# *ACKNOWLEDGEMENTS*

# *Acknowledgements*

I wish to express my sincere gratitude to Mr. Eugene Brady and Mr. Paul Craddock, my project supervisiors for their invaluable assistance throughout the duration of this project. I am forever indebted to you both.

My thanks to Teagasc, Oak Park, Co. Carlow and in particular Mr. Tony Fortune, without whom this project would not have been possible.

To the technical staff of the Science Department Sligo I.T. for their patience and generous support over the last number of years.

I would also like to acknowledge the professionalism and guidence of the academic staff of Sligo I.T.

To my fellow postgraduate students for their good humour and encouragement which helped to make this project worthwhile. The research lab will never be quite the same again.

To my parents, Dominick and Noreen, and my boyfriend Eamonn, who in addition to spending many hours proof reading and editing errors provided constant support and help. I will be eternally grateful.

Thank you everyone for all your individual contributions.

# DECLARATION

## *Declaration*

This Thesis has not previously been submitted to this, or any other college. With acknowledged exception, it is entirely my own work.

Jean Gilligan
Jean Gilligan

# *ABSTRACT*

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## *Abstract*

Historically, shifts to reduced and no-tillage management for production of crops were fostered by needs to decrease soil erosion and loss of organic matter, reduce fuel and labour costs and conserve soil water, as compared with conventional fallow tillage management. Recent interest in maintaining soil quality has been stimulated by a renewed awareness of the importance of soil condition to both the sustainability of agricultural production systems and environmental quality (Doran and Parkin, 1996).

The aim of this project was to determine the impact on the physical, chemical and microbiological status of the soil of conventional and reduced tillage.
It has been suggested that the reduced soil disturbance associated with the tine cultivator improves soil structure, increases nutrient content in the top 10cm of soil, increases microbial activity and improves physical characteristics.
From this study it was determined that the environmental benefits linked to reduced tillage in literature, did not develop in the first two years of this programmes implementation.

The results of this study determined that soil nutrients did not increase in concentration in the top 10 cm of soil under reduced cultivation. The only exception was exchangeable potassium. As potassium is not a mobile nutrient its movement is dependent on soil disturbance, therefore under reduced cultivation its concentration was allowed to accumulate in the upper horizon of the soil profile.

Microbial activity was greater in the conventionally tilled treatments, as determined by total aerobic bacterial numbers. This could be due to the increased rates of soil aeration in this treatment. Numbers of aerobic bacteria were greater in the conventional tillage treatments at both incubation temperatures of 22 and 32 °C.

The physical characteristics of the soil determined, indicate that below the depth of soil cultivation, cone penetration resistance increases. Therefore the reduced cultivation treatments would be more prone to soil compaction, higher in the soil profile.

# *TABLE OF CONTENTS*

## *TABLE OF CONTENTS* *PAGE*

## *List of Contents*

3.10. Implications of nutrient use in environmental Tillage

Chapter.6. DISCUSSION

Chapter. 7. CONCLUSION

Chapter. 8. RECOMMENDATIONS

APPENDIX

## *List of Plates*

## *List of Figures*

## *List of Tables*

***List of Results Tables***

***List of Results Tables***

***List of Results Tables***

*List of Results Tables*

## *List of Results Graphs*

## *List of Results Graphs*

## *List of Results Graphs*

***List of Results Graphs***

*List of Results Graphs*

***List of Results Graphs***

# 1.0. INTRODUCTION

# *CHAPTER.1. INTRODUCTION*

Farmers have a wide range of tillage systems at their disposal, for integrating crop residues in the soil, preparing a seed bed, and controlling weeds. The conventional tillage system, based on partial or complete inversion of the soil using a mouldboard plough as the primary implementation, has historically been most important (Cochrane, 1979). Problems with the conventional system began to emerge with the advent of mechanization, with an increasing proportion of tillable land allocated to row crops, shorter crop rotations and the on-going search for economies of size and scale through the restructuring of agriculture throughout developed countries (Miller et al, 1988). The combination of soil inversion and more intensive cropping methods have led to greater rates of soil degradation (i.e. organic matter depletion, structural breakdown, compaction and erosion) (Putman and Alt, 1987). Soil degradation in turn has been found to be detrimental to long-term soil productivity and to cause considerable on-site economic damage costs.

This research has been carried out at a time when there is increased public awareness about the state of our environment. Farmers are more aware of the importance of soil quality in achieving sustainable farming systems with the goal of improving the functioning of soil. Therefore improvement in soil quality to maintain high production and reduce negative environmental impacts is necessary for alternative crop production strategies to become socially acceptable and viable in the long term. This increased awareness has led to a renewed interest in reduced cultivation along with continuing pressures on grower margins.

The role to be played by tillage in reducing soil degradation problems is critical. Conservation tillage alternatives, together with longer crop rotations and increased use of conservation structures, constitute the principal means by which farmers can combat soil degradation. Conservation tillage aims to minimise soil disturbance and conserve the natural resources of the soil.

This project aims to determine the effect that conventional and reduced cultivation methods have on the soil eco-system, and also their environmental implications. The work has involved system research, where complete establishment systems were compared, and component studies where individual factors e.g. nutrient movement were studied in detail. As soil eco-systems are complex, assessing soil quality requires the integration of data over a broad range of parameters; these include the physical, chemical and microbiological status of soil.

In order to compare these cultivation systems it was necessary to implement field trials. These trials were developed by Teagasc, Oak Park, at their Knockbeg Road site. This trial is a replicated winter wheat experiment where reduced cultivations and conventional establishment systems are being compared, with and without the incorporation of straw.

The purpose of the Oakpark programme is to determine the future role of reduced cultivation systems. To date the mechanisation/labour research has shown higher work rates, lower energy inputs and lower establishment machinery costs for reduced cultivation systems compared to plough based systems. The effect of the system on crop soil and other environmental factors are detailed in this study.

# 2.0. AIMS AND OBJECTIVES

# *CHAPTER.2. AIMS AND OBJECTIVES*

The objective of this study was to investigate the impact on the physical, chemical and microbiological status of soils from the methods and machinery used in the tillage industry, and ultimately to determine the method that could lead to the highest levels of crop productivity, with minimal environmental implications and be a socially acceptable farming system. In the determination of these objectives a number of field plot trials have been implemented by Teagasc, at their Knockbeg Road site. These include plots, which have been treated by both conventional and reduced tillage (with and without the incorporation of straw). The purpose of this direct comparison is to determine whether the degree of soil disturbance impacts on soil properties.

To assess the impact of soil disturbance, as affected by cultivation method, a number of key objectives were examined in detail, these include,

To determine whether the incorporation or removal of straw has any impact on the physical, chemical or microbiological status of soils.

To determine if soil compaction is affected by cultivation method.

To determine the effect on soil structure due to cultivation methods.

To determine if soil organic matter levels increase under reduced cultivation, therefore improving soil quality and structure (as stated by literature).

To determine if nutrient distribution in the soil profile is affected by cultivation method.

To determine if total aerobic bacterial numbers and distribution are affected by the degree of soil disturbance.

# 3.0. LITERATURE REVIEW

# *CHAPTER.3. LITERATURE REVIEW*

## *3.0. CEREAL PRODUCTION IN IRELAND*

Tillage is an important Industry in Ireland, providing employment for in excess of 20,000 people in the food processing and service sector in addition to the 16,000 growers. It occupies 9% of the total land area farmed and contributed 405 million euro to Gross Agricultural Output.

In recent years cereal production is around 2 million tonnes, with over one million tonnes of this being barley and 0.5-0.8 million tonnes being wheat. The cereal area has stabilised at 300,000 hectares including maize, which is now close to 20,000 hectares. Spring barley is the main arable crop accounting for 57% of the cereal area in 2001 but the area of winter wheat peaked in 2002 at an estimated 74,000 hectares.

Cereal prices have dropped by 30% since 1995. Fertilisers and energy prices have increased by 17% and 23% respectively since 1999 having remained stable since 1990. Plant protection products have increased steadily by 1.5% per annum approximately. The cost of labour and insurance have increased dramatically in recent years.

The decline in the number of cereal growers and increase in scale is likely to continue, and will be intensified due to financial pressure. The main avenues to improved profitability are increased scale and improved efficiency. The importance of financial analysis for both whole farm and crop/field performance is emphasised. Standing still is not an option. A radical assesment of scale and overhead cost such as land, labour and machinery, will be rewarding (O'Mahony, J., 2003).

## *3.1. SOIL PHYSICAL PROPERTIES*

### *3.1.1. Introduction*

Hillel (1982) described soil as hetrogenous, polyphasic, particulate, disperse and porous system, in which the interfacial area per unit volume could be very large. The three phases of ordinary nature are present in the soil as follows - the solid phase constitutes the soil matrix; the liquid phase consists of soil water which always contains dissolved substances so that it should properly be called the soil solution; and the gaseous phase is the soil atmosphere.

The solid matrix of soil includes particles, which vary in chemical and mineralogical composition as well as in size, shape and orientation. It also contains amorphous substances such as organic matter, which binds mineral grains together to form aggregates. The organisation of the solid components of the soil determines the geometric characteristics of the pore spaces in which water and air are transmitted and retained. Soil water and air vary in composition both in time and space. The relative proportions of these three phases vary continuously and depend on such variables as weather, vegetation and management (Larney, F.J, 1985).

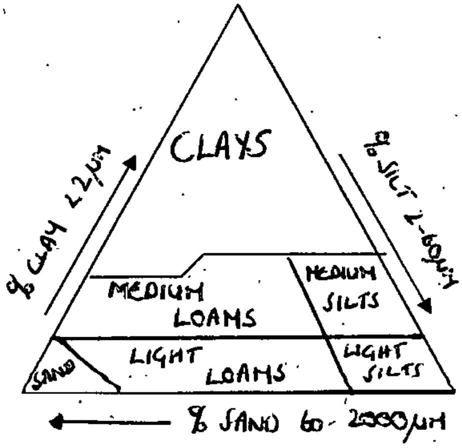
### *3.1.2. Soil Texture*

The relative size of soil particles in the soil matrix is expressed by the term texture, which refers to the fineness or proportions of sand, silt and clay. Russell (1973) stated that in former times soil texture was synonomous with workability and the terms ‘light’ and ‘heavy’ were in common usage for sandy and clayey soil respectively.

According to Hillel (1982) these can be misleading expressions since sandy textured soils are generally more dense, that is have a lower porosity, than clay soils and thus are heavier rather than lighter in weight, at least in the dry state. The amount and type of the clay are both important, particularly for cation holding properties of soils. Sand and silt have a considerable effect on water holding capacity but much less on nutrient holding.

Variation in organic matter content influences water and nutrient holding capacity, ease of cultivation and root penetration. Soil texture and organic matter content strongly influence topsoil structure and the risk of soil damage and root restriction following cultivation. Subsoil structure can have a great influence on root penetration during dry times. In particular, plough pans may severly limit root penetration below plough depth (Archer, J., 1988).

Figure.1. Soil Texture (Archer, J., 1988).



### *3.1.3. Soil Structure*

The physical arrangement of the soil solids dictates, the distribution possibilities of the liquid and gaseous components within a soil, as both occur in the voids between the soil solids. The voids are referred to as the soil pores or pore space, irrespective of their shape and size. The size and disposition of the pores may simply be determined by the size and arrangement of the primary soil particles as in the case of a loose sand. However, in most soils several processes associated with the presence of plant roots, the soil fauna, micro-organisms and organic matter, as well as physical forces due to the presence of water, result in the non-random arrangement of the primary soil particles and development of aggregation and so soil structure (Gardner et al., 1999).

Good soil structure means the presence of aggregation, which has positive benefits for plant growth. These benefits arise from the wider range of pore sizes, which result from aggregation. The nature of the pore spaces of a soil controls to a large extent the behaviour of the soil water and the soil atmosphere, and influence soil temperature. These all affect root growth, as does the presence of soil pores of appropriate size to permit root elongation. Favourable soil structure is therefore crucial for successful crop development. The destruction of soil structure may result in a reduction in soil porosity and/or change to the pore size distribution.

Soil structure is described in terms of its form and its stability. Structural form can be considered from two perspectives; the arrangement of the primary particles in aggregates, or the consequences of this arrangement for the size, shape and continuity of the pore space between and within the aggregates. Structural stability is the soils ability to maintain its structural form despite the application of stresses due to tillage, machinery or raindrop impact (Gardner, et al 1999).

The maintenance and improvement of soil structure, comes through optimising the organic matter content and the activity and species diversity of the soil biota (Lal, 1994). In most cases, optimising means increasing the organic matter content, which will lead to increased faunal and microbial activity. Without organic matter additions, possibilities for soil structural improvement are restricted by the mineralogy and chemistry of the inorganic fraction. Physical cultivation i.e. ploughing, enhances soil structure but often only temporarily. If organic matter is present this may encourage more permanent structural improvement. Generally, the conditions which favour successful plant growth, also favour biological activity in the soil and so structural improvement.

Structural degradation may be induced by tillage if the soil is cultivated at an inappropriate water content, and as a consequence of the loss of organic matter due to oxidation. Continued cultivation without organic additions can result in loss of micro-aggregation leaving a soil very vulnerable to compaction and erosion. Repeated tillage to the same depth, can create a smeared and compacted layer just below the tilled soil which can restrict root penetration and soil drainage (Gardner, et al 1999).

### *3.1.3.1. Processes responsible for the creating of soil structure.*

Soil structural form is described and classified in terms of the shape, orientation, size and degree of development of the aggregates present. Aggregates generally posses a well developed internal structure. Even small spheroidal soil aggregates will part into smaller structures on gentle handling. In fact structural organization occurs at all scales. The aggregates visible to the eye in the field represent the upper end of a hierarchy of structural form.

The processes causing the arrangement of soil primary particles into microstructures and aggregates, and the stabilisation of the aggregates, cannot be readily separated. It is the interaction between the clay, other inorganic and organic colloidal particles within which control the arrangement and stabilisation of aggregates. The flocculation of the soil colloidal material is important in the binding of the primary particles at the macro-scale and in aggregate stabilisation. Stable aggregate formation in silt or sands in the absence of clay requires the presence of organic material.

The expression of aggregation in a flocculated soil, at the micro as well as at the field scale, at a given time, results from the net effect of drying and wetting, freezing and thawing, compression and shear due to animals or agricultural equipment, and bio pore formation as a result of the growth of plant root systems, is activity of soil fauna and micro organisms. These processes introduce physical forces to the soil medium, which result in rearrangement of the soil particles at both the macro and micro scale. The result is that particles in some zones of the soil are brought closer together, enhancing the possibilities for bonding between them. In adjacent zones greater porosity is created and so a potential failure zone.

The process of aggregation requires some means of moving soil particles apart so that pores are created in the soil mass, and a mechanism for maintaining that arrangement. The process responsible for creating porosity and hence aggregates include drying and wetting, tillage and the activity of roots and the soil biota (Gardner et al., 1999).

### *3.1.3.2. The Role of Organic Matter in Soil Structure*

A direct positive relationship generally exists in soils between degree of aggregation/granulation and organic matter content (Neal, 1953). Beaver (1935) found a significant correlation between the percentage of aggregates larger than 0.05 mm and the carbon content of a wide variety of soils. A higher correlation was found for aggregates larger than 0.1 mm indicating that organic matter tends to favour the formation of relatively large aggregates. Myers (1937) reported that colloidal organic matter was more effective than clay in formation of stable aggregates with fine sand particles.

The stability effect of organic matter arises from interdomain and intermicroaggregate bonding in which the polysaccharide fraction of the organic matter may be of dominant importance (Clapp and Emerson, 1965). Clay soils tend to have higher organic matter contents than sandy soils under similar management systems, firstly, because of longer cool-wet periods which slow down microbial decomposition and, secondly, the formation of clay-humus complexes. A study of Irish pasture soils by Brogan (1966) showed a strong negative correlation between sand content and organic matter levels (Larney, F.J., 1985).

## *3.2. SOIL QUALITY*

Plants require soil to obtain water and nutrients for growth, and for anchorage and stability. Soil is one of the most important natural resources for crop production. It is estimated that the rate of soil formation is about 2.5 cm every 150 years, therefore soil is non-renewable within the human life span (Friend, 1992). For satisfactory plant growth, it is essential that the soil provide a favourable physical environment for root development that can exploit the soil sufficiently (Gardner et al., 1999).

Soil quality has been defined as the capacity of a soil to function within ecosystem boundaries to sustain biological productivity, maintain environmental quality, and promote plant health (Doran and Perkin, 1994). Recently, the concept of ideal soils has been introduced in which edaphic characteristics are grouped according to the functions that the soil has to fulfil to produce healthy and nutritious crops (Orellana and Pilatti, 1999).

Sustainability stresses the fact that soil quality must be maintained for future generations (Aon et al, 2001).

Soil in its natural state rarely provides the most favourable physical conditions for crop growth. The benefits of soil cultivation and of adding/removing water, to improve the soil physical condition, combined with appropriate crop selection for the enhancement of yields, has been long appreciated. The greater degree of intervention through engine driven mechanization has often been beneficial, improving the extent and manner of soil cultivation and enabling much greater areas to be farmed through use of irrigation and/or drainage schemes. However, exploitation though initially improving soil physical conditions can in time lead to a deterioration in soil quality through, for instance degradation

of soil structure, or increase in erosion susceptibility management of soil physical conditions. To ameliorate the constraints for plant growth will not only preserve the soil quality for the future but also contribute to the mitigation of soil degradation.
The ability of soils to keep the integrity of nutrient cycles and energy flows through them as well as their capacity to recover from perturbations introduced by for example, management systems for crop production, are crucial in the evaluation of soil health and quality (Doran and Perkin, 1994).

Good soil structure means the presence of aggregation, which has positive benefits for plant growth. These benefits arise from the wider range of pore size, which result from aggregation. The nature of the pore space of a soil controls to a large extent the behaviour of the soil water and the soil atmosphere, and influence soil temperature. These all effect root growth, as does the presence of soil pores of appropriate size to permit root elongation. Favourable soil structure is therefore crucial for successful crop development. The destruction of soil structure may result in a reduction in soil porosity and/or change to the pore size distribution. In some circumstances, a structure less soil mass can result, or physical rearrangement of particles into crusts and pans occur. Structural stability is the soils ability to maintain its structural form despite the application of stresses due to tillage or machinery (Gardner et al, 1999).

Because eco-systems are complex, assessing soil quality requires the integration of many kinds of data over a broad range of spatial and temporal scales. Since the introduction of the term, agricultural scientists have moved rapidly to develop quantifiable indicators of soil quality. Larson and Pierce (1991) developed the concept of a 'Minimum Data Set (MDS)'which could be used to monitor soil quality. They recommended a set of indicators sensitive to soil management inputs that could easily be determined from relatively standard and straightforward methods. A combination of physical, and chemical indicators comprises their minimum data set (Table 1).

Table 1.
Minimum data set of soil quality proposed by Larson and Pierce, 1991.

| Soil quality indicator |
|---|
| Nutrient availability |
| Total organic carbon |
| Labile organic carbon |
| Texture |
| Plant available water capacity |
| Soil structure (bulk density) |
| Soil strength (bulk density or penetration resistance) |
| Maximum rooting depth |
| PH |
| Electrical conductivity |

Arshad and Coen (1992) listed similar physical and chemical criteria and recommended that long-term experiments (20 to 30 yrs) be conducted to determine the impact of management practices on soil quality. Doran and Parkin (1994) expanded the minimum data set listing to include biological properties, in addition to physical and chemical soil properties.

Soil biological properties are more difficult to assess than chemical and physical properties but biological indicators are critical to characterising soil quality (Parr et al., 1992). Research is still needed to determine what microbial indicators should be included in a minimum data set for soil quality (Turco et al., 1994). Visser and Parkinson (1992) suggested that laboratory determination of microbial process level indicators like soil organic matter decomposition rates, microbial biomass, nitrogen cycling, and soil enzymes could rapidly assess changes in soil quality

## *3.3. SOIL PROFILE*

Soil refers to the loose material composed of weathered rock and other minerals, and also partly decayed organic matter, that covers large parts of the land surface of the Earth. As used in agricultural context, soil supports crop growth and can be tilled (Buckman, et al., 1969).

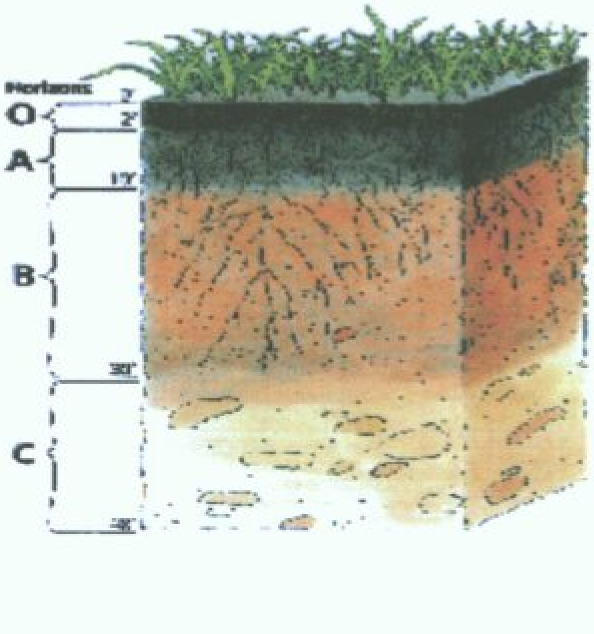
Soils develop over long periods of time, perhaps ten thousand years, as a response to the soil forming factors (climate, parent material etc). With time, soils generally become deeper and develop distinct layers or horizons, such a section is called a profile and the individual layers are regarded as horizons. These horizons above the parent material are collectively referred to as the solum, from the Latin legal term meaning soil, or land.

A soil profile is defined as the vertical face of a soil that can be exposed, for example, by digging a pit or a road cutting. It includes all the layers (horizons) from the surface down to the parent material (Wild, 1993).

The soil profile in mineral soils has four horizon types, from the surface downward called O, A, B, and C. Horizons can usually be distinguished by colour differences, but closer study also shows differences in chemical and physical properties. Individual horizons have defining characteristics designated by a subscript such as Ah, Bt, or Cca (Buckman, et al., 1969).

The upper layers or horizons of a soil profile generally contain considerable amounts of organic matter and are usually darkened because of such an accumulation.
The underlying subsoil contains comparatively less organic matter than the upper layers. The various subsoil's layers, especially in mature, humid region soils, present two very general belts, an upper zone of leaching and a lower zone of accumulation of compounds, such as iron and aluminium oxides, clays, gypsum and calcium carbonate (Wild, 1993).

Fig. 2. Soil Horizons



## SOIL HORIZONS

O HORIZON; refers to a surface layer of raw or partly decomposed organic material. The organic matter content of this horizon is several times greater than the underlying horizons (Buckman, et al., 1969).

A HORIZON; is the top layer of soil (topsoil). This thin layer, usually less than 20 cm, is the most fertile part of the soil because of the organic matter, which has accumulated from plant and biological activity. In this layer, roots are most dense and exude nutrients, which stimulate microorganisms, resulting in high biological activity. In grassland soils the upper A horizon is usually the darkest layer in the profile.
Topsoil is very important and can be easily eroded by water and wind and it is in this layer that the most leaching occurs. This downward movement of percolating water moves small mineral particles and salts giving rise to a process called eluviations.

B HORIZON; the soil under the top layer is called the subsoil. It is usually lighter in colour because it does not contain as much humus, making it less fertile. This layer can vary in thickness from a few centimetres to a meter. The B horizon shows accumulation of mineral particles such as clay and salts due to leaching from the topsoil. This process is called ‘illuviation’. The B horizon usually has a denser structure than the A horizon, making it more difficult for plants to extend their roots. B horizons are distinguished on the basis of colour, structure and the kind of material that has accumulated by leaching of the horizons above (Buckman, et al., 1969).

C HORIZON; this horizon lies under the subsoil and is called the 'parent material'. This is the original material from which the soil has developed. This layer has deposits of sand, gravel, pebbles, boulders and rock in various mixtures. The original parent material could be deposits from glacial activity, from sand and silt carried by the wind, from sediments carried by flowing water, including water in flood plains, or from gravity moving material down a slope (Buckman, et al., 1969).

Each of these horizons may be further sub-divided. If such subdivisions are present a suffix is usually appended to the horizon letter i.e. A1, O2 etc. Sometimes letters are used to signify that the subdivision is based on the presence of a particular characteristic, e.g. B2ir, means that the B2 horizon is rich in iron (Thorn, 1990).

Within the soil profile the part that contains plant roots or is influenced by plant roots is referred to as the solum. It is this part which is examined in this project.

A pedon is the smallest volume that can be called a soil. The point of this definition is that a soil is three-dimensional, that is, it has a lateral extension as well as the two dimensions seen in a vertical face. A pedon is therefore a vertical slice of a soil profile of sufficient thickness and width to include all the features that characterise each horizon (Wild, 1993).

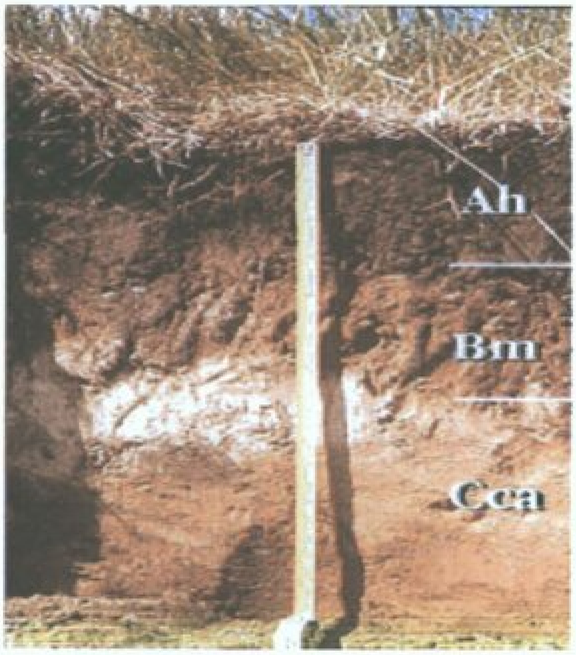
### *3.3.1. Subsoil and Surface soil.*

The productivity of a soil is determined in no small degree by the nature of its subsoil. This is of practical significance since the subsoil normally is subject to little field alteration except by drainage. Even when roots do not penetrate deeply into the subsoil, the permeability and chemical nature of the subsoil influence the surface soil in its role as a medium for plant growth.

The situation in respect to the surface soil is somewhat different. In the first place, it is the major zone of root development, it carries much of the nutrients available, to plants, and it supplies a large share of the water used by crops.

Second, as the layers are ploughed and cultivated, it is subject to manipulation and management. By proper cultivation and the incorporation of organic residues, its physical condition may be modified. It can be treated with chemical fertilisers and limestone and it can be drained. In short, its fertility and to a lesser degree its productivity may be raised, lowered, or satisfactorily stabilised at levels consistent with economic crop production (Gardner et al., 1999).

Plate. 1. Subsoil and surface soil.



## *3.4. SOIL WATER*

Water is present in soils in pore spaces. The saturated water content of soil is determined by the total volume of pore space present. The size of a pore influences how strongly water is held and how readily water may be transmitted through the soil. Several factors are responsible for holding water in soil these include the effect of pore size, and are quantified using the concept of potential energy. Water moves in soils and in plants, along potential energy gradients, from zones of high potential to zones of low potential. Water will move into plant roots if the root water potential is less than that of the surrounding soil.

In an unsaturated soil, the water present completely fills some pores but only forms thin films over the surface of others. Water is held there by capillary and surface absorption forces. The narrower the water filled pores and the thinner the water films, the greater these forces. Their strength depends, therefore, on the size and the configuration of the pores of the soil matrix and the soil water content. The energy required to remove water from a soil, against the forces attracting the water to the soil matrix, increases as the water content decreases. This is because the size of the pores which remain water filled, and the thickness of the water films present, decreases as water is removed.

The relationship between soil moisture content and moisture tension is called the soil moisture characteristic curve or water retention curve.

### *3.4.1. Factors affecting soil water*

Moisture retention decreases as coarse fragments increase and clay content decreases. De Jong et al, (1983) found that soil texture was the main property influencing water retention curves of 18 Canadian soils.

Compaction changes water content and transmission by altering the void size distribution of soils. The maximum amount of water retained by the soil as saturation is decreased by compaction. Compacted soils retain less water at low tensions as they have fewer large pores, but more water at high tensions as they have a greater number of small pores.

Chang and Warkentin (1968) and Croney and Coleman (1984) found that compaction increased water retention in the range where it is available to plants for both clay and sand. Hill and Summer (1967) found that in sandy soils increasing the bulk density increased water content at a given suction. The magnitude of this increase became smaller as suction increased that is, the effect of bulk density was less at 1500 kPa than at 100kPa. Increasing the bulk density of clay soil increased water retention but the magnitude of the increase became greater as suction increased due to the fact that clay soils allow closer packing to form small voids. In loam soils increasing bulk density resulted in decreasing water retention at low suction and increasing retention at high suction (Larney, F.J., 1985).

## 3.5. SOIL ORGANIC MATTER

The organic contents of soil are vitally important in providing energy, substrates, and the biological diversity necessary to sustain numerous soil functions. The concept of 'soil quality' has recognised soil organic matter as an important attribute that has a great deal of control on many of the key soil functions (Doran and Parkin, 1994; Franzluebbers, 2002).

There is considerable concern that, if soil organic matter concentrations are allowed to decrease too much, then the productive capacity of agriculture will be compromised by deterioration in soil physical properties and by impairment of soil nutrient cycling mechanism. It is well known the additions of organic matter e.g. manures, composts, above ground crop residues, or increases in soil organic matter, e.g. below-ground crop residues, microbial biomass, can improve soil qualities (Loveland and Webb, 2003).

An increase in soil organic matter is still seen, by many conventional farmers, as a desirable objective. Better plant nutrition, ease of cultivation, penetration and seedbed preparation, greater aggregate stability, reduced bulk density, improved water holding capacity at low suctions, enhanced porosity and earlier warming in spring have all been associated with increased amounts of soil organic matter (Carter and Stewart, 1996).

The Royal Commission on Environmental Pollution (RCEP), in its report on 'Sustainable Use of Soil' (Department of the Environment, 1997), commented on the undesirability of allowing soil organic matter to decrease too much, although it avoided recommendation of limiting values (Loveland and Webb, 2003). However, soil organic matter varies among environments and management systems, generally increasing with higher mean annual precipitation, with lower mean annual temperature, with higher clay content, with an intermediate grazing intensity, with higher crop residue inputs and cropping intensity, with native vegetation compared with cultivated management, and with conservation tillage compared with conventional tillage (Burke et al., 1989; Franzluebbers et al., 1998; Burke et al., 1989; Rasmussen and Collins, 1991).

Soil inversion by mouldboard plough tends to concentrate plant residue at the bottom of the plough layer (Allmaras et al., 1996). However, annual inversion results in a progressive homogenisation of soil organic carbon in the plough layer (Yang and Wander, 1999; McCarty et al., 1998; Wander et al., 1998). Shallow tillage will also homogenize soil organic carbon within the depth of tillage, but may result in some stratification of soil organic carbon with depth (Franzluebbers and Arshad, 1996b; Yang and wander, 1999). The degree of stratification is usually a function of intensity of disking and ploughing, with the amount of surface residue remaining after tillage acting as the most important variable (Duiker and Lal, 1999).

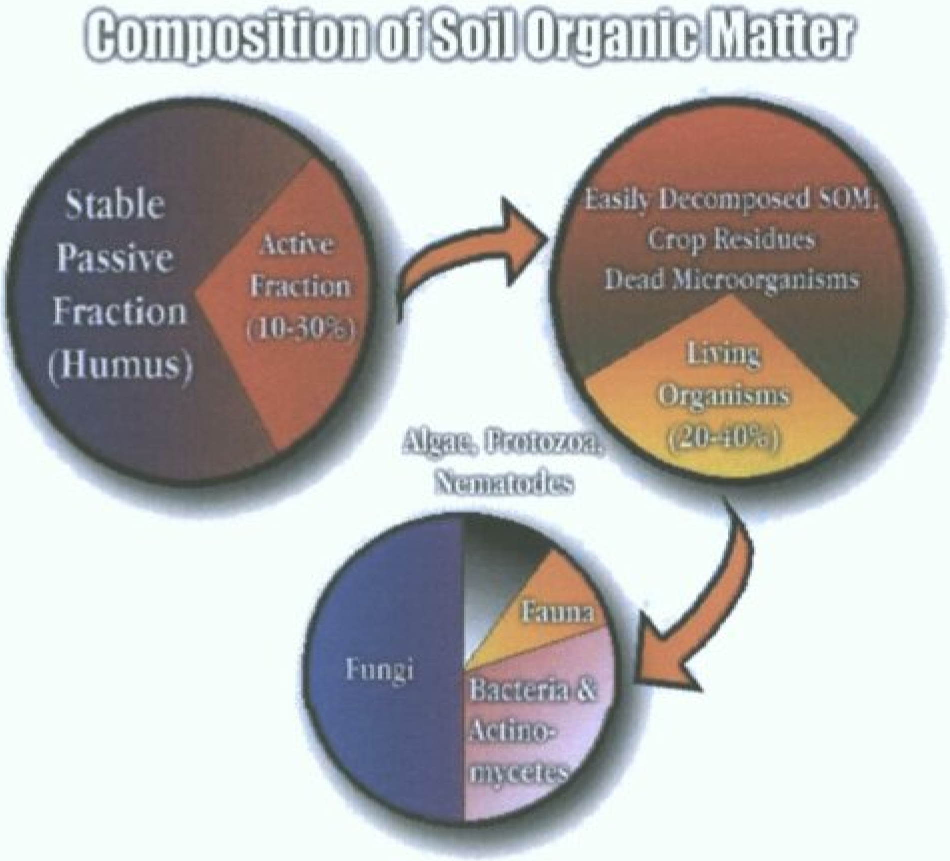
Conversion from conventional tillage to no-tillage or reduced tillage results in an immediate change in the placement of aboveground crop residue and the reduced fragmentation of the soil matrix may also slow the mineralization of soil organic carbon. Crop residue that was mechanically disturbed throughout the tillage zone under conventional tillage remains at the soil surface under conservation tillage. Leaching of organic solutes and redistribution by soil faunal activities become the primary physical transport mechanism under reduced tillage. Initial changes in soil organic carbon under conservation tillage would be expected to primarily reflect changes in the placement of carbon, with carbon being gained in the vicinity of the soil surface and lost at lower depths. The balance between the two processes could change with time (Kay and VandenBygaart, 2002).

Research indicates that soil organic carbon accumulates near the soil surface and is lost at lower depths soon after a conversion from conventional tillage to conservation tillage practices (Kay and VandenBygaart, 2002). Reduced tillage systems yielded results which were approximately mid way between those for conventional and no-tillage (Franzluebbers et al., 1996).
Research carried out by the US department of agriculture determined that soil organic carbon concentration was relatively uniformly distributed within the surface 15-20cm under long-term conventional tillage in Georgia and Texas. In contrast, no tillage management resulted in a significant increase in soil organic carbon at the soil surface at both these locations. Accumulation of soil organic carbon at the soil surface was a result of surface placement of crop residues and a lack of soil disturbance that kept residues isolated from the rest of the soil profile. Greater soil organic carbon under conventional tillage compared with no tillage at a depth of 7.5-15cm in Georgia was a result of tillage operations that incorporated surface organic carbon throughout the 15cm tilled zone. Decomposition of surface-placed residues is often slower than when incorporated in the soil profile (Brown and Dickey, 1970; Ghidey and Alberts, 1993), primarily because of less optimal moisture conditions (Franzluebbers et al., 1996). Due to less than optimal decomposition environment when soil is left undisturbed and residues are at the surface compared with disturbance and incorporation with tillage, transformation of organic carbon from plant-derived residues into soil organic carbon may be more effective under no tillage than under conventional tillage (Franzluebbers et al., 1998).

Soil organic carbon concentration decreased with increasing soil depth under both conventional tillage and no tillage in

Alberta/British Columbia. Unlike in Texas and Georgia, no tillage management did not significantly increase soil organic carbon at the soil surface compared with conventional tillage. The cold, dry climate conditions and shallow tillage depth (10-15cm with conventional tillage) probably did not offer a significant decomposition advantage to conventional tillage over no tillage, as is often observed in warmer wetter climates (Franzluebbers, 2002).

Fig. 3. Composition of soil organic matter.



Edwards. C.A. (2004).

### *3.5.1. The role of Earthworms in organic matter redistribution.*

Earthworms are extremely important in soil formation, principally through activities in consuming organic matter, fragmenting it, and mixing it intimately with soil mineral particles to form water stable aggregates. During feeding, earthworms promote microbial activity by an order of magnitude, which in turn also accelerates the rates of breakdown and stabilisation of humic fractions of organic matter. All earthworm species contribute in different degrees to the comminution and mixing of the organic and inorganic components of soil and decrease the size of not only organic particles, but also mineral particles (Joshi, N.V., Kelker, B.V., 1952).

During passage through the earthworm gut, the different kinds of mineral particles become mixed with organic matter and form aggregates, which improve both the drainage and moisture-loading capacity of the soil. These aggregates are usually very water stable and improve many of the desirable characteristics of soils. There have been various suggestions as to possible ways in which earthworms form aggregates, such as by production of gums or calcium humate, by plant residues, or by means of polysaccharide molecules (Parle, J.N., 1963).

Earthworms move large amounts of soil from the deeper strata to the surface. The amounts moved in this way range from 2 to 250 t/ha per annum, equivalent to bringing a layer of soil between 1mm and 5 cm thick to the surface every year, creating a stone-free layer on the soil surface (Edwards, C.A., Bohlen, P.J., 1996).

## *3.6. NUTRIENT STATUS OF SOILS*

The distribution pattern of macronutrients, micronutrients and other trace elements in topsoil is usually modified by the tillage systems (Lavado et al., 1990; Steiner and Lavado, 1998). Moreover, tillage techniques affect some soil properties like concentration of organic matter or pH. This gives rise to changes in bioavailability of several elements in root biomass distribution (Blevins et al., 1983; Scheiner and Lavado, 1998). All these processes affect the root absorption of macronutrients and trace elements (Hargrove, 1985; Carter and Gupta, 1997). Tillage does not affect element absorption in a single way. In addition, nutrient availability changes continuously due to application of macro, micronutrients and other trace elements through fertilizers, bio solids, irrigation water or through indirect sources (such as car exhausts, rainfall and atmospheric deposition from several sources).

Concern over the adverse impact of nutrient losses from agriculture has increased the need for management regimes that reduce or eliminate such losses. Farm management must also have regard to the increasing scope of legislation within which agriculture will have to operate in the future. Reducing nutrient loss requires that nutrients are not supplied in excess of crop requirements. This in turn requires an in-depth understanding of the factors influencing nutrient cycling in soils and nutrient availability to crops. By applying recommended amounts of nutrients at the correct times, and avoiding management practices that are likely to increase the risk of nutrient loss, the environmental impact of arable farming can be minimised while profitability is optimised (Carton et al., 2002).

An important step toward an understanding of the functioning of nutrient cycling and capacity of soil recovery from perturbations, is to realize how biological, physical and chemical characteristics in soil interact (Aon et al 2001).

Fertiliser advice in Ireland is based on the relationship between soil analysis and the crop nutrient requirement. Fertiliser and manure are then applied to the soil to make up the shortfall between plant demand and soil supply of the nutrient in question. The fertiliser advice is based on agronomic knowledge of both the soil supply and plant demand. This information is obtained from field experiments in which the crop response to nutrient inputs is measured, and/or soil test calibration is carried out on a range of soils over a number of years. For economic reasons, it has always been in the interest of farming to apply no more nutrients than are required by the crop. Recently, however, the environmental impact of nutrients in farming has been called into question. There is an increasing need to ensure that nutrients are applied in amounts and ways that optimise their utilisation and minimize their impact on the environment (Carton et al 2002). In 2001, Teagasc issued its fertiliser advice manual for grassland and tillage crops. The main changes occur in the nitrogen fertiliser advice for cereals. The manual mainly deals with the optimisation of agronomic requirements of the crops but the advice also considers economic factors in addition to the consequences to the environment of fertiliser applications (Coulter, B.S., 2001).

### *3.6.1. Teagasc fertiliser application guidelines.*

Advice on nutrient and trace element application rates depend on the quantity of the element in the soil that is available to the crop. Apart from nitrogen, this is determined by soil analysis, the soil is extracted with a suitable reagent and the amount extracted is deemed to be related to the amount available to the plant. For elements that are extracted, the analysis unit is milligram per litre of soil (mg/l).

It is normal to classify soil available levels of nutrients and trace elements into classes. The class is refered to as the Soil Index. At Johnstown Castle, soil analysis levels are classified into Index 1 – 4. The exact interpretation of the Soil Index varies somewhat with the element and the crop but the definitions in Table 2 apply in most circumstances (Coulter, 2001).

Table 2 Teagasc Soil Index.

| Soil Index | Index Description | Response to Fertilisers |
|---|---|---|
| 1 | Very low | Definite |
| 2 | Low | Likely |
| 3 | Medium | Unlikely/Tenuous |
| 4 | Sufficient/Excess | None |

### *3.6.2. Soil Index guidelines for Phosphorus and Potassium*

The Soil Index for phosphorus and potassium depends on the level of each nutrient available in the soil. This is determined by measuring the amount of each element that is extracted by Morgans solution. The ranges are shown in the following tables.

Table.3. Available Phosphorus Index

| Soil phosphorus Index | Soil phosphorus ranges mg/l –Mineral soil |
|---|---|
| 1 | 0 – 3.0 |
| 2 | 3.1 – 6.0 |
| 3 | 6.1 – 10.0 |
| 4 | Above 10.0 |

Table.4. Exchangeable Potassium Index

| Soil potassium Index | Soil potassium ranges mg/l – Mineral soil |
|---|---|
| 1 | 0 – 50 |
| 2 | 51 – 100 |
| 3 | 101 – 150 |
| 4 | Above 150 |

For agricultural crops it is advised (a) to apply nutrients only in the growing season and then not in large amounts, but in a number of small applications, and (b) not to build up the soil phosphorus level on grassland above an Index of 2 to minimise possible losses of nutrients to the environment (Coulter, 2001).

## *3.7. NITRATE IN SOILS*

Tillage has been found to influence both the amount and the distribution of soil nitrogen reserves (McCarthy et al., 1995).

Regular soil disturbance causes a decline in soil nitrate due to mineralization of organic matter (McCarthy et al., 1995). Cultivation exposes organic matter previously not accessible to microbial attack. Therefore most nitrate losses occur during the first few years after cultivation (Stevenson, 1965).

Lower mineralization, higher leaching and higher denitrification (due to higher surface water content) in reduced tillage tend to lower the available nitrate, particularly in spring (Thomas and Frye, 1984), while in the presence of a crop cover (Dalal, 1989). Without a crop cover the potential for nitrate leaching was greater, especially in the spring and early summer in temperate climates before the crop canopy emerges (Bandel et al., 1975; Blevins et al., 1984). Tillage was found to influence both the amount and distribution of soil nitrate.

Over 90% of the total soil nitrogen reserves occur in complex organic forms, which become available as the organic matter content of the soil is broken down to release nitrate and ammonium forms of mineral nitrogen. The amount of mineral- nitrogen available to crops depends on place in rotation and soil type. In light textured soils the organic matter fraction in the soil is broken down quickly, giving a high release of mineral- nitrogen in the first two years after ploughing up grass leys. After a few years in tillage, light soils have low levels of residual nitrogen. Consequently, they have high fertiliser nitrogen requirements and respond to higher levels of fertiliser nitrogen, especially when crops are growing 5 years or more after grass leys. On the other hand, soil types with medium-heavy to heavy textures release mineral nitrogen much more slowly, and therefore have lower fertiliser nitrogen requirements and give a reduced response to fertiliser nitrogen application.

It is clear that the major potential nitrogen loss pathway from tillage farming is nitrate leaching. The risk of nitrogen loss in runoff will be lower as these events are associated with wetter, heavier soils often considered unsuitable for tillage production. Gaseous nitrogen losses are relatively small when compared with grassland farming (Carton et al 2002).

Generally, the rate of nitrate-nitrogen mineralization declines during the autumn/winter period as soil temperature decreases. Rates increase during the spring/summer as soil temperature rises. The mineralization of nitrate during the summer months can be limited to moisture stress. Then, following a dry summer period rates can increase as the soil moisture increases during the early autumn period and soil temperatures are still relatively high (Carton et al., 2002). Herlighy (1979) measured the mineralization patterns in Irish soils. The nitrate release through mineralization continued throughout the year, with pronounced peaks in May and September. He stated that nitrate losses may be lower in the reduced tillage due to the greater degree of compaction.

In winter, nitrate-nitrogen is lost due to leaching via water movement and also due to the absence of nitrogen uptake by plants in the dormant season (Humphreys et al, 1999).

Soil residues can immobilize nitrogen and thereby reduce excess nitrate leaching (Christensen, 1986).

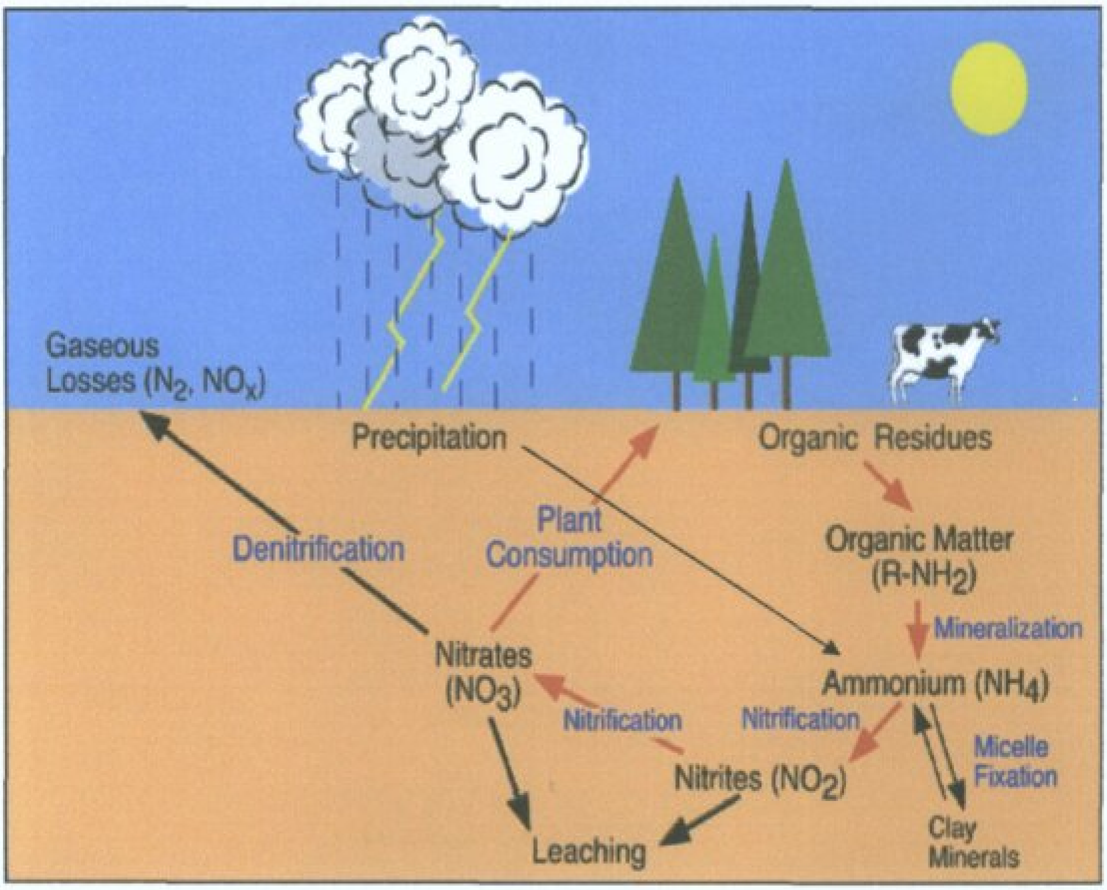
### *3.7.1. Nitrate Transport*

Nitrate nitrogen is the form of nitrogen that is most mobile and that is subject to leaching and movement into water supplies. The magnitude of nitrate leaching is difficult to estimate and depends on a number of variables, including quantity of nitrate, amount and time of rainfall, infiltration and percolating rates, evapotranspiration, water-holding capacity of the soil, and presence of growing plants. Leaching is generally greatest during cool seasons when precipitation exceeds evaporation; downward movement in summer is restricted to periods of heavy rainfall (Carton et al 2002).

Nitrate nitrogen concentration in river and soil drainage waters are related both in agricultural practice and research with arable land use. Neill (1989) studying seven river catchments, found a direct relationship between river nitrate concentration in the southwest and the percentage of the land area ploughed in the river catchments. The data from nine years of measurements showed that the mean nitrate loss from unploughed land was 1.9 kg/ha/year, whereas the corresponding loss from ploughed land was 75.9 kg/ha/year (Carton et al 2002).

The lower river nitrate nitrogen levels in summer reflected the diminished soil water movement and uptake of nitrate by growing crops. The annual variations of nitrate nitrogen concentrations for other rivers in the southeast followed similar patterns, with the levels varying from catchments to catchments. It was the amount of land area ploughed not nitrogen fertiliser input that gave the best relationship with high river nitrate nitrogen concentration (Carton et al 2002).

Fig. 4. The nitrogen cycle.



### 3.7.2. *Nitrogen Fertilisation*

Cereals are very responsive to nitrogen although excess amounts can reduce yields and quality. Nitrogen fertiliser advice for cereals is determined mainly by soil type and the soil nitrogen supply status as designated on the basis of a nitrogen index system. The nitrogen advice for cereals assumes normal yields of cereals, e.g. 9t/ha or more for winter wheat (Carton et al 2002).

Winter wheat is the highest yielding crop grown in Ireland. As a result, the nitrogen requirement of winter wheat is greater than for other cereal crops (the nitrogen requirement of the crop depends on the soil nitrogen supply status). Factors that affect the yield potential of the crop will also affect its nitrogen requirement (for example, where sowing is delayed until December or January yield potential will be reduced and hence the requirement for fertiliser nitrogen will be reduced).

It is important to match the amount of nitrogen applied to crop demand, as excess nitrogen fertiliser can have deleterious effects on the crop. The most significant of these is the increased risk of lodging as the fertiliser nitrogen level increases. Additionally, increased levels of nitrogen can make the crop more susceptible to disease (Carton et al 2002).

Nitrogen from soil, fertiliser and manure sources is inefficiently used (30 to 60%) in most crop production systems. As a consequence, unused inorganic nitrogen can move off crop fields and contaminate surface and ground water reserves. Governments have responded with guidelines, standards, regulations and in some cases fines, when off-field losses of nitrogen have not been reduced. Numerous technologies and time proven practices are available for producers to employ that will result in improved crop nitrogen use efficiency (Kitchen et al., 2001).

Crop nitrogen needs, including nitrogen source, amount and timing are difficult to anticipate because of spatial (within and between fields) and temporal (within and between growing seasons) variability (Kitchen et al., 2001).

The weather dominates nitrogen loss, through the impact of rainfall and temperature on drainage, crop growth, and nitrogen utilization. This position is most clear for arable and horticultural systems, and a set of best management practices for optimum nitrogen use and efficiency are globally applicable, which include, Farmers should choose the highest-yielding variety appropriate to maximise the use of available nitrogen.

A green cover should be maintained as much as practicable. Use a cover crop if necessary and drill autumn sown crops early.

Fertiliser requirements should be calculated using a fertiliser recommendation system, allowing for soil mineral nitrogen, mineralised nitrogen from soil organic matter, crop residues, legumes and manures.

Nitrogen management strategies should start with a good understanding of precipitation patterns and variability in order to minimize nitrogen loss but not be nitrogen deficient with the crop.

By synchronizing nitrogen application with crop requirements, and by splitting spring fertiliser applications, leaching of soil nitrogen may be reduced (Kitchen et al., 2001).

### *3.7.3. Effects of reduced tillage on nitrate concentrations in soils.*

The use of reduced tillage continues to increase as an alternative for nearly all forms of crop production. However, adoption of conservation tillage practices may result in some nitrogen moving from the soil-plant systems into the environment under certain conditions (Folett, 2001).

There is no question that conservation tillage is effective in decreasing particulate nitrogen losses associated with soil erosion and surface water runoff. However, effects of conservation tillage on leachable nitrogen are not so well delineated as surface losses. Generally, conservation tillage provides a wetter, cooler more acidic, less oxidative soil environment. Under such conditions, processes of ammonification and denitrification may be favoured over nitrification. Conversely, for nitrate that is already present, the leaching potential may be greater under conservation tillage. This is because more undisturbed soil-macro pores exist for nitrate and water movement. Increased water flow, into and through the root zone, has been observed under no-till compared to conventional tillage soils. This higher flow has been attributed to decreased water evaporation because of surface residues and increased numbers of undisturbed channels (earthworm) continuous to the soil surface. The surface mulch enhances the environment for earthworms and the lack of tillage preserves existing channels for several years (Folett, 2001).

The crop fertiliser nitrogen requirement is a function of many factors. Among these are residual and mineralisable soil nitrogen and those elements of crop and soil management that influence the fraction of total nitrogen that is a readily mineralisable form (Stanford and Smith, 1972; 1976). Crop residue management influences the availability of nitrogen. When crop residues low in nitrogen are incorporated, there is immobilization of residual mineral nitrogen remaining in the soil after harvest. After maximum immobilization, mineralization of the previously immobilized nitrogen occurs, resulting in a net release of nitrate (Allison and Klein, 1962). When fertiliser nitrogen is added to soil, a portion is immobilized, but the mineralization rate of the recently immobilized fertiliser nitrogen is greater than that of indigenous organic nitrogen for the same period (Freney and Simpson, 1969; El-Harris et al., 1983).

### *3.7.4. Nitrate losses in Irish soils.*

To date, studies investigating the effect of winter cover crops on reducing nitrate leaching from fallow land have not been carried out in this country. Francis et al., (1998) have shown that nitrate uptake by cover crops significantly reduced soil mineral nitrate concentration in the 0-1 m zone compared to leaving land fallow. Cover crops sown in September will produce substantially more above ground dry matter and remove more mineral nitrate from the soil by the start of the winter than crops sown in October or November. Such cover crops reduce nitrate nitrogen leaching losses when drainage events occur after the crops have taken up considerable amounts of soil nitrogen. Depression of yield in subsequent cereal crops, through immobilisation of nitrogen via incorporation of large amounts of above ground herbage, can be overcome by limited grazing of the cover crop (Carton et al.,2002).

Mineralization of soil organic nitrogen is the main reason for high loss of nitrate from tillage systems (Ryan et al., 2001). In lysimeter studies at Johnstown Castle the mean nitrogen (32 kg/ha) leached annually from the soil profile in years 10-13, where spring barley was grown continuously, was less than half the amount (78 kg/ha) leached annually in years 1 –3, even though the applied nitrogen was greater. This was a reflection of much lower release of soil mineral nitrogen in the latter years to the crop. In that experiment, the mean nitrate nitrogen concentration in the drainage water in years 1-3 was 10.7 mg/l from barley receiving 100 kg N/ha, it was only 4.7 mg/l in years 10-13 from barley receiving 130 kg N/ha. Fallowing of land without a winter crop is a high risk strategy with regard to leaching of nitrate. A related aspect of the lysimeter work outlined measured nitrogen loss from fallow land receiving zero nitrogen over the 13 years of the study. The mean loss was 170 kg N/ha in years 1-3 reducing to 107 kg N/ha in years 9-13, both of which were higher than the losses from the barley crop. Mean nitrate-nitrogen concentrations in the drainage water were 27.4 and 13.6 mg/l for the fallow in those early and late cultivation years, respectively. It was year 13 before the drainage water from the fallow soil had a mean nitrate-nitrogen concentration that was less than the maximum admissible concentration of 11.3 mg/l for drinking water (Carton et al, 2001).

## *3.8. PHOSPHORUS IN SOILS*

Phosphorus is an essential element for plant growth and its input has long been recognised as necessary to maintain profitable agriculture and crop production (Carton et al., 2002).

Soil phosphorus exists in inorganic and organic forms. In most agricultural soils, 50-75% of the phosphorus is inorganic, although this fraction can vary from 10-90%. Inorganic phosphorus forms are dominated by amorphous and crystalline aluminium and iron compounds in acidic, non calcareous soils, and by calcium compounds in alkaline, calcareous soils. Organic phosphorus forms include relatively labile phospholipids, nucleic acids, inositols and fulvic acids, while more resistant forms are comprised of humic acids. The laibility of these forms of phosphorus is based on the extent to which extractants of increasing acidity or alkalinity, applied sequentially, can dissolve soil phosphorus (Sharpley and Rekolainen, 1979).

Phosphorus additions in either organic or inorganic form, are needed to maintain adequate available soil phosphorus for plant uptake in modern agricultural systems. The level of these applications varies with both soil and plant type (Pierzynski and Logan, 1993). Once applied, phosphorus is either taken up by the crop and incorporated into organic phosphorus (Mc Loughlin et al, 1988) or becomes weakly (physisorption) or strongly (chemisorption) absorbed onto aluminium, iron, and calcium surfaces (Syers and Curtin, 1988). After the initial absorption reaction, there is a gradual fixation (absorption) of added phosphorus, which renders a proportion of absorbed phosphorus unavailable for plant uptake. Organic phosphorus compounds may also become resistant to hydrolysis through complexation with aluminium and iron (Tate, 1984).

With the application of phosphorus, available soil phosphorus content increases. The increase in available soil phosphorus is a function of certain physical and chemical soil properties, such as clay, organic calcium, iron and aluminium and calcium carbonate ($CaCo_3$) content. The continual application of phosphorus can increase soil-test phosphorus above levels required for optimum crop yields (Sharpley and Rekolainen, 1979).

Although once considered to be largely irreversible, fixed phosphorus can be slowly released back into the soil solution when reserves of less strongly held phosphorus are exhausted (Tiessen et al, 1983; Johnston, 1989).

The potential loss of phosphorus from agricultural land is dependent on several factors. These factors include the overall balance of phosphorus inputs to and outputs from agricultural systems, amount, form and availability of phosphorus in soil; and the relative importance of surface and subsurface runoff in a catchments area (Sharpley and Rekolainen, 1979).

Microbial phosphorus plays an important intermediary role in the short term dynamics of organic phosphorus transformations and suggests that management practices maximising the build up of organic matter during the autumn and winter may reduce external phosphorus requirements for plant growth during the following spring and early summer. This accumulation may also contribute to higher phosphorus losses in runoff in early spring and autumn than in summer months (Sharpley, 1980; Yli-halla et al, 1996).
Murphy and Culleton (1979) demonstrated that in Irish grassland soils, the soil phosphorus concentration tended to decline with increasing depth in the soil profile.

### *3.8.1. Phosphorus transport*

Phosphorus is transported in dissolved (DP) and particulate (PP) forms. Particulate phosphorus includes phosphorus sorbed by soil particles and organic matter eroded during flow events and constitutes the major proportion of phosphorus transported from cultivated land (Pietilainen and Rekolainen, 1991; Sharpley et al, 1992).

Ryden et al, (1973), proposed that phosphorus losses be considered as due to three types of runoff, surface, storm and base flow. Although rainfall has a low phosphorus content, the highest phosphorus concentrations are observed in surface runoff, reflecting both the high phosphorus content of surface soils and the occurrence of soil erosion. The latter can be especially important in determining phosphorus losses under arable conditions, particularly when there is little crop cover and low soil infiltration rates. In comparison, with base flow, storm runoff represents precipitation that moves quite rapidly across or through the upper soil horizons, which have the highest soil phosphorus contents, before reaching a drainage channel. Although storm runoff has a limited contact time with the soil, it is often rich in phosphorus, thus drainage water containing phosphorus increases during flood events (Stevens and Smith, 1978; Johnson, 1979). Base flow, originating from ground water reserves usually has low drainage water phosphorus concentration, often less than 20ug P $L^{-1}$ (Ryden et al, 1973). The occurrence of runoff relative to the timing of application of phosphorus fertilizer is an important determinant in the extent to which phosphorus losses will occur. In general, as the time between application and runoff increases, losses of phosphorus decline exponentially (Carton et al 2002).

Different land use types present a different degree of risk in terms of phosphorus loss. In general, cereal crops appear to maintain a

better phosphorus balance than for example root crops (Withers, 1994). For arable farming the main pathway of phosphorus loss is usually soil erosion, with phosphorus predominantly removed in particulate form. This process is a storm driven event (Heathwaite, 1979).
The mobility of phosphorus in soils is low compared with other plant nutrients because of the generally low solubility of phosphate compounds and strong phosphorus-binding capacity of soil material. Plant roots, therefore, have a ‘contact problem’ relative to both soil phosphorus and applied fertilizer phosphorus. A plant root gets most of its phosphorus from within 2mm of the root surface during its period of active phosphorus uptake (Nyle and Tinker, 1977; Barber, 1985). Agricultural crops generally take up only 5-10% of the applied fertilizer phosphorus the first year (Greenwood et al, 1980).

Several studies have reported that the loss of dissolved phosphorus in runoff is related to soil phosphorus concentration (Schreiber, 1988; Yli-Halla et al, 1995; Sharpley and Rekolainen, 1997). Sharpley and Rekolainen (1997) stated that as soil phosphorus concentration increased, the potential for dissolved phosphorus transport in runoff increases. This can be attributed to the fact that more phosphorus is released from soil to the soil solution as the degree of phosphorus saturation increases and hence is more easily lost to surface runoff during runoff events (Breeuwsma and Silva, 1992). The process of phosphorus desorption from surface soil under rainfall involves a continuous application and removal of water at the soil surface. This process involves the release of dissolved phosphorus to runoff water. However, as dissolved phosphorus is removed in runoff it does not slow down further dissolved phosphorus release from labile phosphorus fraction in the soil. Further dissolved phosphorus can therefore become available from the labile phosphorus fraction through desorption (Humphreys et al, 1999).

### *3.8.2. Phosphorus uptake*

A generalised phosphorus balance and efficiency of several European countries indicates the potential for phosphorus accumulation in agricultural systems. Although, the magnitude of phosphorus input and output varies among countries, the relative proportions of phosphorus uptake in plants are similar. The efficiency of phosphorus uptake by plants depends on a number of edaphic, management and environmental factors. Plant uptake of phosphorus increases as soil temperature, moisture, aeration and nutrient status increase. The availability of phosphorus to crops is reduced by complexation in soil with calcium at high pH, by iron and aluminium at low pH and high clay content. Liming can increase phosphorus availability in soils by stimulating mineralization of organic phosphorus or may decrease phosphorus availability by the formation of insoluble calcium phosphates at pH > 6.5. In other situations, liming can increase phosphorus availability via increased pH (Hartikainen, 1981). A fall in pH or increased biological activity in the rhizosphere, including vesicular-arbuscular mycorrhizal associations with plant roots can considerably enhance phosphorus uptake especially on low-phosphorus soils (Sharpley and Rekolainen, 1979).

### *3.8.3. Phosphorus sorption capacity of soil.*

The ability of a particular soil to absorb phosphorus is dependent on differences in phosphorus buffering capacity between soils caused by varying levels of clay, iron and aluminium oxides, carbonates and organic matter. However, for a particular soil type, the greater the degree of phosphorus saturation the less well able that the soil is to absorb phosphorus from the soil solution and the greater is its capacity to release phosphorus in the soil solution. Soils with a high degree of phosphorus saturation and a low ability to absorb phosphorus therefore have greater potential to loose phosphorus to water through the process of desorption (Carton et al., 2002).

In a study carried out by Teagasc at the Bellgrove catchment in Cavan, it was determined that the loss of dissolved phosphorus takes place from the upper 3mm of soil. Humphreys (1999) however, in his study determined that the phosphorus concentration of samples taken to a depth of 1 cm were substantially higher than the phosphorus concentration of samples taken to a depth of 10 cm. The higher concentration of phosphorus in the upper layer of the soil was attributed to, phosphorus extracted by plant roots from subsurface layers which is then transferred to the herbage, and decomposes directly returning phosphorus to the soil surface. Application of phosphorus fertilisers and animal manures further compound the build up of phosphorus in the upper layers of soil.

### *3.8.4. Phosphorus fertilisation.*

The need to supplement soils with water soluble or potentially water-soluble phosphorus fertiliser arises from inability of the relatively small pool of native soil phosphorus to supply and maintain adequate amounts of soluble orthophosphate to the soil solution for satisfactory crop growth. In principal, this approach is not different from supplying nitrogen (N) or potassium (K) fertilisers and results in poor (25% or less) efficiency of recovery of an annual application in the growing crop (Barrow, 1980; Haynes, 1984).

In addition to the immediate effect of fertiliser phosphorus in the year of application, there is a trend for higher optimum yield with increasing levels of soil phosphorus built up over time (Herlihy and Hegarty, 1994). Agricultural crops generally take up only 5-10% of the applied fertiliser phosphorus in the first year (Greenwood et al., 1980). Others also have noted that a high level of available soil phosphorus showed more yield productivity than an immediate application of fertiliser phosphorus, irrespective of the amount applied. This benefit arises because of restricted mobility of fertiliser phosphorus, although pursuit of this benefit by keeping soils high in phosphorus would conflict with good environmental practice.

In contrast, recovery of fertiliser nitrogen or potassium by a crop in the season of application may be as high as 80%. In essence, then, whereas nitrogen and potassium fertilisers in soils are relatively accessible to crop roots, this is not so with phosphorus fertilisers, which after dissolution in the soil water, are quickly immobilized by reactions with various soil constituents. As a result, phosphorus nutrition of field crops is largely dependent on the subsequent release of phosphorus from these reactions products to the soil water (Morgan, 1979).

Phosphorus application to agricultural land, particularly in areas with phosphorus deficient soils, improves crop production and maintains soil fertility. Plant uptake of phosphorus by most field crops and grasses generally varies between 10-25 kg P ha$^{-1}$ yr$^{-1}$ (Sharpley et al., 1994), although phosphorus application rates can often far exceed this (Hedley et al., 1995). Fertiliser phosphorus application for arable crops on permanent pastures in the UK generally vary between 20 to 40 kg P ha$^{-1}$ yr$^{-1}$, depending upon crop species and soil phosphorus status (Maff, 1994). These fertiliser phosphorus application practices appear to be broadly consistent with plant up take (Hoda et al 2000).

### *3.8.5. Phosphorus in Irish soils.*

For good water quality under Irish conditions it is considered that phosphorus concentration in water should average not more than 0.035 mg P/L. this is equivalent to an annual loss of less than 0.35 kg P/L (Anon., 1998). There is a growing body of literature indicating the contribution that agriculture makes to phosphorus loss to water and the factors influencing it. It is now generally accepted that there is a positive relationship between soil test phosphorus and loss to water (Tunney et al., 1997). Soil test phosphorus is not the only factor influencing phosphorus loss to water from a particular agricultural area, timing and rate of fertiliser spreading or direct losses from farmyards are examples of other controllable factors that can influence it (Magette, 1998).

Dissolved reactive phosphorus loss from four field sites with different soil test phosphorus levels was measured in 1997 (Morgan et al., 2000). The relationship between soil test phosphorus and phosphorus loss to water indicates that annual dissolved reactive phosphorus loss (kg/ha) to water increases exponentially as soil test phosphorus increases (Tunney et al., 2002). The relationship established in this work is in broad agreement with the results of a number of other studies including Brookes et al., (1997), and indicates that the soluble phosphorus in water lost from a grassland soil is proportional to the square of the Morgan's or water soil test phosphorus value. The results indicate that to have a water soluble phosphorus level under 0.05 mg P/L, the soil test phosphorus should be under 6 mg P/kg soil, which is near the lower limit for optimum grass production. It should be noted that the losses reported in these studies were measured at the edges of fields. As there can be attenuation of phosphorus during transport from the field to susceptible water bodies, concentrations at the edge of fields may be higher than the concentration entering receiving waters (Humphreys et al., 1999).

There is very limited data for phosphorus loss in overland flow from Irish tillage soils. It is likely that the potential for losses will be greater on tillage soils with high soil test phosphorus (>10 mg/L). Results on grassland soil in Ireland indicate that most of the phosphorus lost is in water soluble form. It is likely that more soil phosphorus (not water soluble) may be lost from tillage soils than grassland soils. This may be particularly likely on soils where crops are harvested late in the season, when soils may be wet and rainfall high.

However, tillage soils differ from some grassland soils in so far as they are generally on the drier soils that are less subject to runoff and in addition tillage soils are cultivated regularly and the phosphorus is therefore incorporated to plough depth. This is in contrast to grassland soils where all applied phosphorus, both in fertiliser and animal manure is applied to the soil surface and tends to be held in the top few centimetres of soil. The risk of phosphorus loss from this enriched surface layer, more typical of grassland, is likely to be higher than on tillage soil, which will not normally have a phosphorus enriched surface layer (Humphreys et al,1999).

## *3.9. POTASSIUM IN SOIL*

Potassium maintains the salt balance in plants and is important for healthy metabolism. It is also essential for the bacteria in legumes, which fix nitrogen from the air. Potassium is commonly found as potassium chloride (potash) in soil. Exchangeable potassium is defined as that potassium which is free to exchange with cations of salt solutions added to soils. When in good supply this form of potassium appears to be available to plants (Page et al., 1982).

Potassium is present in plants in the highest concentration of plant nutrients and largest amounts are present and cycle through the soil- plant animal system. Yet the quantity of potassium held in an exchangeable condition at any one time often is very small (approximately 1%). Exchangeable potassium ranges from <100 to 2,000 ppm or more compared with total potassium values in the order of 1 to 2%. Water soluble potassium seldom exceeds a few parts per million except for saline soils (Page et al., 1982).

Most of this element is held rigidly as part of the primary minerals or is fixed in forms that are at best only moderately available to plants. Also competition by microorganisms for this element contributes at least temporarily to its unavailability to higher plants. Thus, the situation in respect to potassium utilization parallels that of phosphorus and nitrogen by virtue of the fact that a large proportion of all three of these elements in the soil is insoluble and relatively unavailable to growing plants. However, unlike the other major nutrients potassium is not a component of and therefore cannot be stored in the soils organic matter. Furthermore most soils do not have a large capacity to store potassium in its inorganic form.

The major losses of potassium are via transport to unproductive areas and removal in products. Surprisingly the leaching losses of potassium are not large in relation to these other losses (Humphreys et al., 1999).

### *3.9.1. Potassium loss in soil.*

Under ordinary field conditions and with an adequate nutrient supply, potassium removal by crops is high, often being three to four times that of phosphorus and equalling that of nitrogen. Moreover, this situation is made even more critical by the fact that plants tend to take up soluble potassium far in excess of their needs if sufficiently large quantities are present. This tendency is termed 'luxury consumption', because the excess potassium absorbed apparently does not increase crop yields to any extent. Luxury consumption can lead to a reduction in magnesium uptake, which would lead to crop deficiencies or 'grass tetany'. For many crops there is a more or less direct relationship between the available potassium in the soil and the removal of this element by plants. The available potassium would, of course, include both that added and that already present. A certain amount of this element is needed for optimum yields and this is termed 'required potassium'. All potassium above this critical level is considered a luxury, the removal of which is wasteful (Edmeadas, 1997).

### *3.9.2. Potassium fertilisation.*

The potassium present in the crystalline structure of primary minerals is significant in maintaining exchangeable potassium levels of soils that are not too highly weathered. When these potassium bearing minerals are present in significant amounts, chemical weathering slowly releases potassium to the soil solution from which the potassium ion can move to an exchange site, to plant roots, or to a fixation site between the lattices of certain clays. In highly weathered soils or soils where the apparent material contained little potassium bearing minerals, the exchangeable potassium can be depleted by plant removal and is replenished only by fertiliser application or return of potassium from plant residue (Page et al., 1982).

## *3.10. EMISSIONS FROM AGRICULTURE TO WATER*

The Nitrate Directive 91/676/EEC,

This Directive, introduced in 1991, focuses on nitrate losses from agriculture to water. It's objective is 'to reduce water pollution caused or induced by nitrates from agricultural sources and prevent further such pollution'. The issue of nitrates in water is of concern because elevated levels in drinking water are considered a danger to human health. Where water is abstracted from streams and rivers, nitrate is contributed by land drainage water. Aquifer water nitrate levels are influenced by the agricultural practice above the aquifer. Nitrate levels in aquifer waters have generally increased over the last thirty years (Archer, 1988). In addition, nitrate in water, particularly estuarine waters, results in growth of algae and plant that cause undesirable shifts in the ecosystem.

The Nitrate directive requires Member States to designate nitrate vulnerable zones (NVZs- areas with known or potential nitrate levels in water that exceed guide values specified in the Directive) and to develop an Action Programme (AP), i.e. a list of measures to be implemented by farmers that will achieve the Directive's objective. Ireland is the last country in Europe to implement the designation of Nitrate Vulnerable Zone's. Member States have a choice in the method of implementation. They can either develop a national Action Programme or they can designate Nitrate Vulnerable Zone's and develop a specific action programme for these zones. The Action Programme is to be based on the Code of Good Agricultural Practice published by the Departments of Environmental and Agriculture in 1996. There is a twelve- month period allowed for the development of the Action Programme that should allow sufficient time for full consultation with the stakeholders. This process is about to start in Ireland.

The Action Programme will be comprised of a series of measures that farmers are legally obliged to implement. They relate to;

Limits on the organic nitrogen loading from animals, i.e. 170 kg organic N/ha. However, for the first four years of the Action Programme, countries can set this limit at 210 kg organic N/ha. Member states can during or after each four year Action Programme adopt different limits but these must be approved by the Commission.

Manure storage requirements that is ‘the capacity must exceed that required for the longest period during which land application is prohibited’.

Limiting nitrogen fertilizer and manure applications so that Good Practice is observed.

Limiting fertilizer use to crop requirements (i.e. as specified by Teagasc in ‘Nutrient and Trace Element Advice for Grassland and Tillage Crops’ published in December 2001).

Therefore, to make a meaningful contribution to the Action Programme debate it is important that tillage farmers consider the potential pathways of nutrient loss from their systems and the strategies available to control them (Carton et al., 2002).

## The Water Framework Directive 2000/60/EC

This, the most recent water quality Directive, is important and challenging. It establishes a framework for the protection of all water resources- groundwater, surface water and coastal waters.

The framework is aimed at,

Preventing further deterioration and protects and enhances the status of aquatic eco-systems

Promoting sustainable water use based on long-term protection of available water resources

Enhancing protection and improvement of the aquatic environment

Ensuring the progressive reduction of pollution of groundwater and preventing its further pollution

Contributing to mitigating the effects of flooding and pollution.

These objectives are to be achieved by designating river basin districts (RBD) for all waters covered by the Directive. Seven such districts have already been selected for Irish waters. Within each river basin district, monitoring programmes (volume, flow rate, ecological and chemical status) must be put in place. A programme of measures must be put in place to achieve the water quality objectives. The development and implementation of these measures will have to involve the active participation of the agricultural stakeholders including tillage farmers. The implementation of existing EU Legislation in relation to water quality is considered a minimum requirement.

In addition, the Water Frame work Directive requires identification of all waters to be used for human consumption above a specified size and the measures that will be put in place to achieve compliance with the Drinking Water Directive. Finally, the principle of recovery of the costs of water services, including environmental and resource cost, has to be applied (Carton et al., 2001).

### *3.10.1. Emissions from agriculture to air.*

The emphasis on nutrient emissions from agriculture has up to now been primarily on water. However, it is important that tillage farmers are aware that agriculture can also impact on air quality. Ireland has signed international agreements to limit its emissions of gases. Agriculture will have a role to play in terms of achieving these targets. These are the three gases of concern, ammonia, methane and nitrous oxide. In a general way, only nitrous oxide is of concern from the perspective of the tillage farmer. Emissions of ammonia and methane relate primarily to animal production systems. However, ammonia emissions from the land spreading of manure will become an issue where a tillage farmer uses animal manure as a nutrient source for crop production.

Nitrous Oxide,

This gas may account for up to 15% of the total global warming potential. Its global warming potential is estimated to be more than 250 times that of carbon dioxide. Moreover, its lifetime residency in the atmosphere is estimated to be about 130 years. Nitrous oxide also leads to ozone depletion. Globally, anthropogenic activity accounts for 64% of total nitrous oxide emission of which agriculture accounts for 92%. Most studies have identified soils as the major source. Therefore, controlling nitrous oxide emissions from soils maybe a requirement in achieving compliance with our national target. In the context of Irish tillage farming, the nitrogen input is the major element that can potentially contribute to nitrous oxide emissions (Carton et al., 2002).

The Kyoto Protocol,

Under which parties to the protocol have legally binding commitments to bring about an overall global reduction of 5% in the combined emissions of six greenhouse gases for the period 2008-2012. However, progress towards this target must be demonstrated by 2005. Ireland is limited to a 13% increase above 1990 levels by 2008-2012 under this agreement. This falls within an overall 8% reduction by the EU as a whole. However, based on a 'business as usual' scenario the target set may in fact be exceeded by as much as 23%. Therefore, agriculture will be required to proportionally reduce its emission of greenhouse gases in the coming years. In the context of tillage farming this will primarily relate to controlling nitrogen inputs (Carton et al., 2002).

Ammonia,

Agriculture accounts for over 90% of Irish ammonia emissions. Livestock production systems are recognised as the largest source of ammonia emissions to the atmosphere. The sources are housing, manure storage, manure application to land and urine and dung deposition in grazed pastures. Once in the atmosphere, gaseous ammonia reacts progressively with acidic compounds forming ammonium salts, for example, ammonium sulphate and ammonium nitrate. These may be transported over long distances depending on meteorological conditions. These are returned sooner or later to the earth's surface. It is this addition of nitrogen to natural ecosystems that is of environmental concern both in terms of its implications for biodiversity and the acidification of soil and aquatic systems.

Ammonia is one of the three most important compounds that are responsible for acid rain the others being oxides of sulphur and nitrogen. Acid precursors in the atmosphere can cross national borders and emissions from one country can adversely affect another country's environment. Therefore, the problems arising can only be solved through international co-operation. Ireland became a signatory to the Convention on Long- Range Transboundry Air Pollution, which set emission ceilings for a number of air pollutants in 1979. No ceiling was put on ammonia at that time. However, in 1999 negotiations for a new protocol were concluded and signed by the relevant Ministers in Gothenburg. This set new ceilings for national emissions of oxides of sulphur and nitrogen but also included ammonia. This protocol is soon to be replaced by the EU Emission Ceilings Directive, which will require that Ireland reduce ammonia emission levels by 9% by 2010 compared with 1990 base levels. Ammonia is likely to be the largest contributor to acidifying and gaseous nitrogen emissions in Europe by 2010 as the emissions of sulphur dioxide have been already drastically reduced by industry. Therefore, the responsibility for achieving emission reduction targets will rest primarily with the agricultural sector. It is likely that the required reduction in ammonia emissions will be achieved by changing the method of manure application to land (Carton et al., 2002).

## *3.11. MICROBIOLOGICAL STATUS OF SOIL*

The soil represents a favourable habitat for microorganisms and is inhabited by a wide range of microorganisms, including bacteria, fungi, algae, viruses and protozoa. Microorganisms are found in large numbers in soil- usually between one and ten million microorganisms are present per gram of soil, with bacteria and fungi, being the most prevalent. However, the availability of nutrients is often limiting for microbial growth in soil and most soil microorganisms may not be physiologically active in the soil at a given time.

Soil microorganisms are very important as almost every chemical transformation taking place in the soil involves active contributions from soil microorganisms. In particular, they play an active role in soil fertility as a result of their involvement in the cycle of nutrients like carbon and nitrogen, which are required for plant growth. Soil microorganisms are responsible for the decomposition of the organic matter entering the soil and therefore in the recycling of nutrients in soil. Certain soil microorganisms such as mycorrhizal fungi can also increase the availability of mineral nutrients (e.g. phosphorus) to plants. Other soil microorganisms can increase the amount of nutrients present in the soil. For instance, nitrogen-fixing bacteria can transform nitrogen gas present in the soil atmosphere into soluble nitrogenous compounds that plant roots can utilise for growth. These microorganisms, which improve the fertility status of the soil and contribute to plant growth, have been termed ‘bio fertilizers' and are receiving increased attention for use as microbial inoculants in agriculture. Similarly, other microorganisms have been found to produce compounds (such as vitamins and plant hormones) that can improve plant health and contribute to higher crop yield. These microorganisms (called 'phytostimulators') are currently studied for possible use as microbial inoculants to improve crop yield.

In contrast to these beneficial soil microorganisms, other soil microorganisms are pathogenic to plants and may cause considerable damage to crops. Large numbers of pathogenic microorganisms are routinely found in the soil and many of them can infect the plant through the roots. However, certain native microorganisms present in the soil are antagonistic to these pathogens and can prevent the infection of crop plants. Antagonism against plant pathogens usually involves competition for nutrients and/or production of inhibitory compounds such as secondary metabolites (anti microbial metabolites and antibiotics) and extra cellular enzymes. Other soil microorganisms produce compounds that stimulate the natural defence mechanisms of the plant and improve its resistance to pathogens. Collectively, these soil microorganisms have been termed 'bio pesticides' and represent an emerging and important alternative (i.e. biological control) to the use of chemical pesticides for the protection of crops against certain pathogens and pests.

Tillage systems affect the soil physical and chemical environment in which soil organisms live, thereby affecting soil organisms. Tillage practices change soil water content, temperature, aeration, and the degree of mixing of crop residues within the soil matrix. These changes in the physical environment and the food supply of the organisms affect different groups of organisms in different ways. Populations, diversity and activity may all be affected by changes in tillage system (Kladivko, 2001).

Soil organisms perform important functions in soil, including structure improvement, nutrient cycling, and organic matter decomposition.

Although soil organisms respond to tillage-induced changes in the soil physical environment, they also have an impact on soil physical and chemical conditions.

Microorganisms as well as micro fauna, mesofauna, macro fauna play essential roles in nutrient cycling and organic matter decomposition in the soil. Interactions among different organisms can have either beneficial or harmful effects on crops. Thus soil organisms are both affected by tillage and the soil physical/chemical environment.

A general picture of the relation between microbial activity and soil moisture is described by Linn and Doran (1984) and illustrates that the wetter, denser and cooler conditions typically associated with reduced tillage systems, result in higher amounts of organic matter and greater microbial activity, principally in the upper layers of the soil (Dalal et al., 1991).

Reduced tillage systems are often characterised by an accumulation of crop residues on the soil surface, this has led to greater carbon and nitrate, and greater water contents on the soil surface, compared to conventionally tilled soils (Linn and Doran, 1994). The greater number of microorganisms and microbial activities in the surface (75mm) of reduced tillage soils are largely a reflection of these higher carbon, nitrogen and water contents (Doran, 1980). Facultative anaerobes and denitrifying bacteria are also more numerous in the surface (150mm) of reduced tillage soils and constitute a larger proportion of the total microbial population than in the ploughed soils. Thus, the greater number of organisms capable of anaerobic activity and the greater potential for denitrification indicate the biological environment of reduced tillage soils to be less aerobic that that of the ploughed soils. Major factors responsible for the less aerobic conditions in reduced tillage soils are higher soil water contents and/or bulk densities which result in lower total soil porosity and greater water-filled pore space (WFPS) in comparison with ploughed soils (Linn and Doran, 1984b).

Most of the studies of micro flora found less soil microbial biomass (defined as mass of living microbial tissue) in conventional than in reduced tillage (Wardle, 1995), although differences were usually small. Greater microbial biomass under no tillage than conventional tillage is likely due in part to cooler, wetter conditions and less fluctuation in temperature and moisture in no tillage (Kladivko, 2001).

After reduced-till systems have been established for a number of years, many studies have found an increase in soil organic matter in no-till compared to conventional tillage systems (Logan et al., 1991; Karlen et al., 1994; Reeves, 1997). At first glance, the higher microbial biomass with no-till may appear to be contradictory to a build-up of soil organic carbon content. However, some studies have found a decrease in the efficiency of use of carbon sources by soil micro organisms under conventional tillage, as evidenced by greater carbon dioxide evolution per unit microbial biomass under conventional tillage compared with no tillage systems (Haynes, 1999). In addition, many studies have not explicitly considered the seasonality of tillage operations and microbial activity, in particularly the flush of microbial growth and activity directly after tillage and residue incorporation (Logan et al., 1991).

By definition, no-till systems have less mechanical mixing of crop residues into the mineral soil than do conventional tillage systems. From that standpoint, the no-till systems are a little more like undisturbed natural eco-systems and may depend more on soil organisms for proper functioning (House and Parmelee, 1985; Wardle, 1995). When there is no mechanical loosening of soil or mixing of soil residues, the actions of the ecosystem engineers and the litter transformations may become much more important than in systems disturbed and mixed by a mouldboard plough (Linn and Doran, 1984).

Conversion of agricultural fields from conventional tillage practices to reduced tillage systems usually stimulates populations of soil fauna and microorganisms. The increased soil moisture and smaller fluctuations in soil temperature under no-till are generally beneficial for microbial activity as well as some of the faunal groups (Kladivko, 2001).

Microbial behaviour follows the observed changes in the soils physical and chemical conditions. It has been noticed that aerobic activity is generally stimulated deeper in the soil profile (~15cm) in conventional tillage than in no tillage management. The latter is reflected by microbes since higher populations of fungi, aerobic bacteria and autotrophic nitrifiers in conventional tillage than in no tillage have been described (Aon, M.A. et al, 2001). Thus, the potential for mineralization of organic matter and nitrification is greater in conventional tillage.
However, no tillage appears to have a greater potential for anaerobic metabolism and denitrification than conventional tillage (Klalviko, 2001).

Doran (1980) yielded results for populations of total and bacterial organisms which were increased almost two-fold by the addition of surface residue.

Plate. 2. Mycorrhizal fungi.

Mycorrhizal fungi colonize the root systems of many plants and aid in the uptake of nutrients by the plant, thereby improving plant growth and overall health.

## 3.12. CULTIVATION METHODS

The production of all crops involves the use of some type of tillage system. On the one hand, the tillage system may be very simple, involving either digging or punching holes to sow seeds. On the other hand, it may be a complex system comprised of primary tillage and several secondary tillage operations before and after crop establishment with different machines and equipment (Gardner et al, 1999).

The benefits of carrying out tillage include,

- Improvement of the soil environment by affecting desirable soil water relations in seedbeds
- Control of weeds and
- Reduction of the mechanical impedance to root growth.

(Gardner et al, 1999).

Challenges facing tillage farmers continue to change and it is now necessary for producers to explore every avenue to maximise profits and minimise costs.

Conventional cereal establishment using the plough and subsequent cultivation is energy demanding and consequently relatively slow and expensive (farm mechanisation accounts for approximately 40% of production costs). Where cereals are produced continuously, there is concern that plough based systems coupled with straw removal may be leading to a deterioration in soil structure. Reduced or minimum cultivation systems, which established crops with less intensive cultivation, offer scope for machinery and labour cost reduction. Combined with straw incorporation, they may also help to reduce the deterioration in soil structure. Reduced cultivation systems are not new. Systems were developed, evaluated and adopted about 30 years ago in the

UK and elsewhere but management problems, particularly grass weeds, led to a decline in use (Forristal and Fortune, 2003).

Recent developments have resulted in a renewed interest in reduced cultivation systems. These include,

- Price cost squeeze, with much lower cereal prices
- Need to reduce labour and increase scale to maintain viability
- Newer chemical weed control options
- Subtle changes to the minimum cultivation technique
- Improved minimum tillage drills.

(Forristal and Fortune, 2003).

The evaluation of alternative cultivation systems is not a simple process. Adopting a reduced cultivation system can have effects on many factors including,

- Crop yield and quality characteristics
- Machinery demands, power, scale, work rates and costs
- Labour requirements and demand patterns
- Soil structure effects
- Environmental effects (nutrients, and soil fauna).
- Weed control and herbicide use
- Reliability and sustainability of establishment system
- An additional factor would be the increase in awareness of soil; its structure and organic matter levels (Forristal and Fortune, 2003).

Gardner et al (1999) states that farmers are aware of the benefits to minimise soil erosion by practicing reduced tillage, this occurs as the organic matter content of the soil increases and stability can be further improved with the addition of straw.

Regardless of whether this is done using a hoe or machines, tillage invariably cuts, loosens and in some cases, mixes and inverts the soil. Depending on the objectives it may smooth or shape the soil surface. In some tillage systems, large clods created, during primary tillage may be pulverised during secondary operations thus exposing soil aggregates and particulate surfaces to the atmosphere with the resultant oxidation of organic matter. The loss of organic matter through oxidation may exacerbate the structural instability of some soils following continuous cultivation. Because of this deleterious effect on soil structure, Phillips and Phillips, (1984) have, during the last two decades, questioned the logic in following certain conventional tillage practices (for instance, those that remove or bury crop residue, invert the soil and pulverise large clods through several disk harrowing operations).

The current trend in many developed countries is to replace "conventional tillage", which may accelerate organic matter decline and increase erosion potential, with conservation tillage systems. This is because conservation tillage systems reduce the detrimental effects of the soil degradation process. However, there are two schools of thought on the appropriateness of tilling soils. Some researchers believe that tillage has beneficial effects on soil because it is necessary for weed control, for loosening compacted and crusted soils and for increasing the root depth of shallow soils. Others believe that by cutting, mixing, pulverising and inverting, tillage in the long run does more harm than good to soils and should therefore be discontinued (Gardner et al., 1999).

### *3.12.1. Conventional Tillage*

Conventional tillage may be defined as "a process of ploughing and cultivation which incorporates all residues and prevents growth of all vegetation except the particular crop desired during the growth season" (Soil Science Society of America, 1987). Although this definition emphasises residue incorporation, conventional tillage also includes systems in which all residues are either removed or burned before sowing, or removed for other purposes (livestock feed or bedding, building or fencing material, etc). In this system, most of the soil surface is left bare especially at seeding and during the initial crop growth stages until a full crop canopy is established. The conventional tillage system has been adopted in the past because it reduces competition between crops and weeds for water, nutrients and sunlight. In developed countries, weeds and residues are incorporated using inversion tillage (e.g. mouldboard, disk or lister ploughs) and subsequent disk harrowing to break up large clods. Not only does conventional tillage involve inversion of soil; it also involves soil mixing using implements such as disk harrows, tandem disks, one-way disks and rotary tillers. These implements usually incorporate about 50 percent of the surface residue at each operation. Whereas, soil inversion and mixing equipment loosen, mix and invert soil, other equipment loosen the soil without inverting and mixing. However, even those implements, result in some losses in residue. Therefore, repeated operations often leave the soil devoid of residues at planting time, particularly in situations where initial residue amounts on the soil surface are low (Gardner et al, 1999).

By effectively incorporating residues in the soil, conventional tillage eliminates or minimises the interference of residues with sowing, cultivating and weed control. It also facilitates the incorporation of fertilisers, lime and pesticides. Other advantages of conventional tillage include,

- Machinery is familiar and widely available
- System is flexible and adaptable to a wide range of soil and crop conditions
- Soils may warm faster when crop residues are incorporated
- Breaking soil crusts to enhance water infiltration and
- Increasing soil surface roughness to increase temporary surface water storage.

Thus it facilitates infiltration of water that would otherwise be lost as runoff and reduces susceptibility to wind erosion. Conventional tillage also loosens condensed and impermeable soil horizons that restrict or even prevent root penetration, movement of fluids and activities of soil organisms. It buries crop residues to control the proliferation of pathogens and insect pests that reside in and/or live on the residue during the off-season period for crop production.

The main disadvantage of conventional tillage is that it leaves the soil surface devoid of residues and it renders most soils vulnerable to soil erosion by water and/or by wind. This is because residues are no longer present to reduce the impact of raindrops, retard overland flow of water, and reduce wind speeds at the soil surface. Field traffic is also greater, increasing the risk of compaction and spreading of weeds in the field and equipment, fuel and labour costs associated with seedbed preparation are higher (Gardner et al, 1999).

### *3.12.2. Reduced Tillage.*

The Food and Agricultural Organisation of the United Nations defines sustainable agriculture as the use of agricultural practices which conserve water and soil and are environmentally non-degrading, technically appropriate, economically viable and socially acceptable (Fowler and Rockstrom, 2001).
This tillage system attempts to minimise or reduce the many tillage operations, often involving primary tillage and four or more secondary tillage operations using disk harrows, chisels, and sweep implements that characterise conventional tillage. The major objectives for reduced tillage are to conserve soil and water by retaining crop residues on the surface during periods of the year when the soil is prone to erosion (Gardner et al, 1999).

Conservation tillage is the generic term given to soil management systems, which aims to conserve natural resources. The maintenance of at least 30% soil surface cover by plant residues is often regarded as essential for conservation of soil and water, but may not affect the usage of other resources such as time, fuel, and money. Residues levels alone, therefore, do not adequately define all conservation tillage practices.
While the production and preservation of soil cover is desirable, the critical component of conservation tillage in such areas is the minimisation of soil disturbance, and the term 'conservation tillage' reminds agriculturists that the primary causes of resource loss and environmental degradation are the hand hoe and mouldboard plough (Gardner et al, 1999).

Notably among the advantages of reduced tillage are,

- Soil erosion and runoff is reduced
- Many of the advantages of conventional tillage are maintained
- Input costs are lower compared to conventional tillage
- Maintained or increased crop yields when compared with conventional tillage
- Involved fewer cultural operations, thus reducing fuel and oils required for crop production and also reducing the labour and machinery time.

Major disadvantages of this system include,

- Lower soil temperature in spring, which may delay seed germination, emergence and crop establishment due to crop residues
- Poor seed placement, because of the presence of residues on the surface
- Possible pest problems
- Planter modifications may be required
- And a larger tractor may be necessary.

(Gardner et al, 1999).

Many factors have come into focus and are responsible for the resurgence in reduced cultivation. The development of plant growth regulators and, in particular, the non selective contact weed control materials, that have become commercially available have provided the ability to eliminate or severly suppress existing vegetation. These materials have provided a base for recommendations and allowed for consistent yields and predictable performance. All of which are responsible for the renewed interest in reduced tillage (Phillips and Phillips, 1984).

### *3.12.3. Crop residues.*

Tillage practices, which preserve higher levels of surface residues retain more water (Berry et al., 1985). Ideally soils should at all times have a minimum of 30% plant residue cover, but Oldreive (1993) maintains that even 10% is better than using mouldboard plough because of the damage this does to soil structure.
Surface placement of crop residues with conservation tillage can improve soil physical, chemical and biological properties compared with incorporation of residues with conventional tillage (Hatfield and Stewart, 1994).

Erenstein (1999) advocated crop residue mulching for improved resource conservation and productivity. Plant residues on the soil surface affect soil temperature and moisture, and consequently crop and weed germination, speed of emergence and root growth. They affect soil water and gas flow, soil structure, residue decomposition, nutrient cycling and availability, weed spectrum and competition, and plant disease dynamics (Lafond and Derksen, 1996). The presence of residues at the soil surface in different types of tillage system has a tremendous effect on soil runoff and erosion as well as on the availability and population and activities of soil fauna and therefore on soil organic matter content (Blevins et al., 1985).

Soil organic matter content increases with surface placement of crop residues compared with incorporation, especially in warmer climates, where decomposition of buried residues is faster than in colder climates. Specific mechanisms that lead to increases in soil organic matter due to surface placement are not well understood. Less favourable conditions for decomposition or greater chemical resistance to decomposition are generally assumed. Whether surface placed residues become more chemically resistant to decomposition needs to be investigated in order to better understand nutrient cycling under conservation tillage systems (Doran, 1987).

Chemical alterations during decomposition may be different in buried and surface residues (Harper and Lynch, 1981). Nitrogen concentration (initially 34 mg N g $^{-1}$) of surface placed hairy vetch (Vicia villosa Roth.) during decomposition (78%) in Kentucky stabilised to 24 mg N g $^{-1}$ residue remaining at the end of 4 weeks in the field, while buried residues stabilised to 17 mg N g $^{-1}$ residue remaining during decomposition (93%) (Varco et al., 1993).

The benefits derived from mulch depend on the agro-ecological zone. Where marginal or erratic rainfall or drought is a problem, the major benefits are increased moisture capture and retention, with weed suppression in these and more humid areas. Leguminous residue mulches are most likely to increase nutrient supply. The minimum quantity of mulch needed for short term moisture conservation benefit is 5 t ha$^{-1}$, which is often difficult to achieve due to alternative uses for the residue, especially in semi-arid regions. Smaller quantities (2-3 t ha$^{-1}$) may improve soil physical properties in the long term if applied each year (Fowler and Rockstrom, 2001).

Plate. 3. Crop Residue

## *3.13. PHYSICAL EFFECTS OF TILLAGE*

During tillage operations the soil is subject to shearing, compressive and tensile stresses. A pure shear stress causes a change in shape without change in soil volume. Pure compression results in volume change without change in shape. In practice shear and compression usually occur together in soils. Tensile stresses cause tensile failures, which open up fissures and cracks, this decreases the bulk density of the soil but causes little alteration to the soil between the failure zones. The stresses that tillage imposes result in deformation of the soil and failure. Brittle failure, compressive failure or tensile failure may occur. The effect of tillage can therefore create new failure zones and weaken existing ones. Alternatively, where compaction has occurred, failure zones can be strengthened. The soil water content at the time of the tillage operation has a significant impact on the effectiveness of the work. Tillage also has other effects. In particular, the impact of wetting and drying cycles in the surface soil is increased, due to increased porosity, and so possibilities for structural change due to shrink-swell processes are enhanced (Gardner et al, 1999).

### *3.13.1. Soil erosion.*

Soils differ dramatically both in response to conservation tillage and in susceptibility to soil erosion. Soils, which are well drained because of soil texture, depth to water table and slope, perform well under conservation tillage, since they dry and warm quickly under crop residue. Generally these soils are very susceptible to erosion. Poorly drained soils, such as those found in depressions, or low lying level land conditions, seldom erode but they are difficult to manage regardless of tillage (Gardner et al., 1999).

Soil erosion and surface sealing are among the most deleterious processes to agriculture and environment (Sumner, 1995). During rainfall, raindrop compaction and soil suspension movement by water result in high shear stresses, leading to an intensive local deformation in soil erosion (Ghadiri and Payne, 1986; Rose et al., 1990). As a concomitant process the soil surface transfers into a layer, ranging from 1 to 10 mm. This results in higher bulk density, lower porosity and lower hydraulic conductivity as well as in an increase in the soil strength of surface soil (Moore, 1981).

The conditions suitable for erosion are,

- Lack of vegetation
- Soft fluffy soil conditions
- Excessive rainfall, particularly in short periods with strong winds
- Steep slopes
- Excess water run-off from higher ground

The susceptibility of soils to erosion has increased under the modern system of high powered methods of tillage farming. These include,

- Ditch removal and field enlargement to increase furrow and stoke length
- Destruction of old 'ditch and dyke' system
- Increase in high powered traction systems that tend to plough up and down the slopes for safety and economical reasons
- Increased use of tramlines

- Reduction in the use of manure
- Reclamation of upland areas and destruction of natural vegetation.

(Zhang et al, 2001).

Minimisation of soil erosion,

- The risk of soil erosion can be reduced with careful management
- Contour ploughing and cultivation including rolling in high risk areas
- Planting a catch crop in high risk areas, to stabilise the crop until the next crop is sown
- Practising eco-tillage to increase the organic matter content of the soil and improve stability with straw
- Erection of barriers to reduce the risk of gullying by water flowing from higher ground.

(Farmers Journal, 2001)

Although mouldboard and chisel tillage make up the major part of an annual sequence of tillage operations, they do generally not result in a surface that is smooth enough for seeding or planting. Most often, a sequence of mouldboard and chisel tillage is followed by harrowing to reduce clod size and surface smoothening before seeding is carried out. The possible contribution of harrowing and seeding activities to total tillage erosion has largely been overlooked in tillage experimental studies. Most publications have hitherto focussed on mouldboard, chisel and cultivator implements (Govers et al., 1999). Only in some studies, the combined effect of a whole sequence of tillage operations, including harrowing and/or seeding, was investigated (Thaps et al., 1999). However, their results do not allow to infer the contribution of each individual tillage operation to total erosivity.

Evidence that harrowing may move substantial quantities of soil material can be found in experimental studies on wheel dispersal. Several authors tried to quantify horizontal seed movement due to different implements, using seeds as tracers for soil movement (Marshall and Brian, 1999). Results indicate clearly that harrowing can cause tracers and soil to move over significant distances. Marshall and Brian (1999) found that the observed mean seed displacement distances following harrowing (1.58 m) is far more important than the mean displacement due to ploughing (0.36 m) or due to two types of tine cultivation (0.71 and 1.21 m). However, as these results are only applicable for soil movement on level land, they cannot be used to assess the erosivity of harrowing operations (Muysen and Govers, 2002).

Alberts et al., (1985) dealing with the problems of erosion on arable areas, maintain that high erosion losses are most likely to occur in growing spring crops.

Soil strength was linked to soil erosion (Torri et al., 1987), soil aggregate detachment (Nearing and Braford, 1985; Torri et al., 1987) and seal formation (Bradford et al., 1992). Tensile strength of soils has been reported to decrease with decreasing bulk density and increasing water content (Zhang et al, 2001).

For a given soil, the higher the bulk density the higher the penetration resistance detected with penetrometer (Zhang et al, 2001).

### *3.13.2. Soil compaction.*

As farm tractors and field equipment become larger and heavier, there is a growing concern about soil compaction. Soil compaction can be associated with a majority of field operations that are often performed when soils are wet and more susceptible to compaction. Heavy equipment and tillage implements can cause damage to the soil structure.

Soil compaction occurs when soil particles are pressed together, reducing pore space between them. Heavily compacted soils contain few large pores and have a reduced rate of both water infiltration and drainage from the compacted layer. This occurs because large pores are the most effective in moving water through the soil when it is saturated. In addition, the exchange of gases slows down in compacted soils, causing an increase in the likelihood of aeration- related problems. Finally, while soil compaction increases soil strength- the ability of soil to resist being moved by an applied force a compacted soil also means that roots must exert greater force to penetrate the compacted layer.

Soil compaction changes pore space size, distribution, and soil strength. One way to quantify the change is by measuring the bulk density. As the pore space is decreased within a soil, the bulk density is increased. Soils with a higher percentage of clay and silt, which naturally have more pore space, have a lower bulk density than sandier soils.

Slightly compacted soil can speed up the rate of seed germination because it promotes good contact between the seed and soil. In addition, moderate compaction may reduce water loss from the soil due to evaporation and, therefore, prevent the soil around the growing seed from drying out. A moderate amount of compaction can increase root branching and secondary root formation, allowing roots to more thoroughly explore the soil for nutrients. This is especially important for plant uptake of non-mobile nutrients such as phosphorus.

Excessive soil compaction impedes root growth and therefore limits the amount of soil explored by roots. This in turn, can decrease the plants ability to take up nutrients and water. From the standpoint of crop production, the adverse effect of soil compaction on water flow and storage may be more serious than the direct effect of soil compaction on root growth (Gardner et al., 1999).

In dry years, soil compaction can lead to stunted, drought stressed plants due to decreased root growth. Without timely rains and well placed fertilizers, yield reductions will occur. Soil compaction in wet years decrease soil aeration. This results in increased denitrification. There can also be a soil compaction induced nitrogen and potassium deficiency. Plants need to spend energy to take up potassium. Reduced soil aeration affects root metabolism. There can also be increased risk of crop disease. All of these factors result in added stress to the crop and, ultimately, yield loss.

In a dry year, very low bulk densities, yields gradually increase with an increase in soil compaction. Soon, yields reach a maximum level at which soil compaction is also optimal for the specific sol, crop, and climatic conditions. However, as soil compaction continues to increase beyond optimum, yields begin to decline. With wet weather, yields are decreased with any increase in compaction.

There are several forces, natural and man induced, that compact a soil. This force can be great, such as from a tractor, combine or tillage implement, or it can come from something as small as a raindrop. The following include some of the types of soil compaction and their causes,

### Raindrop compaction

This is a natural cause of compaction, and can be seen as a soil crust (usually less than ½ inch thick at the soil surface) that may prevent seedling emergence. Rotary hoeing can often alleviate this problem.

### Tillage operations

Continuous mouldboard ploughing or disking at the same depth will cause serious tillage pans (compacted layers) just below the depth of tillage in some soils. This tillage pan is generally relatively thin (1-2 inches thick), may not have a significant effect on crop production, and can be alleviated by varying depth of tillage over time or by special tillage operations.

### Wheel traffic

This is without a doubt the major cause of compaction. With increasing farm size, the window of time in which to get these operations done in timely manner is often limited. The weight of tractors has increased from less than 3 tons in the 1940's to approximately 20 tons today for the big four-wheel-drive units. This is of special concern because spring planting is often done before the soil is dry enough to support the heavy planting equipment.

### Minimal crop rotation

The trend towards a limited crop rotation has had two effects, 1. Limiting different rooting systems and their beneficial effects on breaking subsoil compaction, and 2. Increased potential for compaction early in the cropping season, due to more tillage activity and field traffic.

When a soil is compacted aeration is reduced, normally due to the reduction in pore space. Soil compaction always reduces air filled porosity (non-capillary pore space) although not always water filled porosity according to Froehlich and McNabb (1983). Soil aeration is necessary for the development and functioning of the plants root system. It is also necessary for aerobic microbial activity that takes place in the soil. Reduction in soil aeration due to compaction can cause reduced root growth and microbial activity. This can lead to reduced site productivity in the compacted area.

Soil strength is defined by Beekman (1987) as the 'resistance of a soil structure to impact on forces which relates the forces on the soil to the reaction of the soil structure'. Compaction increases soil strength, which depends on a number of factors in the soil, these include,

- Cohesive forces
- Density of the soil
- Frictional strength
- Soil structure

Although the cohesive forces and the soil structure tend to breakdown when a soil is disturbed significantly, the overall soil strength increases. This is mainly due to the increase in bulk density.

Six physical properties have been chosen as yardsticks of compaction based on studies of urban soils. They provide both direct and indirect diagnostic clues to the degree of compaction and its effect on crop establishment and survival. Exceeding these thresholds could become limiting to growth according to Chi Yung Jim (1993). These properties include,

- Bulk density
- Soil penetration resistance
- Total porosity
- Aeration levels
- Infiltration capacity
- Shear strength

The overall consequences of soil compaction on soil structure have been comprehensively summarized by Chi Yung Jim (1993) as the,

- Breakdown of aggregates due to plastic or brittle deformation and the weakening of aggregate stability

- Coalescence of original aggregates and their fragments, with an increase in size of some fuse aggregates

- Collapse of some interpedal pores

- Decrease in total porosity

- Loss of pore continuity necessary for the conductance of air and water

- Alteration in the orientation of elongated pores in the forms of fissures parallel to the soil surface associated with platey structure, and the resulting decrease in pores in the vertical direction

- Decrease in air capacity porosity

- Increase in available water porosity with light compaction but decrease with extreme compaction

- Increase in bulk density

- Increase in shear strength

- Decrease in infiltration capacity

- Water perched on soil surface, poor drainage and water logging

- Decrease in saturated hydraulic conductivity, but increase in unsaturated hydraulic conductivity with increase in available water due to light compaction

- Increase in thermal conductivity and heat absorption

### *3.13.2.1. Factors affecting soil vulnerability to compaction.*

The relative vulnerability of soils to compaction can be influenced by a number of factors, including soil type, texture, soil moisture content and organic matter content according to Felt (1986).

Texture

Soil texture is defined by Brady (1974) as a physical property concerned with the proportions of various sized mineral particles in a given soil. Medium textured soils (loams and silt loams) appear to compact to greater densities than predominantly fine or coarse textured soils according to Swanston and Dryness (1973) and Froehlich (1976).

When soil is compacted the soil macro porosity is reduced according to Greacen and Sands (1980). Coarse textured soils protect the macro pores due to larger particles sizes. In fine textured soils the degree of compaction occurring depends on the relationship between water content and specific surface area of soil particles.

## Soil moisture content

Regardless of whether a soil is classified as moisture, sensitive or insensitive, substantial compaction from vehicles can occur at any moisture content. Soil moisture should not be the sole criterion determining where and when ground based operations should proceed advise Froehlich and McNabb (1984). However, water plays several important roles in the compaction process. At low suctions and high water contents, soils have low resistance to deformation and are prone to compaction numerous studies have shown that drainage of wet soils reduced compaction from traffic according to Greacen and Sands (1980). Films of water of increasing thickness around soil particles decrease the cohesion between adjacent particles and provide lubrication, thus permitting the particles facility to form a closer packing under pressure.

For a given compactive force, the density of a soil is found to increase progressively, with the water content of the soil up to a limit, and to decrease thereafter. If comparable samples are tested with different forces of compaction, the maximum density is found to increase and the optimum water content for compaction to decrease with increasing force suggests Felt (1986).

Soil moisture resulting in the greatest compaction is about midway between field capacity and the permanent wilting point as found by Swanston and Dyrness (1973).

### Organic matter

The susceptibility of a soil compaction may also largely depend on the organic matter content in the soil. There are frequent examples found by Larson and Allmaras (1970), where the addition of organic matter to soil has improved structure and reduced compaction as the soil will be more difficult to compact.
Organic matter has a high elasticity under compression forces and reduced soil compactability by increasing the resistance to deformation and/or increasing the rebound effects is advised by Wronski and Murphy (1994).

### *3.13.2.2. The impact of soil compaction on nutrient availability.*

Where soil compaction exists water penetration will be slow to occur in the soil profile, the soil may find it difficult to recharge and this can lead to problems in both dry and wet years. Wheel traffic has also been shown to reduce soil permeability by a thousand fold every time the field is trafficked. Where this occurs root growth is reduced and there is then very poor absorption of water and nutrients, the oxygen level in the soil is reduced, legumes do not produce nodules in the same way and the availability of nutrients can be dramatically reduced (Shotliff, 1990).

Work at Iowa State University showed that under soil compaction conditions 70% less potassium was available for the plant to take up, 30% less nitrogen, 20% less magnesium and 10% less calcium (Shotliff, 1990).

### *3.13.3. Soil crusting.*

A soil crust is a thin, dense, hard layer at the soil surface. Crusts are characterised by greater density and shear strength, but finer pores and lower saturated hydraulic conductivity, than the underlying soil (Shainberg, 1992). Soil crusts interfere with seedling emergence, hamper gas exchange, between soil and the atmosphere, reduce infiltration and encourage runoff and hence erosion. Because of their role in sealing the soil surface to water infiltration, crusts are often referred to as seals when wet but there is no clear morphological or developmental reason for distinguishing between crusts and seals (Gardner et al., 1999).

The prime cause of crusting is breakdown of soil structure at the soil surface due to water drop impact and soil wetting, and the consequent re-organization of the soil particles. Two main types of crusts are recognised, structural crusts, which develop in situ, and depositional crusts which are formed predominantly of material that has been transported from its original location.
Whether crusting occurs and the nature of the crust that develops is influenced by soil properties including particle size distribution and aggregate stability, the nature of the incoming rainfall or irrigation, antecedent moisture conditions and local topography both at the micro scale (e.g. ridge and furrow relief) and larger scale. All of these are influenced by tillage practice.

A crust may form in the course of a single rainfall event. The development process may continue during succeeding rainfall events, depending on rainfall character and the degree of drying which takes place in the intervening period. Prolonged drying may result in cracking of a crust and development of new aggregates. Repeated cycles of drying and wetting by gentle rain will encourage weakening of a crust and soil aggregation. The intensity of crust formation may be measured in terms of final infiltration rate, crust strength or thickness (Gardner et al.,1999).

### Rainfall characteristics

Crusting is initiated by aggregate breakdown and slaking as a result of raindrop impact and sudden wetting. The impact forces associated with rainfall depend upon the size distribution of the raindrops, their velocities and intensities. It is clear that both rates and intensity of crust formation, increase with increase in raindrop impact energy.

### Soil texture and aggregate stability

The relationship between soil texture and crusting arises firstly from the implications that textural characteristics influence aggregate stability, and secondly, the mobility of different particle size fractions when soil is dispersed. Crusts occur on most soils except coarse sands with very little silt and/or clay present. Soils with a high silt content are prone to crusting due to their susceptibility to dispersion. And, for the same reason, crusts are more likely to occur on sandy loams than clay loams.

### Antecedent soil water content

The water content of an aggregate influences its susceptibility to raindrop impact and slaking on wetting. Aggregates which are initially dry collapse mainly due to slaking when wetted. In contrast it is the mechanical impact of raindrops which is most important in the breakdown of aggregates with a high water content. Consequently, under wet conditions the degree of aggregate breakdown and crust development depends on rainfall energy and duration. In dry conditions, aggregate breakdown depends more on initial rainfall intensity.

### Slope and micro topography

Crusting is less likely on steeper slopes because rainfall intensity is reduced and the increased negative water potential is likely to remove disaggregated material, and may erode any crust that does develop. The micro topography of the soil surface due to the presence of large aggregates or clods after tillage, and/or ridging, may encourage depositional crust formation in micro topographic lows. Larger aggregates and clods are more resistant to breakdown under raindrop impact than smaller ones of the same soil, due to the increased negative water potential at the top of the clods and so greater cohesion. Also the sloping sides of clods and ridges are subject to reduced raindrop impact. Soil micro topography will decline and associated crusting will increase in the course of a rainfall and repeated rainfall events. Therefore the initial improvement of infiltration after tillage is likely to decline with time. Bielders et al., (1996) observed that on a course textured soil, crust distribution was related to the initial soil micro topography, resulting from cultivation, not the final topography.

The effects of soil crusting can be divided into those that directly influence plant growth, in particular seedling emergence, and those which have an indirect impact on crops through the change in infiltrability of the soil surface, and those such as erosion which have consequences for the cropped area generally, and areas further away (Gardner et al., 1999).

Crusts can prevent seedling emergence to the extent that a substantial amount of seed may be wasted and resowing may be necessary if production of a crop is to be worthwhile. This occurs because the mechanical strength of a crust maybe too great for seedling shoots to penetrate so that emergence is impossible. Until a seedling emerges and photosynthesis can commence, it is entirely dependent upon the reserves of the seed for growth. Thus there is only limited potential for the shoot to grow before emerging.

Seedling emergence in crusted conditions may be delayed due to the greater time required for shoots to penetrate the crust with possible consequences for subsequent crop development. In addition, the emergent seedlings are often smaller and weaker than those from comparable but uncrusted soil, this has consequences for crop development and yields (Sale and Harrison, 1964).

### *3.13.4. Soil strength*

Soil strength as measured by cone penetrometers depends on several parameters, but is mostly affected by soil water content and bulk density (Vaz et al, 2001).

Soil penetrometers are common measurement devices and are used in many fields because of their easy, rapid and economical operation. Although there may be a complex relationship between the soil resistance to penetration and other physical features of the soil, in most situations the penetration force versus depth of penetration is a useful measure of soil resistance in studies of soil compaction (Farrell and Greacen, 1966).

Soil penetrability is a measure of the ease with which an object can be pushed or driven into the soil. The resistance to penetration for the cone of a penetrometer is related to the pressure required to form a spherical cavity into the soil, large enough to accommodate the cone of the penetrometer, and allowing for the frictional resistance between the cone and it's surrounding soil. If the soil-cone friction is known, the point resistance of the cone may be computed from theoretical stress relations for the compression zone around the cone (Farrell and Graecen, 1966).

Soil resistance to penetration is measured in terms of the 'cone index' or force per unit area. The cone index is the force per unit of the base area of the cone required to push the probe through the soil at the uniform rate of 30 mm/s (Barone and Faugno, 1996). The unit of measure is typically PSI, although scientific reports use kilopascals. Penetration resistance can generally be divided into four categories, low (less than 150 PSI), medium (150-300 PSI), high (300-450 PSI), and heavy (450+ PSI). a measure of 725 PSI (5,000 kPa) is usually considered to be the maximum value that roots can penetrate. This depends on site conditions and crop type (Rooney et al., 2000).

Soil cone penetrometers are used to characterize soil strength for assessment of soil traffic ability, crop growing ability, resistance to root penetration, seedling emergency and soil compaction by machinery. Penetration resistance is influenced by soil and probe characteristics. The soil-to-probe friction is governed by probe factors such as cone angle, diameter, roughness, and rate of penetration. Soil factors influencing penetration resistance are matric potential (or water content), bulk density, soil compressibility, soil strength parameters, soil structure and others (Bradford, 1986). Although soil structure can be significant in specific conditions, in many situations it plays a minor role (Koolen and Kuipers, 1983).

Although there are many types of penetrometer, they fall into 2 categories, impact and electronic recording.

The impact type measures the resistance to penetration by determining the energy needed to drive the cone one inch into the soil (number of blows) according to Parker and Jenny (1945).

With the electronic recorder penetrometer, there is a pronounced effect of moisture content on penetrometer readings. It is a rapid increase in resistance with decreasing moisture, indicating that soil strength becomes greater as the particles are brought closer together during the drying process. While soil moisture appears to be the dominant factor influencing the penetrometer readings, there is no simple relationship between reading and the water content (Unger and Kaspar, 1994).

Among the soil characteristics that influence penetration resistance are texture, porosity, structure, water content, cementing agents, and compaction. Correlations between particle size and penetration resistance were presented by Kasim et al., (1986), where coarse textured soils showed greater penetration resistance when compared to fine textured soils. Water content is inversely related to penetration resistance. Faure and DeMata (1994) found that penetration resistance was very low, or close to zero, when water contents were very large, especially, when the soil was nearly saturated. For any soil at a given bulk density, penetration resistance decreased as water content increased. Penetration resistance is bound to increase with cementation due to the effect of cementing agents such as carbonate, silica, hydrous silicate, and hydrous iron oxide. Lowery and Schuler (1994) showed that penetration resistance and bulk density increased with increasing levels of compaction.

Miller and Sirois (1986) note that soil compaction does not seem to affect the nutrient content of the soil to a significant extent but the microbial immobilisation might be slowed down due to poor aeration. Poor aeration and mechanical resistance seem to be the main results of soil compaction according to Wasterlund (1985).
In addition, the displacement of the organic layers can lead to nutritional problems, particularly nitrogen loss in the wheel tracks according to Miller (1987).
Several studies describe the deleterious effect of compact soil horizons on crop root growth (Unger and Kaspar, 1994). Observations suggest that the root systems of several crops, are limited by compact soil layers (Lorenz and Maynard, 1988). The numerous tillage and residue management options in use today have

complex effects on soil properties. Tillage implements, vehicular traffic and residue cover all effect soil strength.

Tillage influences penetration resistance indirectly (Grunwald et al, 2001). Taboada et al. (1989) demonstrated that zero tillage increased penetration resistance significantly in a sandy loam from 0.8 to 5.0 Mpa and in a silty clay loam from 1.9 to 3.2 Mpa, which were attributed to soil hardening. Banada (1979) showed that penetration resistance was significantly higher for minimum ridge-tillage system compared to conventional tillage.

Fig. 7. Cone Penetrometer.

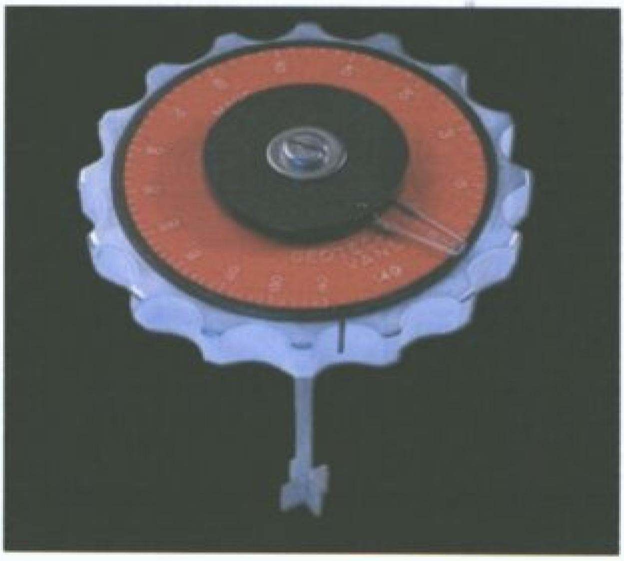
### *3.13.4.1. Shear strength*

Soil strength depends not only on soil and the measuring condition but also on the method of measurement itself (Bradford et al., 1992). The penetrometer is used to determine an overall soil strength within soil to a variable depth. The shear vane is used at the surface of soil to determine the parameters of soil shear strength. They are not comparable because the physical properties of the related soil volume or area are different, and the parameters derived from these methods have different physical meaning.

A shear vane estimates soil strength and mechanical characteristics. Shear strength is measured using an apparatus with winglets that are embedded at 4 and 12 cm into the soil. The torque (N- M/m$^2$) required to deform the soil was defined as the soils 'torque index'. This is not the true 'shear resistance' as defined by Bowles (1986), but some limitations of the Bowles method are accepted to allow rapid and inexpensive measurements. The applied torque provides only an approximate value for shear resistance.

Advantages of the shear vane include, the fact that it is cheap and easy to use and it is also reproducible at a range of small normal stresses simulating the situation during a rainfall.

Fig. 8. The Shear Vane.



### *3.13.5. Bulk density.*

Soil bulk density is most often used as an index of soil traffic ability and compaction. It is defined as the mass of dry soil per unit volume of solid, liquid, and gaseous phase, by Froehlich and McNabb (1984).

Bulk density varies with inherent soil properties such as soil texture and organic matter content but it is also dependent on stresses arising from management (for example tillage machinery and vehicular traffic) and other environmental factors (such as swelling, freezing, overburden, rainfall and plant roots) (Rawls, 1983; Larson et al., 1980). Consequently, measurements of bulk density are of limited value as measure of the effect of management on soil structure, when soils with different inherent characteristics are compared (Soane et al., 1981). However, since many soil processes are sensitive to changes in bulk density ways are being sought to quantify the separate effects of inherent soil properties, taking management and environmental factors into account or by normalizing the bulk density in some way to recover the influence of inherent soil characteristics.

Logsdon and Cambardella (2000) measured the temporal changes in bulk density in medium-textured soils, in mid-western America for 3 years following the introduction of conservation tillage and found no significant differences between the first and last sampling times in the conservation tillage soils. However, bulk density in the top 2cm varied from 0.91 to 1.20 Kg during the seven sampling periods, with the variation diminishing in the 2-4 cm depth (Kay and VandenBygaart, 2002).

Changes in bulk density following a more modest reduction in tillage such as that associated with chisel ploughing have been less dramatic. Bulk density was similar under conventional tillage and chisel plough to a depth of 40cm at the end of 20 years in a silt loam soil from Ontario (Yang and Kay, 2001a).

Most productive soils are characterised by relatively low bulk densities, ranging from about 0.5g/cm3 to 0.9g/cm3, and as a result have high micro porosity, high infiltration rates and low soil strength according to Froehlich (1976). Froehlich observed a 35% increase in bulk density on tractor trails after 6 trips with a tractor under wet conditions compared with an 18% increase under dry conditions.

## *3.14. TILLAGE EFFECTS ON SOIL PROPERTIES AND PROCESSES*

The major soil property that is normally affected by tillage is soil structure. This in turn influences water movement into (infiltration), out of (evaporation, drainage) or within (hydraulic conductivity) a soil. Therefore, tillage can control the water regime (water conservation) of the soil profile.

Tillage effect on soil structure also influences heat movement in soil. Consequently, it affects temperature regime and thus the rate of chemical reactions and biological activities.

Tillage effects on soil structure also affect soil aeration. By influencing structure, tillage affects the hydrological characteristics, particularly overland flow of water (runoff) and sediment transport (erosion). Through its effect on movement of water within the soil, soil structure also influences movement of agrochemicals, including chlorides, nitrates and pesticides, through the soil profile to contaminate groundwater (Gardner et al, 1999).

The presence of soil residues at the soil surface in different types of tillage systems has a tremendous effect on runoff and erosion. The residues also have an effect on soil temperature, soil reactions, nutrient distribution and availability, population and activities of soil fauna and therefore, on soil organic matter content. Conventional tillage increases the rate of organic matter decomposition while soils that have been under conservation tillage for several consecutive years have a higher organic carbon content, with a build up occurring mostly in the surface 0-10 cm layer (Blevins et al, 1985; Unger 1991). Other changes that occur in the chemical properties of soil under conservation tillage include lower pH and exchangeable calcium and magnesium, higher levels of exchangeable aluminium and manganese, lower nitrate concentration and higher levels of available phosphorus and potassium (Blevins et al, 1985).

A number of changes in soil microbial population and activities occur when an undisturbed soil is tilled. The changes are due largely to the effect tillage has on temperature, water, and organic matter content of soils. Different tillage systems have different effects on these factors because of the varying degrees of reduction of surface residues and the resultant reduction of the mulch effect of the residues left after tillage. Ploughing also pulverizes soil aggregates and disrupts the continuity of soil pores. Soil conditions after tillage may favour soil micro-organisms with short life cycles, have rapid dispersal, high metabolic activity, and an unspecialised food and habitat requirement. As a result, there will be changes in microbial species composition, which may alter the nutrient cycling dynamics. Alternatively, by enhancing conditions of the habitat and/or resource availability, tillage and other soil management practices may increase the abundance and diversity of soil organisms. Thus, ploughing may loosen compacted soils to improve soil aeration, while irrigation and drainage may optimise soil water content for microbial growth and activities (Gardner et al, 1999).

### *3.14.1. Conservation tillage induced changes on soil properties.*

Reducing tillage affects several aspects of the soil. With time, conservation tillage improves soil quality indices (Dick, 1983; Lal et al., 1998), including soil organic carbon storage (Unger, 1991; Edwards et al., 1992; Potter et al., 1998). Several factors probably contribute to the rate of soil improvement when tillage is reduced. Clay content, cropping history and soil fertility, and crop diversity influence the changes in soil properties (Rhoton, 2000; Martens, 2001; Bruce et al., 1990).

Conversely, increased losses of soil organic carbon have been documented where conventional tillage was employed (Lamb et al., 1985; Studdert et al., 1997). During the first 4 years of tillage, losses of soil organic matter caused by tillage have been estimated to be between 16 and 77% (Mann, 1986).

Another mechanism by which soil organic matter is retained in conservation tillage systems may be due to reduced oxygen availability below the surface of no-till systems, which affects decomposition rates and the distribution of aerobic and anaerobic microbes and microbial processes (Wershaw, 1993; Doran, 1980). Slower subsurface decomposition rates would lower oxidative losses of organic carbon. Residues left on the surface often undergo wider fluctuations in moisture content, ranging from wet to dry, and theses extremes are a clear contrast to the environmental conditions of buried residues (Franzluebbers et al, 1994; Schomberg et al., 1994). Buried residues decompose at 3.4 times the rate of residues left on the soil surface (Beare et al., 1993). This suggests that reduced oxygen availability may not decrease decomposition rate as much as greater soil-residue contact and improved moisture conditions accelerate it. Reduced residue-soil contact and extreme variation in moisture and temperature at the soil surface undoubtedly play significant roles in reducing surface residue decomposition rates. However, surface (0-30cm) soil itself in a no-till system was shown to contain more moisture and to be cooler than a comparable plough-tillage soil (Doran et al., 1998).

In addition to increases in soil organic matter concentration changes attributed to a reduction in tillage intensity have also been demonstrated for soil microbes and microbial activity, and for soil physical properties, including soil structure (Linn and Doran, 1984; Martens, 2001). The biological component of soil can be a good integrator of factors that affect soil quality. Microbial biomass is the smallest portion of organic carbon in soil (Martens,

2001). Microbial biomass is more sensitive to changes in soil conditions than is the component of total carbon, and it has been proposed that the ratio of microbial carbon to total carbon in the soil (Cmic:Corg) may be a sensitive index of changes in soil organic matter dynamics (Sparling, 1992; Wardle, 1992).
Tillage greatly affects the size of soil microbial biomass (Martens, 2001). Microbial biomass was found to range from 1.2 to 1.4% of the organic carbon with plough tillage and from 3.5 to 5.1% for no-tillage (Angers et al., 1993). Tillage also affects the distribution of soil microbial biomass, being displaced toward the soil surface with no-tillage, and toward lower depths with plough tillage after 4 years (Carter and Rennie, 1982). Specific microbial population distribution may also be affected by tillage (Doran, 1980). Holland and Coleman (1987) reported an increase in the fungal to bacterial ratio with no-tillage, which may have implications for carbon and nitrogen cycling in the soil.

Stratification of soil properties is a natural consequence of soil development that can become accentuated in soils subject to reduced tillage. Unger (1991) and Bruce et al. (1995) reported that soil nutrients become stratified when no-till management is employed. There is a marked stratification of soil organic matter with soil depth under no-tillage (Blevins et al., 1984). Havlin et al. (1990) determined that reducing tillage and maintaining surface residues in a long-term study increased soil organic carbon and nitrogen in the surface 2.5cm of soil. When crop Stover was returned to the soil, Clapp et al., (2000) reported a 14% increase in soil organic carbon in the top 15cm, but soil organic carbon content decreased in the 15-30cm depth. Similar apparent re-distribution of soil carbon generated by conservation tillage was offset by decreases in subsurface organic carbon content, has been documented (Ellert and Bettany, 1995). Soil specific responses to tillage induced carbon storage were reported by Wander et al. (1998) in which carbon accretion was not apparent in all soils in that trial. Ploughing was shown to move dispersed organic carbon from the 0-20 cm soil depth down to the 60-80cm depth in corn plots (Romkens et al., 1999).

When crop residues are returned to the soil, an increase in phosphorus availability may occur by decreasing the adsorption of phosphorus to mineral surfaces (Ohno and Erich, 1997).

### *3.14.2. Effects of Tillage on Soil Water*

Loss of water by evaporation from the soil surface can be reduced through the use of mulches or by tillage. The effect of tillage is variable. The aim is to achieve a coarser layer with large pores at the top of the soil profile. Generally the soil has already lost a substantial amount of water before its condition is suitable for tilling. The loosening and opening up of the surface layer will expose damp soil and so tend to speed its drying initially but may reduce upward water movement from lower layers. Thus tillage may have little effect on water loss from bare soil. It is most likely to be beneficial in the case of clay soils, which shrink and crack appreciably on drying. Soil water loss also occurs via the cracks in such soils and can result in very dry hard soil. Tillage of the surface before drying can prevent serious cracking by reducing the amount of drying. Tillage can also be useful if it removes weeds and so cuts water wastage by weed transpiration.

Reduced tillage can have a much larger effect on how water moves through the soil than it does on the total amount percolating to groundwater. Soil macro porosity and the proportion of rainfall moving through preferential flow paths often increase with the adoption of reduced tillage and can contribute to a reduction in surface runoff. In some medium and fine textured soils most of the water that moves to the subsoil during the growing season (May to October) is probably transmitted by macro pores. If a heavy, intense storm occurs shortly after surface application of an agricultural chemical to soils with well-developed macro porosity, the water transmitted to the subsoil by the macro pores may contain significant amounts of applied chemical, up to a few per cent, regardless of the affinity of the chemical for the soil. This amount can be reduced by an order of magnitude or more with the passage of time or if light rainstorms precede the first major leaching event. Because of movement into the soil matrix and sorption, solutes normally strongly adsorbed by the soil should only be subject to leaching in macro pores in the first few rainstorms after application. Even under extreme conditions, it is unlikely that the amount of additional adsorbed solute transported to groundwater will exceed a few per cent of the application when reduced tillage is used instead of conventional tillage. In the case of non-adsorbed solutes, such as nitrate, movement into the soil matrix will not preclude further leaching. Therefore, when recharge occurs during the dormant season thorough flushing of the soil, whether macro pores are present or not, can move the remaining solutes to groundwater. Thus, the net effect of tillage treatment on leaching of non-adsorbed solutes should be minimal (Shipitalo et al., 1999).

### *3.14.3. Tillage effects on crop yield.*

A number of factors (e.g. weather, incidence of pests and diseases, and drainage) regulate crop growth and yield response. As a result, tillage may have a positive, negative or no effect on crop yield. Under conditions of favourable precipitation, adequate soil water, good drainage and adequate available nitrogen, grain yield is not greatly affected by the type of tillage (Al-Darby and Lowery, 1986; Locke and Hons, 1988).

Alternatively, increased grain yields in conservation tillage systems, particularly no-till, compared with conventional tillage, have been reported from areas having limited precipitation and soil water (e.g. Musick et al., 1977; Unger and Wiese, 1979; Jones, 1981; Baumhardt et al, 1985).

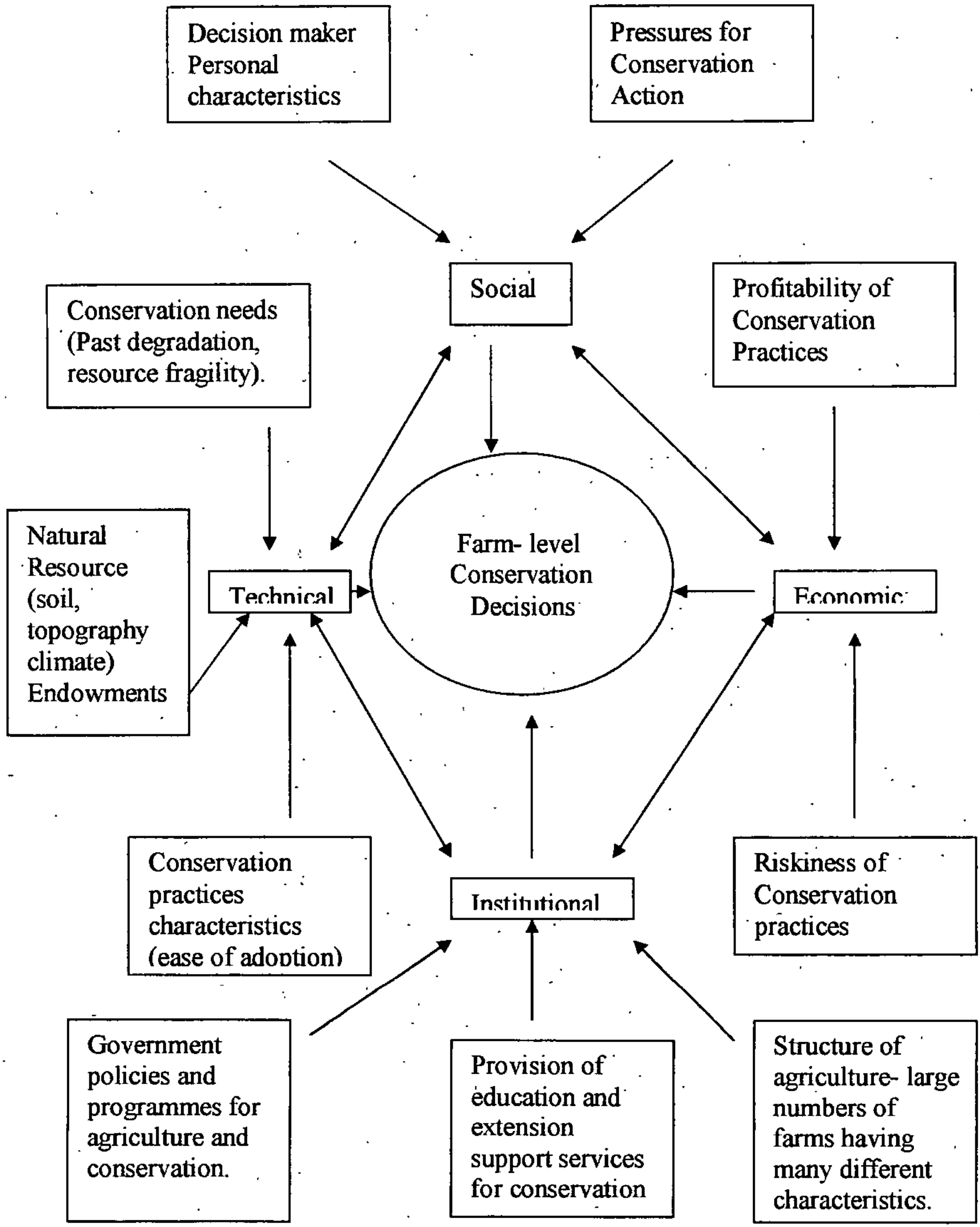
## *3.15. VIABILITY OF REDUCED TILLAGE*

From the vantage point of an individual farmer, the business of producing food must be profitable, as well as sustainable and socially acceptable to one's peers and the general public. Given that a majority of farmers are strongly motivated by profit business operational and investment behaviour becomes closely linked with demonstrated profitability (Duff et al., 1991). Unfortunately, farmers are not motivated on economic grounds to invest in and use on a broad basis most of our presently available conservation practices, because of demonstrated lack of profitability. This is particularly true during years of high inflation and interest rates, as in the 1970s and 1980s, because of the slow and delayed nature of any economic benefits received by farmers from conservation practice investments (Stonehouse et al., 1987). Even where conservation practices may be profitable, as in the case of conservation tillage, investment decision outcomes are not always unequivocally profitable but instead depend on a variety of factors such as soil type, topography, geographic latitude, crops being grown and their sequence, and farmer managerial skills and abilities (Crosson et al., 1986).

The ambiguity of economic outcomes for conservation versus conventional tillage systems in Northern America is confirmed by the most recent research (Zentner et al., 1996). While most conservation tillage alternatives such as no tillage, ridge tillage and direct drill (as defined in Stonehouse, 1991) conserve labour, fuel and machinery outlays, as well as soil, compared with conventional tillage, some may require increased expenditures on seed, fertiliser or herbicides. Where the level of net cost savings is not sufficient to compensate for the value of any yield penalties associated with conservation tillage, farmers will be induced to use conventional tillage, at least in the short term. If in the longer term continued use of conventional tillage causes sufficient soil degradation to reduce soil productivity to the level at which economic outcomes are equivalent between conventional and conservation tillage, then some conservation tillage systems will presumably be preferred (Stonehouse, 1997).

There appear to be four major groups of factors impinging upon farm level conservation decisions; (a) social factors include the philosophy, attitude, orientation, motivation and other personal characteristics of the farmer, as well as influences of the general public, farm organizations, neighbouring farmers, and others; (b) economic factors centre upon the profitability or otherwise and riskiness attached to conservation practices; (c) institutional factors include agricultural policies and programmes and whether these conflict with conservation policies, provision of education and farm extension services for conservation practices, and the large number and wide range of characteristics of farms comprising the agricultural industry; and (d) technical factors encompass the needs for conservation based on past damages or apparent fragility of the natural resource base, local climatic characteristics, and the inherent features of conservation practices such as whether they are difficult to adopt and adapt to local farm conditions, their durability and ease of maintenance. The complex of technical, social, economic and institutional factors influencing farmers' conservation decisions is summarised diagrammatically (Stonehouse, 1997).

Fig. 7. Overview of factors affecting adoption and use of soil conservation practices (Stonehouse, 1997).



## *3.16. CROP PERFORMANCE TO DATE*

The performance of crops, established with conventional and reduced cultivation systems, was recorded in 2001 (by Teagasc, at Oak Park). A fully replicated trial was used with winter wheat. Both conventional and reduced cultivation crops were established in very poor conditions in early October 2000.

Following the wet autumn and winter there were big differences in crop appearance in the spring, with the reduced cultivation systems having much lower and more variable plant populations. However, the wheat crop compensated with extensive tillering and good grain development giving good crop yields at harvest and no significant differences between the establishment systems.

There were fewer ears on the wheat in the reduced cultivation plots, however, their ears were larger and 1000-grain weights slightly higher giving almost equal yields.

Last year 2001-2002 average yields were slightly higher on the reduced cultivation plots but the difference was not statistically significant. Reduced cultivation produced more grains per ear and higher 1000-grain weights.

Table no.5. Plant establishment and components of yield- Winter wheat, Knockbeg, 2001 -2002

| | Plant est. (/m2) C.1 | Plant est. (/m2) C.2 | Ear no's (/m2) | Grains/ear | 1000-grain weight (g) |
|---|---|---|---|---|---|
| Plough – Straw | 212 | 166 | 592 | 48 | 46.9 |
| Plough + Straw | 219 | 171 | 550 | 50 | 47 |
| Reduced + Straw | 158 | 123 | 548 | 53 | 51.7 |
| Reduced - Straw | 169 | 124 | 480 | 55 | 50.3 |
| s.e.d | 11.5 | 8.3 | 16.5 | 2 | 1.6 |

Table no.6.

Grain yield and quality – Winter wheat, Knockbeg 2001-2002

| | Grain yield @15% m.c. (t/ha) | 1000-grain weight (g) | Hecto litre weight (kg/hl) | Screenings |
|---|---|---|---|---|
| Plough - straw | 9.7 | 46.9 | 77.6 | 1.1 |
| Plough + straw | 9.8 | 47 | 77.9 | 1 |
| Reduced - straw | 10.6 | 51.7 | 76.8 | 0.8 |
| Reduced + straw | 10.2 | 50.3 | 77.2 | 1.1 |
| s.e.d | 0.61 | 1.6 | 0.71 | 0.09 |

## *3.17. Rainfall*

Met Eireann provided rainfall measurements for the duration of this project. Through their studies they determined that rainfall levels in 2001 were generally average, with high levels recorded in October and November.

However, rainfall amounts in 2002 were above normal throughout Ireland, and set new records in Leinster and Munster. Particularly heavy falls occurred during the months of February, May, October, and November.

The east, north and northwest of the country experienced heavy rainfall in mid May. Falls of more than 25mm were recorded on the 17th as a band of thunderstorms merged over much of Leinster and Ulster, and daily totals exceeded 50mm in some places.

Both October and November were among the wettest months on record in the south and east. A band of heavy rain brought falls over 25mm to many southern counties on the 25th October. At Rosslare, the rain commenced in the early afternoon and by midnight measured 80mm, over half of which fell in a 2 hour period. This represented the highest midnight-to-midnight fall at Rosslare since the station opened in 1956.

On the 13th of November an area of heavy rain moved into eastern regions, associated with a deep depression of 966 hPa, which became slow moving over the Irish sea. Rain continued for over 30 hours in the Dublin area and caused severe flooding along the valley of the river Tolka. These storm conditions did not continue with the same verosity in December, although 97mm of rainfall was recorded.

During the first four months of 2003, rainfall levels were lower than had been recorded in the previous year in the Dublin area.

Table no.7 Average Rainfall (mm) at Dublin airport throughout the duration of the project.

| ***Year*** | ***Month*** | ***Rainfall (mm)*** |
|---|---|---|
| 2001 | September | 41.7 |
| 2001 | October | 90.3 |
| 2001 | November | 80.6 |
| 2001 | December | 21.7 |
| 2002 | January | 48.4 |
| 2002 | February | 125.9 |
| 2002 | March | 30.3 |
| 2002 | April | 81.7 |
| 2002 | May | 121.3 |
| 2002 | June | 81.2 |
| 2002 | July | 68.9 |
| 2002 | August | 50.8 |
| 2002 | September | 22.6 |
| 2002 | October | 181.2 |
| 2002 | November | 185.8 |
| 2002 | December | 97.3 |
| 2003 | January | 62.8 |
| 2003 | February | 20.9 |
| 2003 | March | 27.1 |
| 2003 | April | 10.0 |

# *4.0. MATERIALS & METHODS*

## *4.0. EXPERIMENTAL DESIGN*

This long-term experiment, which was commenced in September 2001, compared the effects on the physical, chemical and microbiological status of the soil from conventional and reduced cultivation methods. To eliminate the effects of seasonal factors on crop rotations, all crops were sown and harvested each year in September.

Table.8. Treatment types.

| Plot I.D. | Treatment/ Cultivation type |
|---|---|
| Plot A | Conventional tillage with no straw incorporated. |
| Plot B | Conventional tillage with straw incorporated. |
| Plot C | Reduced tillage with no straw incorporated. |
| Plot D | Reduced tillage with straw incorporated. |

This experiment was located on the Knock beg farm in the Wood Field No.2, which consists of draining grey-brown podzolic soil derived from limestone boulder clay. The A horizon, which has a weak structure, overlies a heavy textured well structured textural B horizon (40-45% clay and 35% silt). The soil has a high moisture capacity. Although soil moisture is deficient, crops seldom show any drought symptoms.

Plot size (30 m x 24 m) was large by experimental standards, to aid mechanisation of crop treatments and to eliminate the possible disadvantages associated with small plots. The experiment, is of necessity long term, because more than one growth cycle is essential to fully assess the impact of crop rotations. Each year the impact of the conventional and reduced systems on soil parameters are assessed.

### *4.0.1. Block Layout*

Each of the four cultivation methods, were replicated four times in these trials (this was carried out to ensure validity of results). Therefore, there were sixteen plots in total.

For both practical and commercial reasons it was not possible to separate cultivation methods completely. This restriction, meant that treatments, which had incorporated and removed straw for each of the cultivation methods, were positioned together.

### *4.0.2. Reduced Tillage Procedure*

Reduced tillage was carried out by Teagasc at their Knock beg road site. This involved the ground being cultivated with a tine cultivator (1-2 passes) to a depth of 5 -10 cm. This was then left a day or two before sowing, when germinated weeds were sprayed with gylphosphate herbicide (Sting CT). Sowing was carried out with a cultivator drill.

The tine cultivator used, was a Horsch stubble cultivator. This creates precise and shallow stubble cultivation at depths between 5 – 15 cm. The aim is a shallow and level cultivation, moving all of the soil in the width of the machine, to maintain the capillary layers in which the water can find the fastest route to the seed. The tine is arranged in 4 rows so that the straw remains at the surface to avoid erosion and capping. It is designed to turn soil away to the side, so that the majority of crop residue can be mixed in with the soil.

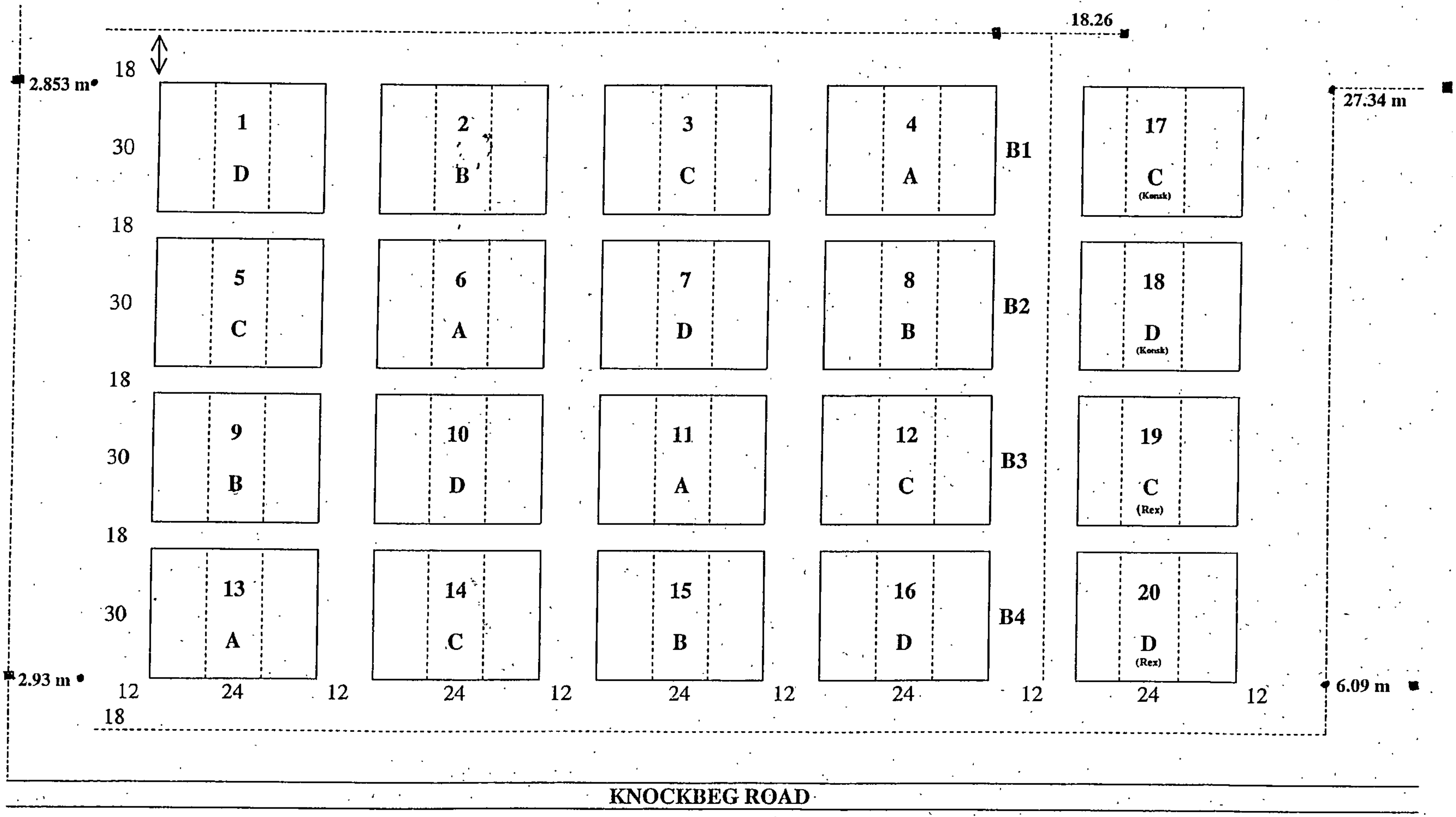
Sowing was carried out using a Vaderstad drill. This drill is equipped with an exact and easily adjustable depth control (information can be obtained on the seed placement centimetre by centimetre).

### *4.0.3. Conventional tillage procedure.*

Conventional tillage was carried out in association with reduced tillage at Knockbeg. This system ploughed the soil at the end of September to a depth of 20-25cm, after which it was furrow pressed. Within days these plots were cultivated for a second time with a power harrow 'the Lely Roterra', to a depth of 10-12cm. They were then rolled and sown with a Vaderstad drill. Both the reduced and the conventional tillage systems used this drill type.

## Cultivation Systems Experiment – Knockbeg

Treatments:
A. Plough + Power harrow + Drill (Straw removed)
B. Plough + Power harrow + Drill (Straw incorporated)
C. Tine cultivator + Press + Drill (Straw removed)
D. Tine cultivator + Press + Drill (Straw incorporated)



## *4.1. SOIL SAMPLING*

Sampling was carried out on a monthly basis from September of 2001 until April of 2003. Throughout this period there were five occasions when sampling was not possible, this was due to wet conditions, which meant the plots were water logged.

Each month samples were collected from 8 of the 16 plots (therefore 2 of each cultivation method were sampled on a monthly basis). In each treatment, 3 core samples were obtained down to a depth of 30cm. These samples were then divided into 3 separate sections based on sample depth, these were 0-10, 10-20 and 20-30cm. Composite samples were compiled by combining each of the same sample depths (i.e. the 3, 0-10cm sample depths within plots were combined). Between each soil sample collected, the corer was cleaned with 95% ethanol to ensure no cross contamination of soil for microbial analysis. Samples were then placed into sterile resealable bags.

To ensure that all plots were sampled consistently, a system of sample collection was determined. This involved measuring a distance of 12 meters across the top left hand corner of each treatment. From this point the measuring tape was then laid 12 meters into the centre of each plot. This marked the first point of sample collection (on a monthly basis this point varied slightly between 10 and 20cm). The two remaining sample points were obtained at 4 meter intervals from the first sample point.

Plate. 4. Plot Layout.

## 4.2. *SAMPLE PREPARATION*

### *4.2.1 Microbiological, Nitrate and Moisture Content Analysis.*

On return to the laboratory, several parameters required immediate analysis to ensure that no transformations or alterations occurred in their concentrations, as this would bias results. These parameters include total aerobic bacteria, nitrates and percentage moisture content. To carry out these three sets of analysis no preparative work was required to the samples. Samples were removed aseptically from the sterile bags and transferred to the appropriate solutions and containers.

### *4.2.2. Sample preparation for Chemical analysis.*

With the exception of the previously mentioned parameters, all other analysis required samples, which were subject to treatment. This preparation involved air drying samples in aluminium trays in a dust free environment for several days. After this they were ground by use of a pestle and mortar, before being passed through a 2 mm aperture sieve. Samples were then placed into sterile resealable bags until they were required for analysis.

## 4.3. CHEMICAL PARAMETERS

### 4.3.1. Organic Carbon

The organic carbon content of soil was determined using the rapid dichromate oxidation technique (Nelson and Sommers, 1982). In this method a known amount of air-dried soil, not exceeding 0.3g was transferred to a 500ml wide-mouth Erlenmeyer flask. To this 10mls of 1N potassium dichromate was added. This was then swirled gently to disperse the soil in solution, and 20mls of concentrated sulphuric acid was added. The contents were swirled immediately, gently at first, and then more vigorously for 1 minute. The flask was then allowed to stand on a sheet of aluminium foil for 30 minutes in a fume hood, after which 200mls of distilled water was added and mixed thoroughly. 10mls of concentrated phosphoric acid was then also added in order to sharpen the end-point.

1ml of diphenylamine indicator (0.5g of diphenylamine in a mixture of 100mls of concentrated sulphuric acid and 20mls of distilled water) was added and the contents of the flask were titrated with 0.2N ferrous ammonium sulphate until a colour change from black to green occurred. At this point a further 0.5mls of potassium dichromate were added to the solution, before continuing with the titration. The end-point was reached when the solution turned a blue/purple colour.

The amount of organic carbon expressed as a percentage of soil is determined as follows;

$$\%\ \text{Organic carbon} = \frac{(V1 - V2/5) \times 0.003 \times 100}{W}$$

V1 = Volume of 1N potassium dichromate
V2 = Volume of 0.2N ferrous ammonium sulphate
W = Weight of air dried soil.

### *4.3.2. Organic Matter*

The organic matter content of the soil can be indirectly estimated through multiplication of the organic carbon concentration, by the ratio of organic matter to organic carbon commonly found in soils. This estimation of organic matter content from organic carbon concentrations is not highly accurate, because the ratio of organic matter to organic carbon is variable from soil to soil and with depth in the profile. Accurate organic matter content estimates are determined by loss of weight on ignition. This gives a quantitative oxidation of organic matter. A disadvantage of this method is the possible decomposition of carbonate minerals, thus resulting in weight losses in excess of the actual organic content.

The organic matter content of the soil in this study was determined using the method reported by Nelson and Sommers (1982), which involves the destruction of organic matter at high temperatures. Approximately 10g (recorded to 4 decimal places) of < 2mm air dried sample was placed in a pre-weighed conditioned porcelain crucible (conditioned at 550 °C for 6 hours and then cooled in desiccators). The sample was then ignited in a muffle furnace at 550 °C for 6 hours, after which the crucible was placed in a desiccator to cool and then reweighed. From the loss in weight the percentage organic matter can be calculated, using the following formula,

$$\% \text{ Organic Matter} = \frac{A - B}{W} \times \frac{100}{1}$$

A = Weight of crucible and soil before ignition (grams)
B = Weight of crucible and soil after ignition (grams)
W = Weight of air dried soil (grams)

### *4.3.3. Soil pH*

Soil pH levels were recorded on samples at a soil to water ratio of 1:2 w/w using a method similar to Peech (1965). Approximately 10g of sieved, air-dried soil were placed in a beaker to which 20 ml of distilled water was then added. The contents were stirred vigorously on a mechanical shaker and then let stand for 30 minutes. Using a calibrated pH meter (Orion Model 210A), the electrodes were placed in the soil slurry, and swirled carefully at a constant rate while the pH reading was taken.

The ph meter was calibrated by use of pH buffers 4, 7 and 10.

### *4.3.4. Nitrate Analysis*

The determination of nitrates in soil was carried out by use of an ion selective electrode, Orion model 210A.

Analysis for nitrate nitrogen was carried out as soon as possible on return to the laboratory, to ensure there were no losses of nitrate through naturally occurring transformations. All glassware was acid washed with 5% hydrochloric acid and rinsed with distilled water before use.

5g of soil weighed to 4 decimal places (not air dried) were placed into 100 ml Erlenmeyer flasks, to this 20 ml of 0.02N copper sulphate was added. Para film was placed over the mouth of the flasks and the solutions were mechanically mixed for 1 hour, after which the solutions were filtered using 0.45um filter papers.

The ion selective electrode was calibrated, its slope determined

(-55 and -60 Mv) and a range of standards were analysed, noting their electrode potential. From this the concentration of nitrate, present in the soil samples, was determined.

### *4.3.5. Available Phosphorus*

There are more then ten different procedures used for estimating available soil phosphorus in the EU (Tunney et al., 1997). In Ireland, the Morgan Test has been used for almost 50 years. A study carried out by Teagasc on soil phosphorus tests determined that the Morgan test best estimated the availability of soil phosphorus to crops, when compared to Olsen and Calcium chloride tests. As this project was carried out in association with Teagasc, the method recommended by there research was used to determine the concentration of available phosphorus in the treatments.

The available phosphorus content of soils was determined by using Morgan's extracting reagent (which is composed of 493 ml of 40% sodium hydroxide, 481 ml of glacial acetic acid and 4 L of distilled water, and is designed to dissolve an amount of phosphorus related to the fraction available to plants) (Byrne, 1979). All glassware was acid washed with 5% hydrochloric acid and rinsed with distilled water prior to analysis.

6g of air-dried soil (<2mm) weighed to 4 decimal places, were placed into a 250ml Erlenmeyer flask. To this 30 ml of Morgan's extracting reagent was added. This flask was then transferred to a mechanical shaker for 30 minutes, after which the solution was passed through a 0.45um membrane filter.

3 mls of the filtrate were then placed into a 100ml glass beaker, to which 6mls of the 'Ag reagent' (which is composed of 290.6mls of distilled water, 3.5mls of ammonium molybdate, 31.5 mls of 18% hydrochloric acid, 10.6mls of ascorbic acid and 7.9mls of sodium

antimony tartrate) were added. This solution was then covered with Para film and mixed thoroughly.

The solution was then allowed to stand for 10 minutes, to allow a colour change to develop (from clear to blue). A characteristic blue colour is developed, when either molybdate or its hetropoly complexes are partially reduced. After which samples were placed in 5cm quartz cuvettes and analysed using an Ultra Violet Visible (UV-Vis) Spectrophotometer, which was set at a wavelength of 880 nanometres. The absorbance reading determined correlated to the level of available phosphorus present.

A calibration curve was plotted of Absorbance readings Versus Phosphorus concentration and the concentration of the samples was extrapolated from this (phosphorus concentration was determined from a range of standards).

Results are expressed in mg/l available phosphorus.

### *4.3.6. Exchangeable Potassium*

The analysis for exchangeable potassium was carried out as a follow on to the analysis for available phosphorus, in that the sample preparation was the same (6g of sample in 30ml of Morgan's extracting reagent, which was mechanically shaken for 30 minutes and filtered using 0.45 um filter papers). To determine the concentration of exchangeable potassium in this filtrate, analysis was carried out using a Corning 400 flame photometer (Knudsen and Peterson, 1982).

The flame photometer was calibrated using a range of standards from 0 to 20mg/l potassium, noting their emission readings. The emission readings of each soil sample was then determined off the flame photometer, and a calibration curve of emission readings versus potassium was plotted to determine the concentration of exchangeable potassium in the soil samples. Results are expressed in mg/l.

The acid content of the Morgans solution is necessary to decompose any organic matter in the sample and free the potassium elements into the solution, thus preventing any interference in flame emission.

### *4.3.7. Moisture Content Analysis*

The moisture content analysis of soil samples was carried out on return to the laboratory. Evaporating dishes were pre conditioned by placing them in an oven set at 105°C for 24 hours before being removed to a desiccator, and allowed to cool for 24 hours. The weight of each crucible was then recorded.

10g of soil weighed to 4 decimal places were transferred into each evaporating dish and dried in an oven at 105°C for 24 hours, after which time they were removed, and placed into desiccators to cool (for 24 hours). When cool the weight of each crucible was recorded.

$$\% \text{ Moisture Content} = \frac{W2}{W1} \times \frac{100}{1}$$

W1 = Original weight of sample

W2 = Weight loss of the sample

## *4.4. PHYSICAL ANALYSIS*

### *4.4.1. Cone Penetration Resistance*

These measurements were taken with a soil 'Bush' cone penetrometer. This measures the resistant force in 'kilograms' of force (kgF) on the cone, as it was pushed through the soil at 15 mm intervals. This allows the calibration of the instrument with kilogram weights as described by Anderson et al (1980). Each kilogram of force unit is equivalent to 100 Kilo Pascals (Larney et al., 1986). The first 15 readings were recorded as a set. Five sets were then averaged to give one representative sample result. Two sample results were taken on each trial plot. The soil litter layer is included in the sample set.

The penetrometer has a cone of 12.83 cm in diameter, which over time can be worn down; therefore prior to analysis the diameter of the cone was checked. The instrument was then balanced to ensure accurate readings.

Using the handles on the cone penetrometer the operator pushes down the main shaft through the soil profile at a constant rate of approximately 3 cm per second. Every 15 mm the logger records the resistance against the cone in kg of force. The logger stored the set of readings, which were written down by the operator before commencing the next measurement. The penetrometer had a maximum reading of 70 Kg F, which was signalled by a bleep to prevent over loading of the instrument.

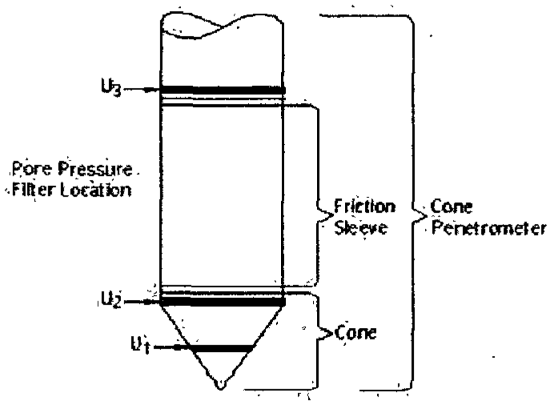
When stones, roots or other obstructions were met, the instrument overloaded and bleeped. This was the warning that the last reading recorded may not be acceptable. The reading was then abandoned and another measurement taken.

The cone penetrometer is based on two strain-gauged force transducers, which are employed to measure the amount of friction between the penetrometer shaft and the soil. The cone tip is connected with a stem, which is inserted in the lower end of the shaft. The penetrometer force acting on the conical tip through the pin, loads the lower strain gauged transducer, which measures the total penetration force acting on the probe. A third transducer measures the depth. Both the output signals of force transducers and the signal of the depth transducer are recorded by a data acquisition system (Barone and Faugno, 1996).

The readings taken are a profile of the soil resistance including that of any litter leaf layer that may exist on the soil surface and the influence of the root mat layer. This often results in high resistance in the upper centimetres of the profile.

Cone penetration resistance is the only parameter to include the upper leaf litter layer in terms of the quantifiable values, as the litter and root mat were by-passed or removed, in the taking of measurements for other parameters.

Fig. 11. Cone penetrometer tip.



### *4.4.2. Shear Strength*

The shear vane instrument was used to measure soil strength at small normal stresses in the soil. It simulates the interlocking forces between soil aggregates or particles and the water film with suspension of particles. It is primarily intended for use in trenches and excavations, at a depth not influenced by drying and excavation procedure.

The range of the instrument is from zero to 26 tonnes / meter$^2$ when 3 different sizes of vanes are used. The accuracy of the instrument should be within 10% of the reading. The calibration certificate supplied states that the calibration tolerance is +/-7%. The measuring part of the instrument is a spiral spring and the maximum torque transmitted is 30 kg/cm.

Before use it is important to ensure that the vane head and the vane blade are both clean and dry, and that the pointer is free to move and does not stick at any position on the head. The shear vane was then pushed perpendicular to the soil surface to a depth of 4 cm. This was sufficient to ensure that shearing did not take place on the vertical edges of the vane blade without the movement of the undisturbed soil surface. The vane pointer was located at the starting position of zero, and the vane head was rotated at a uniform rate of one revolution per minute. When the soil was sheared, the force of the torsion device was released and the pointer registered the maximum deflection to which the spring was subjected. The size of this displacement depends on the torque, which is necessary to turn the vane in the soil. When the soil shears, the sliding ring remains at the maximum point of spring deformation giving the reading in Kpa.

Three sizes of vane are used, 16 x 32 mm (extra), and readings are multiplied by 2, the standard blade of 20 x 40 mm, which gives direct readings and the 25.4 x 50.8 mm which also requires the multiplication of results by 0.5. This makes it possible to measure shear strength of zero to 26 T/m$^2$ (zero to 13 and zero to 6.5 T/m$^2$ respectively. This allows for measurements in varying soil conditions and soil types.

### *4.4.3. Bulk Density*

Samples were taken with a soil sample ring (diameter 50 x 53 mm). The ring was placed inside a closed ring holder, which was attached to a handle with beating head, supplied by Ejikelkamp Agrisresearch equipment.

The leaf litter layer was gently removed below the organic matter layer. The corer was inserted into the soil vertically and without twisting. It was then withdrawn from the soil.

The soil sample ring was carefully removed from the closed ring holder. The excess soil outside the ring was removed using a sharp knife. This ring now contained a 100 cc of undisturbed soil sample, which was then placed into a sealable plastic sample bag.

This sample was then dried at 104°C for 24 hours in a fan oven on an aluminium tray. The sample was then cooled and weighed. The bulk density was weighed g/vol (cc).

## *4.5. MICROBIOLOGICAL ANALYSIS*

### *4.5.1. Total aerobic bacteria*

From the sterile sample bags, 10g of soil were removed aseptically and placed into 90 mls of ringer's solution. Each sample was then placed onto an automatic shaker for 20 minutes to ensure that all microbes were suspended into the diluents uniformly. For each of the samples it was necessary to carry out serial dilutions from $10^{-1}$ down to $10^{-9}$, each of the dilutions were carried out by the use of 9 ml ringers, but only the dilutions from $10^{-3}$ to $10^{-9}$ were plated. Nutrient agar was used to grow any aerobic bacteria present in Petri dishes. Dilutions were then plated in triplicate and incubated at 22°C for 72 hours and also plated in triplicate and incubated at 32°C for 48 hours.

Preparation of Diluents

Ringers Solution,
Dissolve 2.15g of sodium chloride, 0.075g of potassium chloride, 0.12g of calcium chloride and 0.5g of sodium thiosulfate pentahydrate in 1L of distilled water. Adjust pH to 6.6 using either 0.1N sodium hydroxide or hydrochloric acid.

Ringers solution is also commercially available in tablet form, 1 tablet being dissolved in 500 ml of distilled water. The tablets which were used in this project were supplied by Lab M.

Preparation of Media

Nutrient Agar,

The nutrient agar was supplied in a powered form by Lab M, (it consisted of 5g/L peptone, 3g/L beef extract, 8g/L sodium chloride and 12 g/l of agar).

It was prepared by dissolving 28g/L (of the powder) in 1 litre of distilled water and was then autoclaved.

After the relevant incubation periods, counts were determined for total aerobic bacteria. Each colony developed is assumed to have grown from one viable unit, which may be one organisms or a group of many. The enumeration was calculated as colony forming units per ml and expressed per dry weight of soil. Therefore it was necessary to carry out moisture content analysis in conjunction with bacterial counts.

## *4.6. QUALITY CONTROL*

All analysis were conducted using good laboratory practice. In addition, all analytical sequences incorporated blanks (that is all reagents minus sample) and spikes (introduction of known amounts of analyte to analytical samples) at the earliest practicable stage in the analytical sequence.

In all cases, standard solutions were made up in such a manner that the standard matrix resembled the matrix of the analytical sample. Calibrations were conducted under instrumental conditions employed in sample analysis. Linearity of response was considered acceptable via the use of $R^2$ coefficients, a coefficient value of greater than 0.995 being acceptable.

## *4.7. STATISTICAL ANALYSIS*

All data was input to and calculated using Excel (Microsoft XP 2000). Graphs were produced from excel. Statistical tests were completed using the sigma stat 2.03 programme for windows. Analysis of variance was carried out on data.

### *4.7.1. Analysis of Variance (ANOVA)*

For comparison of more than two groups, data can be analysed using Analysis of Variance (ANOVA). For comparison of treatments in the field trials of this study ANOVA was carried out to test for significant differences, using Sigma Stat 2.0. for windows. One-way ANOVA was followed by Tukey's comparison of means test to compare treatments. Differences were regarded as significant if $P<0.05$.

### *4.7.2. Correlation*

Correlation is a measure of the relation between two or more variables. The correlation coefficient r represents the linear relationship between two variables. If the correlation coefficient is squared, then the resultant value ($r^2$) will represent the proportion of common variation in the two variables (i.e. the strength of the relationship). The correlation coefficient r varies between −1 and +1. A correlation of −1 indicates there is a perfect negative relationship between two variables. A correlation of +1 indicates there is a perfect positive relationship between two variables. A correlation of 0 indicates no relationship between variables.

# 5.0. RESULTS

## *5.0. MOISTURE CONTENT RESULTS*

Moisture content analysis was carried out in treatments to determine the percentage of moisture available in the soil at the three different sampling depths. This data also aided in the determination of the Total number of Aerobic bacteria present in the soil, and is referenced in nitrate, phosphorus, potassium, and organic carbon results as well as the physical analysis carried out for shear strength and soil resistance.

Analysis was carried out by gravimetric measurement of the soil samples, which had been placed in an oven and dried at 105°C for 24 hours, before being weighed. The following results were obtained by the averaging of six results for moisture content in soils, at each of the three depths sampled on the dates outlined. Separate tables and graphs are provided for each of the treatments i.e. conventional and reduced tillage, with and without straw.

Table 5.0.1. Soil moisture content for the Conventionally tilled treatments with straw removed. % moisture content.

| | Sept 01 | Oct 01 | Nov 01 | Feb 02 | Mar 02 | Apr 02 | May 02 | Jun 02 | Jul 02 | Aug 02 | Oct 02 | Nov 02 | Dec 02 | Feb 03 | Mar 03 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0/10 | 15.88 | 20.78 | 22.05 | 21.02 | 20.29 | 16.08 | 16.87 | 15.75 | 12.35 | 17.41 | 18.42 | 21.71 | 21.52 | 20.24 | 18.29 |
| 10/20 | 16.71 | 18.93 | 21.56 | 20.01 | 20.49 | 17.89 | 15.85 | 18.60 | 14.83 | 18.31 | 18.23 | 21.15 | 22.84 | 22.19 | 19.33 |
| 20/30 | 15.03 | 17.39 | 21.45 | 18.34 | 18.53 | 18.03 | 14.73 | 18.60 | 14.68 | 18.14 | 17.69 | 19.84 | 18.32 | 16.76 | 18.05 |

Figure 5.0.1. Soil moisture content for the Conventionally tilled treatments with straw removed. % moisture content.

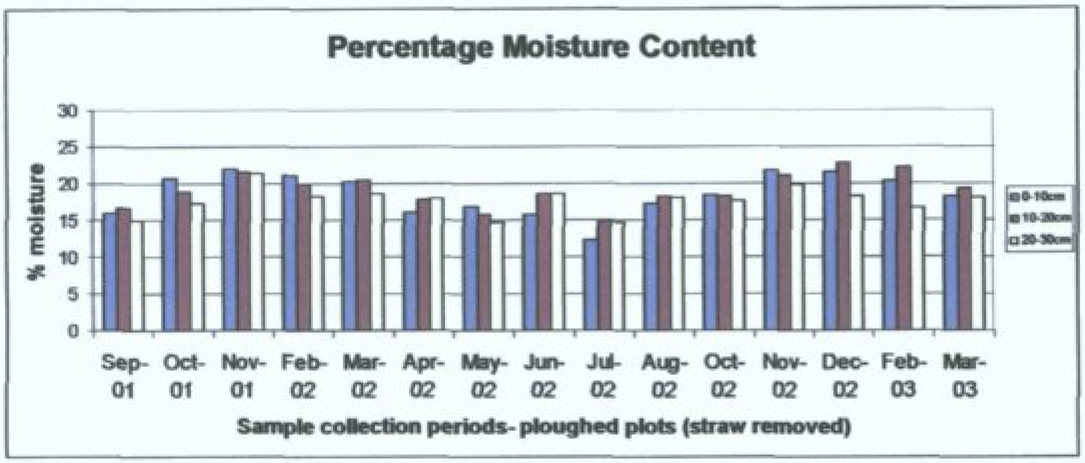


Table 5.0.2. Soil moisture content for the Conventionally tilled treatments with straw incorporated. % moisture content.

| | Sept 01 | Oct 01 | Nov 01 | Feb 02 | Mar 02 | Apr 02 | May 02 | Jun 02 | Jul 02 | Aug 02 | Oct 02 | Nov 02 | Dec 02 | Feb 03 | Mar 03 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0/10 | 16.77 | 19.60 | 21.48 | 20.71 | 19.74 | 15.43 | 17.11 | 15.53 | 12.84 | 17.49 | 18.63 | 22.53 | 19.29 | 20.45 | 18.64 |
| 10/20 | 17.15 | 19.48 | 21.01 | 20.62 | 18.83 | 17.37 | 17.46 | 17.80 | 14.96 | 18.17 | 17.91 | 21.58 | 19.83 | 20.16 | 19.69 |
| 20/30 | 15.22 | 16.69 | 20.49 | 19.69 | 17.70 | 16.70 | 16.30 | 19.28 | 15.51 | 17.96 | 18.43 | 16.60 | 17.14 | 18.39 | 17.80 |

Figure 5.0.2. Soil moisture content for the Conventionally tilled treatments with straw incorporated. % moisture content.

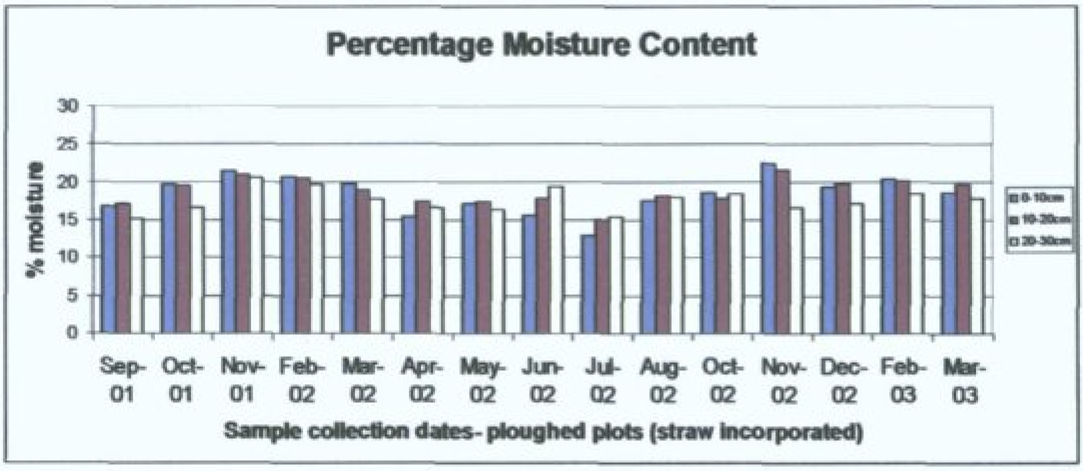


Table 5.0.3. Soil moisture content for the Reduced tillage treatments with straw removed. % moisture content.

| | Sept 01 | Oct 01 | Nov 01 | Feb 02 | Mar 02 | Apr 02 | May 02 | Jun 02 | Jul 02 | Aug 02 | Oct 02 | Nov 02 | Dec 02 | Feb 03 | Mar 03 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0/10 | 16.68 | 20.5 | 22.13 | 19.86 | 23.05 | 14.08 | 16.46 | 14.6 | 12.18 | 16.45 | 17.82 | 20.81 | 20.57 | 20.27 | 16.84 |
| 10/20 | 17.08 | 20.67 | 21.56 | 20.84 | 22.23 | 16.21 | 16.97 | 16.17 | 8.68 | 17.80 | 17.09 | 19.62 | 17.69 | 19.48 | 17.57 |
| 20/30 | 15.95 | 18.58 | 21.99 | 20.32 | 20.38 | 15.78 | 15.90 | 17.02 | 14.26 | 16.09 | 14.89 | 17.45 | 17.05 | 17.42 | 16.60 |

Figure 5.0.3. Soil moisture content for the Reduced tillage treatments with straw removed. % moisture content

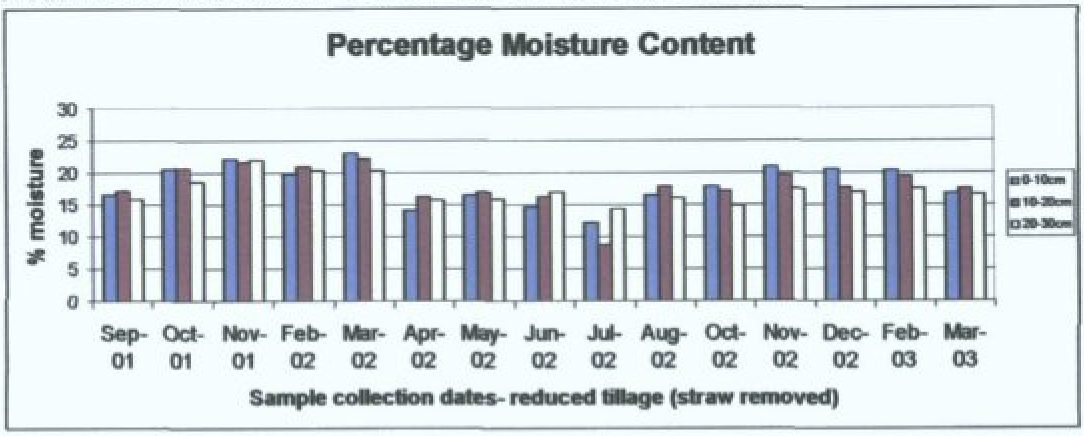
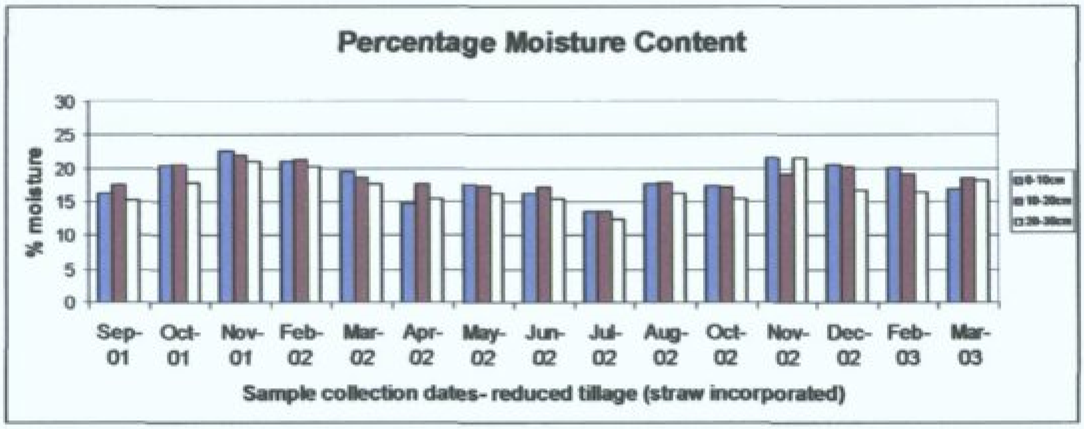


Table 5.0.4. Soil moisture content for the Reduced tillage treatments with straw incorporated. % moisture content.

| | Sept 01 | Oct 01 | Nov 01 | Feb 02 | Mar 02 | Apr 02 | May 02 | Jun 02 | Jul 02 | Aug 02 | Oct 02 | Nov 02 | Dec 02 | Feb 03 | Mar 03 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **0/10** | 16.35 | 20.5 | 22.55 | 21.05 | 19.44 | 14.89 | 17.62 | 16.29 | 13.59 | 17.78 | 17.36 | 21.48 | 20.51 | 20.17 | 16.96 |
| **10/20** | 17.59 | 20.65 | 21.89 | 21.15 | 18.61 | 17.76 | 17.46 | 17.22 | 13.61 | 17.88 | 17.26 | 19.08 | 20.24 | 19.17 | 18.52 |
| **20/30** | 15.25 | 17.94 | 21.01 | 20.24 | 17.67 | 15.51 | 16.22 | 15.48 | 12.42 | 16.28 | 15.46 | 21.53 | 16.76 | 16.36 | 18.14 |

Figure 5.0.4. Soil moisture content for the Reduced tillage treatments with straw incorporated. % moisture content.



### ***Moisture contents in the treatments.***

*Tables 5.0.1. to 5.0.4.*

The moisture content of the soil under all four treatments follows a similar pattern. That is, there are higher moisture levels in the soils in the autumn and winter periods than during the summer months for both systems of cultivation, with and without straw. And at times during the sampling programme the moisture content does not vary greatly through the depths sampled in the soil profile.

After heavy rainfall in may of 2002 (Table no.7.literature review) the moisture content of the soil was observed to *increase in* the samples collected in early June for the conventional treatments, this rainfall event did not increase the concentration of moisture in the reduced tillage treatments. However, moisture contents were higher lower down in the soil profile.

## *5.1. ORGANIC MATTER RESULTS*

Analysis for percentage organic matter was carried out by ignition of the soil samples in a muffle furnace. Each sample collected was analysed in triplicate. As two of each treatment type was sampled on each occasion the following results are determined from the averaging of six values for percentage organic matter.

Previous studies have indicated that the characteristics of organic matter change in both space and time, following a change in tillage practice. Changes in organic matter primarily reflect changes in the form, magnitude and frequency of stresses imposed on soil, the placement of crop residues and the population of microorganisms and fauna in the soil according to Kay (2002). This research aimed to determine if any alteration in organic matter concentration occurred as a result of conversion to reduced cultivation.

The following tables summarise the concentration of organic matter through the soil profile in all four treatments sampled over the project duration.

Treatments were also directly compared at each of the three depths sampled, as well as determining the average percentage organic matter over the sampling programme.

Table 5.1.1. Percentage Organic Matter concentration in the ploughed treatments (straw removed) at different soil depths and on different sampling dates.

| Sample Depth | Sept 2001 | Oct 2001 | Nov 2001 | Feb 2002 | Apr 2002 | May 2002 | June 2002 | July 2002 | Aug 2002 | Oct 2002 | Nov 2002 | Dec 2002 | Feb 2003 | Mar 2003 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0-10 | 2.95 | 3.78 | 3.18 | 3.44 | 2.17 | 3.21 | 3.08 | 3.24 | 3.61 | 3.16 | 3.26 | 2.91 | 2.86 | 2.84 |
| 10-20 | 2.90 | 3.68 | 3.19 | 3.27 | 3.39 | 3.33 | 3.93 | 3.42 | 3.31 | 3.55 | 3.53 | 2.25 | 2.74 | 3.56 |
| 20-30 | 2.51 | 2.81 | 3.88 | 2.90 | 2.57 | 2.73 | 2.89 | 3.49 | 2.80 | 2.67 | 2.90 | 2.78 | 2.28 | 2.74 |
| Mean | 2.79 | 3.42 | 3.42 | 3.20 | 2.71 | 3.09 | 3.30 | 3.83 | 3.24 | 3.13 | 3.23 | 2.65 | 2.63 | 3.05 |
| Std D | 0.24 | 0.53 | 0.4 | 0.28 | 0.62 | 0.32 | 0.55 | 0.13 | 0.41 | 0.44 | 0.32 | 0.35 | 0.31 | 0.45 |
| Signif | ** | *** | ** | *** | *** | *** | *** | ** | *** | *** | *** | *** | *** | *** |

Significance Key
* $P<0.05$
** $P<0.01$
*** $P<0.001$
NS No Significant Differences

Fig 5.1.1. Percentage Organic Matter concentration in the ploughed treatments (straw removed) at different soil depths and on different sampling dates.

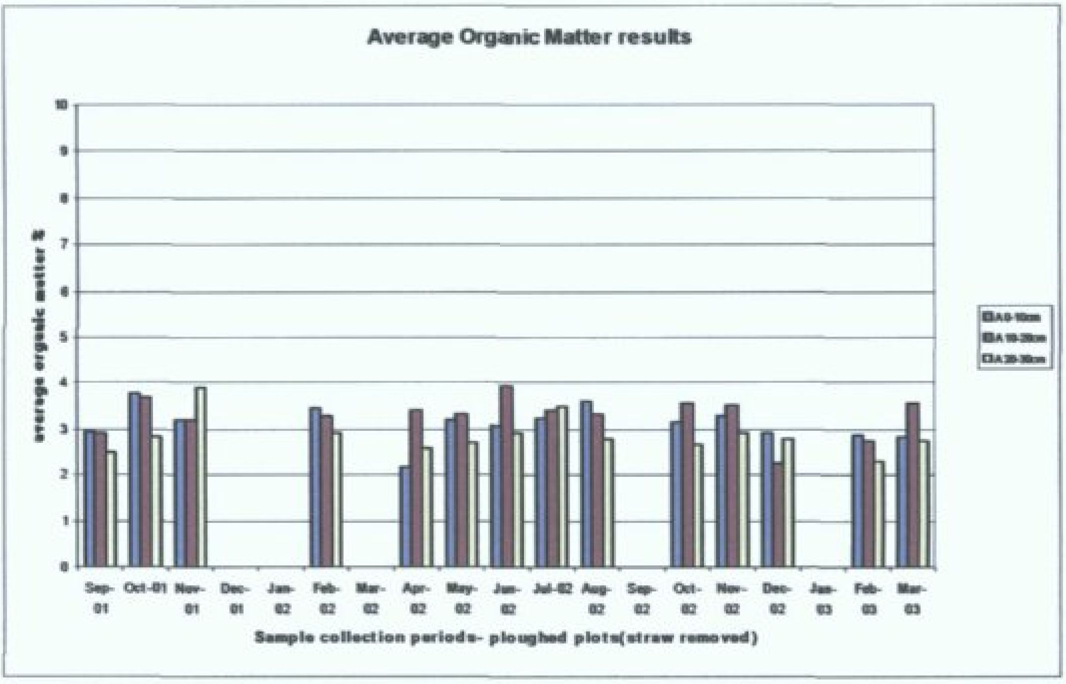


Table 5.1.2. Percentage Organic Matter concentration in the ploughed treatments (straw incorporated) at different soil depths and on different sampling dates.

| Sample Depth | Sept 2001 | Oct 2001 | Nov 2001 | Feb 2002 | Apr 2002 | May 2002 | June 2002 | July 2002 | Aug 2002 | Oct 2002 | Nov 2002 | Dec 2002 | Feb 2003 | Mar 2003 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0-10 | 3.32 | 3.42 | 2.69 | 3.95 | 3.13 | 3.60 | 3.30 | 3.69 | 3.11 | 4.37 | 2.91 | 2.21 | 2.97 | 2.72 |
| 10-20 | 3.36 | 3.46 | 4.84 | 3.15 | 3.48 | 3.31 | 2.87 | 3.80 | 3.01 | 2.91 | 3.28 | 2.70 | 2.74 | 3.33 |
| 20-30 | 2.57 | 2.67 | 4.17 | 3.10 | 2.69 | 2.80 | 3.23 | 3.41 | 2.60 | 3.16 | 2.12 | 2.29 | 1.69 | 2.87 |
| Mean | 3.08 | 3.18 | 3.90 | 3.40 | 3.10 | 3.24 | 3.13 | 3.63 | 2.91 | 3.48 | 2.77 | 2.40 | 2.47 | 2.97 |
| Std D | 0.44 | 0.44 | 1.10 | 0.48 | 0.40 | 0.40 | 0.23 | 0.20 | 0.27 | 0.78 | 0.59 | 0.26 | 0.68 | 0.32 |
| Signif | ** | ** | *** | *** | *** | *** | ** | *** | *** | *** | *** | *** | *** | *** |

Significance Key
*  $P<0.05$
**  $P<0.01$
***  $P<0.001$
NS  No Significant Differences

Fig. 5.1.2. Percentage Organic Matter concentration in the ploughed treatments (straw incorporated) at different soil depths and on different sampling dates.

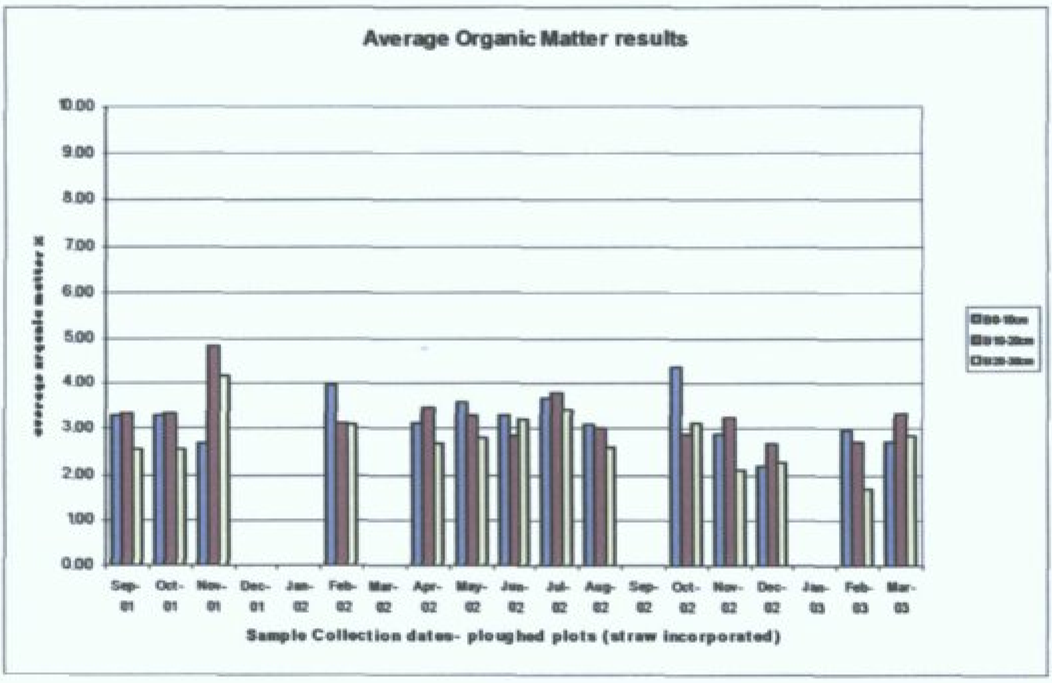


Table 5.1.3. Percentage Organic Matter concentration in the reduced tillage treatments (straw removed) at different soil depths and on different sampling dates.

| Sample Depth | Sept 2001 | Oct 2001 | Nov 2001 | Feb 2002 | Apr 2002 | May 2002 | June 2002 | July 2002 | Aug 2002 | Oct 2002 | Nov 2002 | Dec 2002 | Feb 2003 | Mar 2003 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0-10 | 6.34 | 2.94 | 5.34 | 3.74 | 3.72 | 2.98 | 3.61 | 3.55 | 3.60 | 3.14 | 3.27 | 3.82 | 2.90 | 3.27 |
| 10-20 | 9.55 | 2.89 | 5.83 | 3.55 | 3.33 | 3.16 | 3.66 | 3.39 | 3.31 | 2.94 | 3.47 | 3.10 | 2.81 | 2.99 |
| 20-30 | 7.27 | 2.34 | 6.13 | 3.49 | 2.73 | 2.56 | 2.70 | 3.68 | 3.08 | 2.40 | 2.74 | 2.48 | 2.31 | 2.72 |
| Mean | 7.05 | 2.72 | 5.77 | 3.59 | 3.26 | 2.90 | 3.32 | 3.54 | 3.33 | 2.83 | 3.16 | 3.13 | 2.67 | 2.99 |
| Std D | 0.63 | 0.33 | 0.40 | 0.13 | 0.50 | 0.31 | 0.54 | 0.15 | 0.26 | 0.38 | 0.38 | 0.67 | 0.32 | 0.28 |
| Signif | *** | ** | *** | *** | *** | *** | ** | ** | *** | *** | *** | *** | *** | *** |

Significance Key
*    P<0.05
**   P<0.01
***  *P<0.001*
NS   No Significant Differences

Fig 5.1.3. Percentage Organic Matter concentration in the reduced tillage treatments (straw removed) at different soil depths and on different sampling dates.

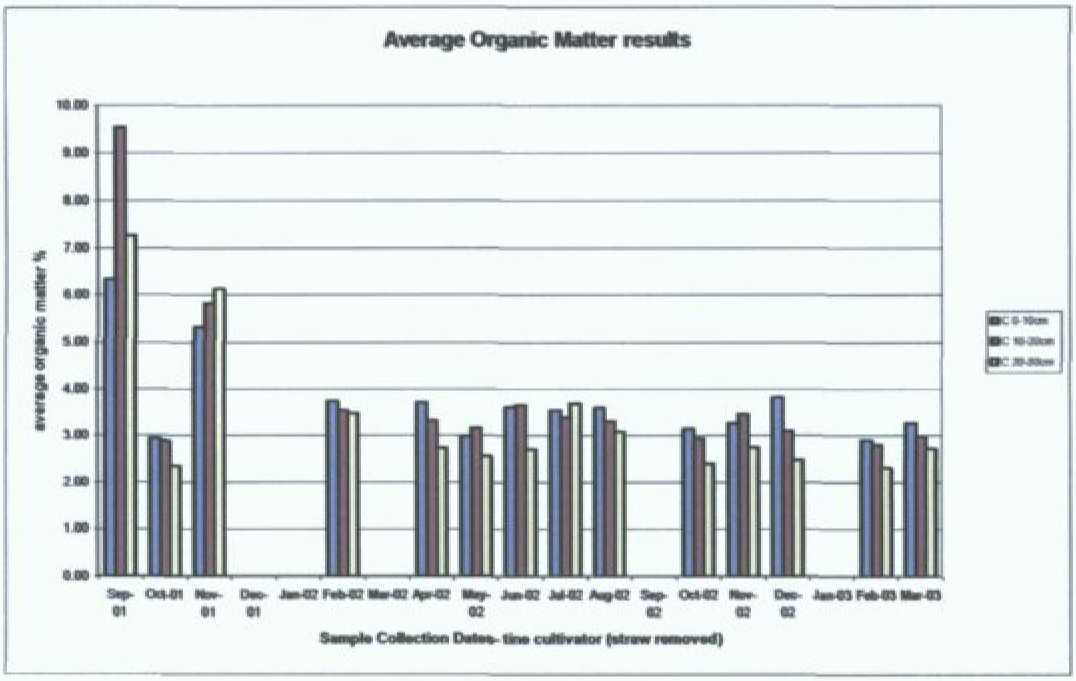
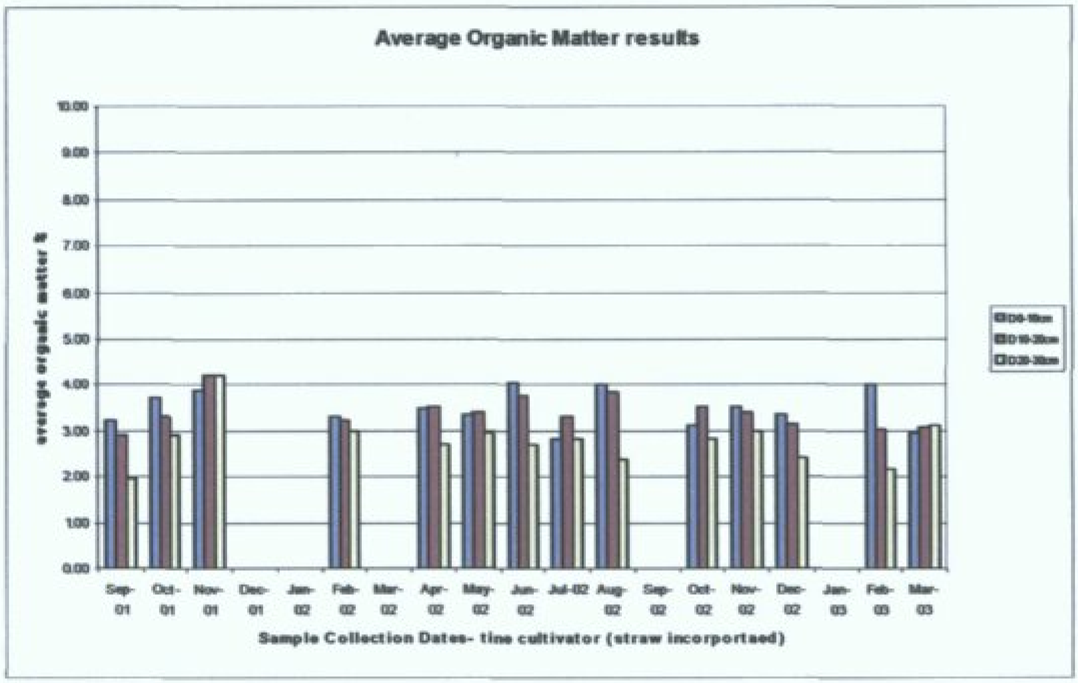


Table 5.1.4. Percentage Organic Matter concentration in the reduced tillage treatments (straw incorporated) at different soil depths and on different sampling dates.

| Sample Depth | Sept 2001 | Oct 2001 | Nov 2001 | Feb 2002 | Apr 2002 | May 2002 | June 2002 | July 2002 | Aug 2002 | Oct 2002 | Nov 2002 | Dec 2002 | Feb 2003 | Mar 2003 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0-10 | 3.22 | 3.74 | 3.89 | 3.31 | 3.49 | 3.35 | 4.07 | 2.83 | 4.01 | 3.10 | 3.53 | 3.37 | 4.00 | 2.97 |
| 10-20 | 2.91 | 3.34 | 4.22 | 3.24 | 3.55 | 3.40 | 3.76 | 3.32 | 3.87 | 3.53 | 3.39 | 3.15 | 3.03 | 3.06 |
| 20-30 | 1.96 | 2.91 | 4.22 | 3.00 | 2.71 | 2.96 | 2.70 | 3.25 | 2.37 | 2.84 | 3.01 | 2.41 | 2.19 | 3.13 |
| Mean | 2.70 | 3.33 | 4.11 | 3.18 | 3.25 | 3.24 | 3.51 | 3.13 | 3.42 | 3.16 | 3.31 | 2.98 | 3.07 | 3.05 |
| Std D | 0.65 | 0.42 | 0.19 | 0.16 | 0.47 | 0.24 | 0.72 | 0.27 | 0.69 | 0.35 | 0.27 | 0.50 | 0.91 | 0.08 |
| Signif | *** | *** | ** | *** | *** | *** | *** | *** | ** | *** | ** | *** | *** | *** |

Significance Key
* P<0.05
** P<0.01
*** P<0.001
NS No Significant Differences

Fig 5.1.4. Percentage Organic Matter concentration in the reduced tillage treatments (straw incorporated) at different soil depths and on different sampling dates.



***Organic matter concentration for each treatment.***

*Table 5.1.1.*

The percentage of organic matter can be seen to fluctuate over the growing season of the crop in the ploughed treatments which had straw removed. Through autumn and winter there is a higher concentration of organic matter in the upper horizon due to decaying vegetation on the soil surface. During this period the breakdown of organic matter through mineralization is at a minimum due to soil temperatures, which limit microbial activity. When the soil temperature increases, during spring and summer, the concentration of organic matter in the top 10cm of soil reduces due to organic matter decomposition, and a greater concentration of organic matter is determined at lower depths in the soil profile.

*Table 5.1.2.*

The incorporation of straw did not increase the concentration of organic matter present in the conventionally tilled treatments over the sampling programme as was expected. This treatment was also prone to fluctuations in organic matter concentration over the growth cycle of the crop. Throughout the majority of the sampling period the greatest concentration of organic matter fluctuated between the 0-10 and 10-20 cm of soil.

*Table 5.1.3.*

Kay (2002) indicated that by reducing the degree of soil disturbance the concentration of organic matter should increase, particularly in the top 10cm of soil. In this study the concentration of organic matter was higher in the reduced cultivation treatments than the conventional tillage treatments. These treatments also contained a clearer soil gradient in organic matter concentration during cooler periods.

*Table 5.1.4.*

The incorporation of straw into the reduced cultivation treatments did not positively affect the concentration of organic matter present in soil. As this treatment contained a lower concentration of organic matter than the reduced treatment which had removed straw. Throughout 8 of the 14 months sampled the concentration of organic matter was greatest in the top 10cm of soil, including the summer periods when the concentration of organic matter was reduced in this profile in the other treatments.

Table 5.1.5. Percentage Organic Matter concentration for all four cultivation methods at the 0-10cm sampling depth over the sampling period.

| Plot Type | Sep 2001 | Oct 2001 | Nov 2001 | Feb 2002 | Apr 2002 | May 2002 | June 2002 | July 2002 | Aug 2002 | Oct 2002 | Nov 2002 | Dec 2002 | Feb 2003 | Mar 2003 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A | 2.95 | 3.78 | 3.18 | 3.44 | 2.17 | 3.21 | 3.08 | 3.24 | 3.61 | 3.16 | 3.26 | 2.91 | 2.86 | 2.84 |
| B | 3.32 | 3.42 | 2.69 | 3.95 | 3.13 | 3.60 | 3.30 | 3.69 | 3.11 | 4.37 | 2.91 | 2.21 | 2.97 | 2.72 |
| C | 6.34 | 2.94 | 5.34 | 3.74 | 3.72 | 2.98 | 3.61 | 3.55 | 3.60 | 3.14 | 3.27 | 3.82 | 2.90 | 3.27 |
| D | 3.22 | 3.74 | 3.89 | 3.31 | 3.49 | 3.35 | 4.07 | 2.83 | 4.01 | 3.10 | 3.53 | 3.37 | 4.00 | 2.97 |
| Std D | 1.60 | 0.39 | 1.15 | 0.29 | 0.68 | 0.26 | 0.43 | 0.38 | 0.37 | 0.62 | 0.25 | 0.69 | 0.55 | 0.24 |
| Signif | *** | NS | *** | NS | *** | NS | *** | ** | *** | * | NS | *** | * | NS |

Key

A = Conventional tillage (straw removed)

B = Conventional tillage (straw incorporated)

C = Reduced tillage (straw removed)

D = Reduced tillage (straw incorporated)

Significance Key

* P<0.05

** P<0.01

*** P<0.001

NS No Significant Differences

Fig 5.1.5. Percentage Organic Matter concentration for all four cultivation methods at the 0-10cm sampling depth over the sampling period.

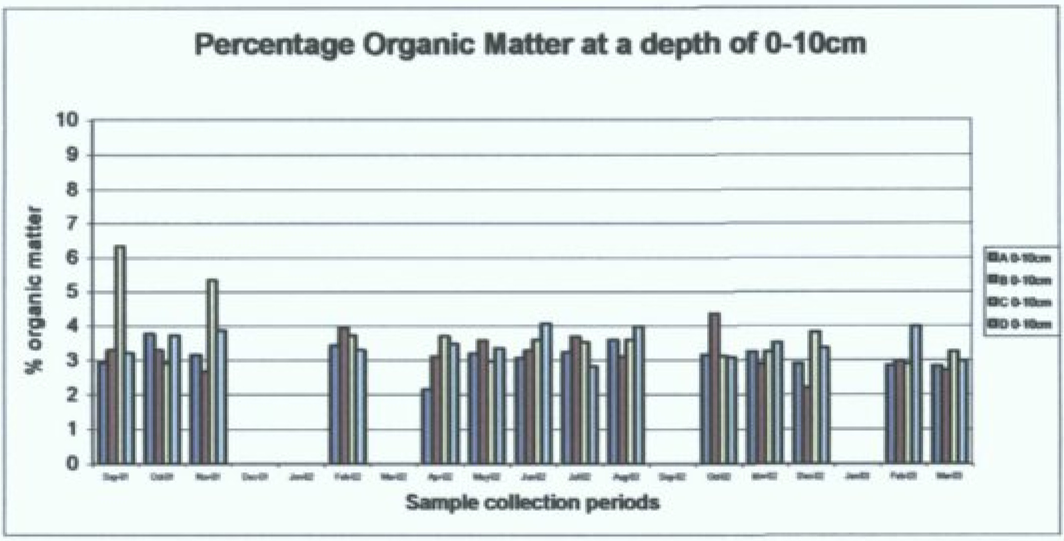


Table 5.1.6. Percentage Organic Matter concentration for all four cultivation methods at the 10-20cm sampling depth over the sampling period.

| Plot Type | Sep 2001 | Oct 2001 | Nov 2001 | Feb 2002 | Apr 2002 | May 2002 | June 2002 | July 2002 | Aug 2002 | Oct 2002 | Nov 2002 | Dec 2002 | Feb 2003 | Mar 2003 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A | 2.90 | 3.68 | 3.19 | 3.27 | 3.39 | 3.33 | 3.93 | 3.42 | 3.31 | 3.55 | 3.53 | 2.25 | 2.74 | 3.56 |
| B | 3.36 | 3.46 | 4.84 | 3.15 | 3.48 | 3.31 | 2.87 | 3.80 | 3.01 | 2.91 | 3.28 | 2.70 | 2.74 | 3.33 |
| C | 9.55 | 2.89 | 5.83 | 3.55 | 3.33 | 3.16 | 3.66 | 3.39 | 3.31 | 2.94 | 3.47 | 3.10 | 2.81 | 2.99 |
| D | 2.91 | 3.34 | 4.22 | 3.24 | 3.55 | 3.40 | 3.76 | 3.32 | 3.87 | 3.53 | 3.39 | 3.15 | 3.03 | 3.06 |
| Std D | 2.25 | 0.33 | 1.11 | 0.17 | 0.09 | 0.1 | 0.47 | 0.22 | 0.36 | 0.36 | 0.11 | 0.42 | 0.14 | 0.26 |
| Signif | *** | ** | *** | * | NS | NS | ** | NS | * | NS | NS | NS | NS | NS |

Key

A = Conventional tillage (straw removed)

B = Conventional tillage (straw incorporated)

C = Reduced tillage (straw removed)

D = Reduced tillage (straw incorporated)

Significance Key

| | |
|---|---|
| * | P<0.05 |
| ** | P<0.01 |
| *** | P<0.001 |
| NS | No Significant Differences |

Fig 5.1.6. Percentage Organic Matter concentration for all four cultivation methods at the 10-20cm sampling depth over the sampling period.

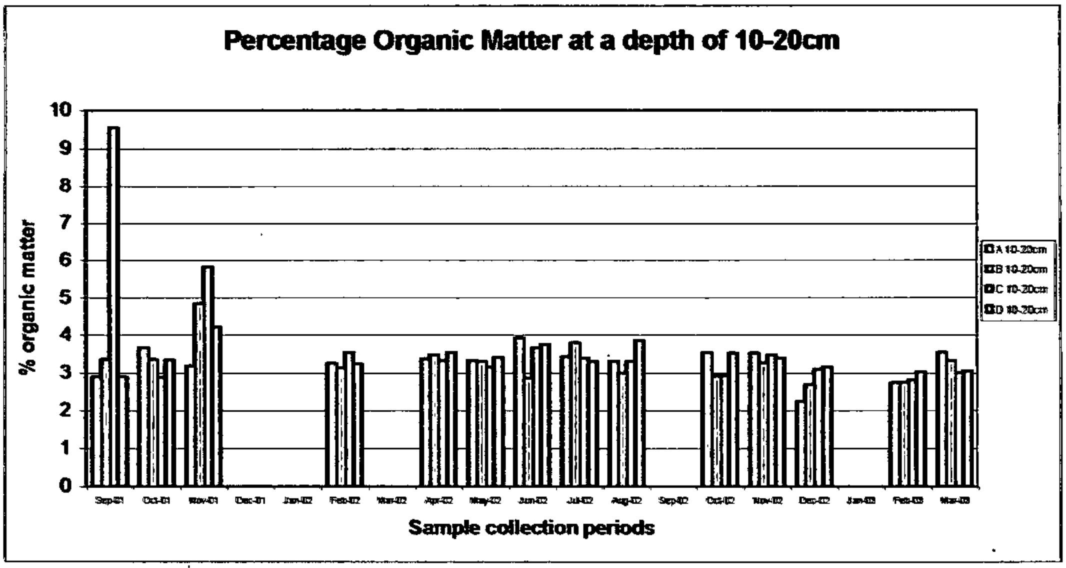


Table 5.1.7. Percentage Organic Matter concentration for all four cultivation methods at the 20-30cm sampling depth over the sampling period.

| Plot Type | Sep 2001 | Oct 2001 | Nov 2001 | Feb 2002 | Apr 2002 | May 2002 | June 2002 | July 2002 | Aug 2002 | Oct 2002 | Nov 2002 | Dec 2002 | Feb 2003 | Mar 2003 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A | 2.51 | 2.81 | 3.88 | 2.90 | 2.57 | 2.73 | 2.89 | 3.49 | 2.80 | 2.67 | 2.90 | 2.78 | 2.28 | 2.74 |
| B | 2.57 | 2.67 | 4.17 | 3.10 | 2.69 | 2.80 | 3.23 | 3.41 | 2.60 | 3.16 | 2.12 | 2.29 | 1.69 | 2.87 |
| C | 7.27 | 2.34 | 6.13 | 3.49 | 2.73 | 2.56 | 2.70 | 3.68 | 3.08 | 2.40 | 2.74 | 2.48 | 2.31 | 2.72 |
| D | 1.96 | 2.91 | 4.22 | 3.00 | 2.71 | 2.96 | 2.70 | 3.25 | 2.37 | 2.84 | 3.01 | 2.41 | 2.19 | 3.13 |
| Std D | 2.48 | 0.25 | 1.03 | 0.26 | 0.07 | 0.17 | 0.25 | 0.37 | 0.30 | 0.32 | 0.40 | 0.21 | 0.29 | 0.19 |
| Signif | *** | NS | *** | * | NS | NS | NS | ** | NS | NS | ** | NS | NS | NS |

Key

A = Conventional tillage (straw removed)

B = Conventional tillage (straw incorporated)

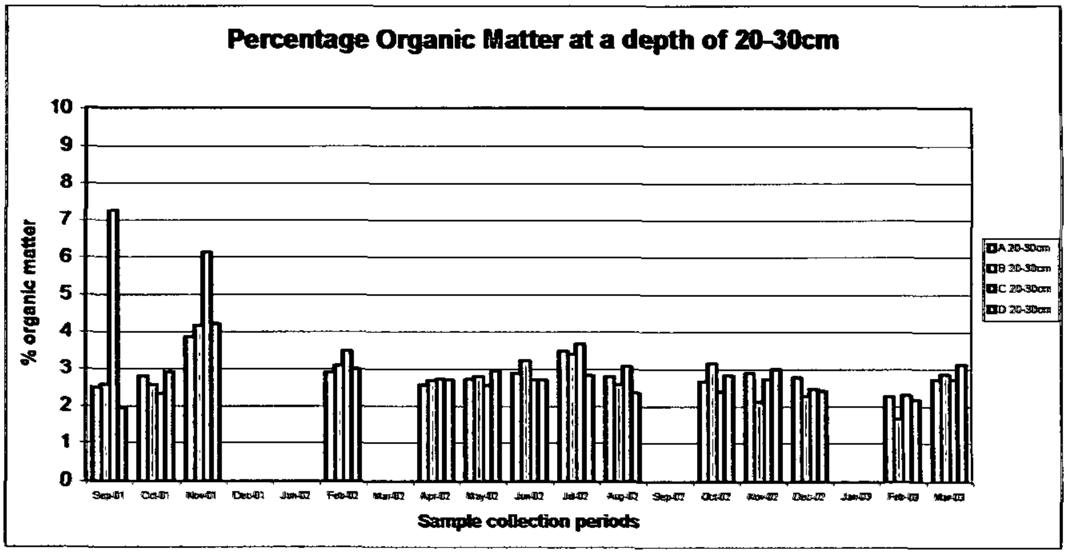
C = Reduced tillage (straw removed)

D = Reduced tillage (straw incorporated)

Significance Key
- * $P<0.05$
- ** $P<0.01$
- *** $P<0.001$

NS No Significant Differences

Fig 5.1.7. Percentage Organic Matter concentration for all four cultivation methods at the 20-30cm sampling depth over the sampling period.



***Organic matter concentration. Comparing the three sample depths***

*Table 5.1.5.*

Previous studies carried out have indicated that reduced cultivation increases the concentration of organic matter in the top 10cm of soil. This was determined for some of the months sampled in this project, although on 5 occasions there were no significant differences in organic matter concentration in the top 10cm of soil between the four treatments.

*Table 5.1.6.*

The majority of results obtained for differences in organic matter concentration at a depth of 10-20cm showed no statistically significant differences in organic matter concentration. The differences in the median values were not great enough among the treatment groups to exclude the possibility of random sampling variability. Where statistical differences did occur in results the reduced tillage treatments contained a higher concentration of organic matter.

*Table 5.1.7.*

The statistical differences in results obtained for the conventional and reduced tillage systems at a depth of 20-30cm, were as outlined in the overlying sampling depth of 10-20cm. Throughout most of the sampling period there was no statistical difference in organic matter concentration.

Table 5.1.8. Variation of Percentage Organic Matter concentration at the three sample depths for each of the cultivation methods.

| Plot Type | 0-10cm depth | 10-20cm depth | 20-30cm depth |
|---|---|---|---|
| A | 3.12 | 3.28 | 2.85 |
| B | 3.23 | 3.29 | 2.80 |
| C | 3.72 | 3.71 | 3.33 |
| D | 3.49 | 3.41 | 2.80 |

Key

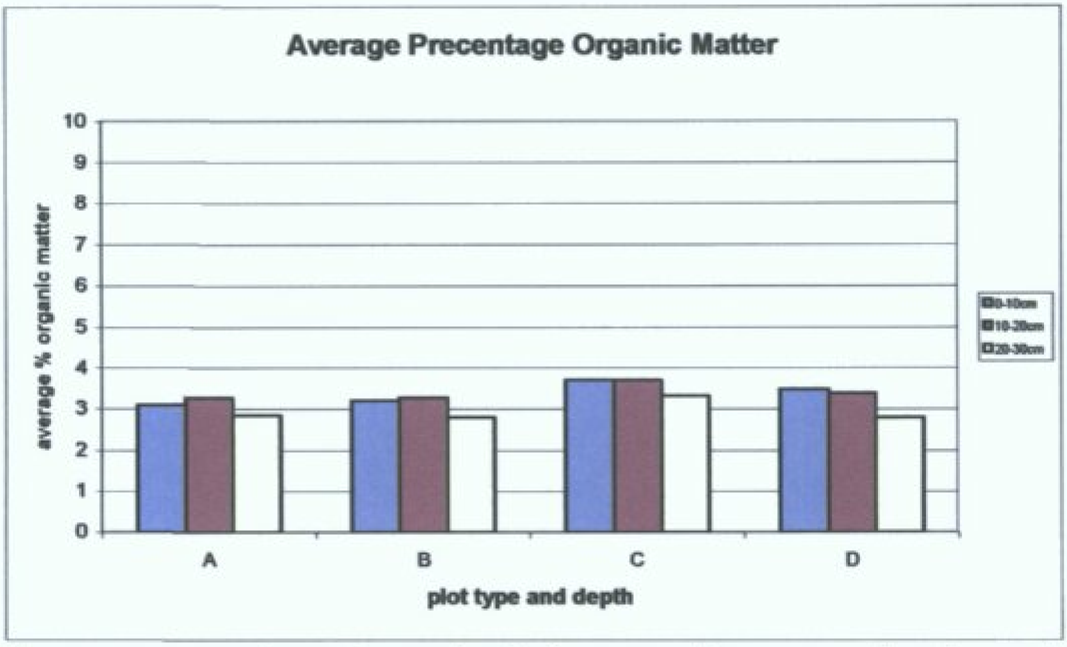
A = Conventional tillage (straw removed)

B = Conventional tillage (straw incorporated)

C = Reduced tillage (straw removed)

D = Reduced tillage (straw incorporated)

Fig 5.1.8. Variation of Percentage Organic Matter concentration at the three sample depths for each of the cultivation methods



The average values determined for organic matter in the soil profile over the 14 month sampling period did not appear to vary significantly between the four treatments. The reduced treatments contain slightly higher values of organic matter in the 0-10cm sample depth and all four treatments display a decrease in organic matter concentration at the lowest sampling depth of 20-30cm.

## *5.2. NITRATE RESULTS*

Tillage has been found to influence both the amount and the distribution of soil nitrogen (Mc Carthy et al., 1995). Types of tillage have differential effects on soil nitrogen dynamics of a newly cultivated soil. Studies indicate that switching from ploughing to reduced tillage systems may result in a more nitrogen conserving system. The implications are that the establishment of conservation tillage systems on soils, which have been cultivated for many years, may have some positive benefits in restoring their organic nitrogen content.

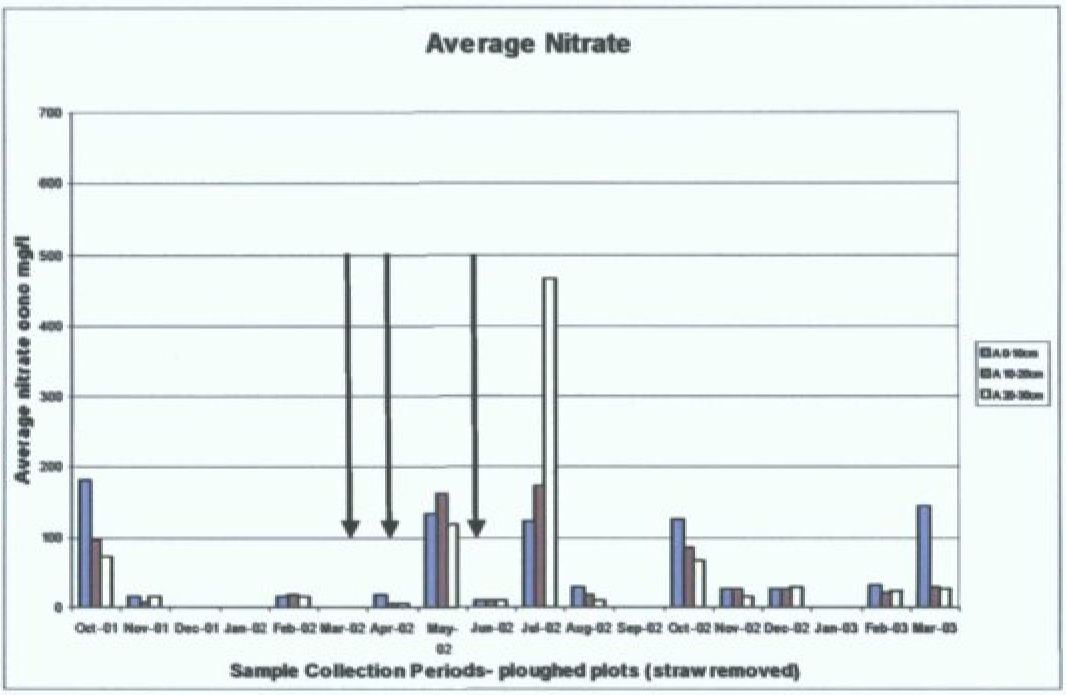
Nitrate-Nitrogen was analysed in this project by use of an ion selective electrode. All samples were analysed in triplicate before being averaged. Results were then tabulated and graphed for each treatment type at the three depths sampled in the soil profile over the sampling programme, as well as for direct comparisons of each treatment at each depth.

Table 5.2.1.Nitrate concentration in the Ploughed treatments (straw removed) at different soil depths and on different dates (mg/l).

| Sample Depth | Oct 2001 | Nov 2001 | Feb 2002 | Apr 2002 | May 2002 | June 2002 | July 2002 | Aug 2002 | Oct 2002 | Nov 2002 | Dec 2002 | Feb 2003 | Mar 2003 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0-10 | 183.5 | 16 | 16.5 | 18 | 133.5 | 11 | 123 | 29.5 | 125 | 26.5 | 25.5 | 33 | 144 |
| 10-20 | 96.5 | 8 | 18.5 | 4.5 | 162.5 | 11 | 174 | 17.5 | 26 | 26 | 26.5 | 20.5 | 29 |
| 20-30 | 73.5 | 15 | 15.5 | 4.5 | 117 | 10 | 466.5 | 10 | 17 | 17 | 30 | 23.5 | 28 |
| Mean | 117.8 | 13 | 16.8 | 9 | 137.6 | 10.7 | 254.5 | 19 | 56 | 23.2 | 27.3 | 25.7 | 67 |
| Std D | 58.02 | 4.36 | 1.53 | 7.79 | 23.03 | 0.58 | 185.36 | 9.84 | 59.93 | 5.35 | 2.36 | 6.53 | 66.69 |
| Signif | *** | * | NS | *** | *** | NS | *** | *** | *** | *** | ** | * | *** |

Significance Key
- *	$P<0.05$
- **	$P<0.01$
- ***	$P<0.001$
- NS	No Significant Difference

Fig 5.2.1. Nitrate concentration in the Ploughed treatments (straw removed) at different soil depths and on different dates (mg/l).



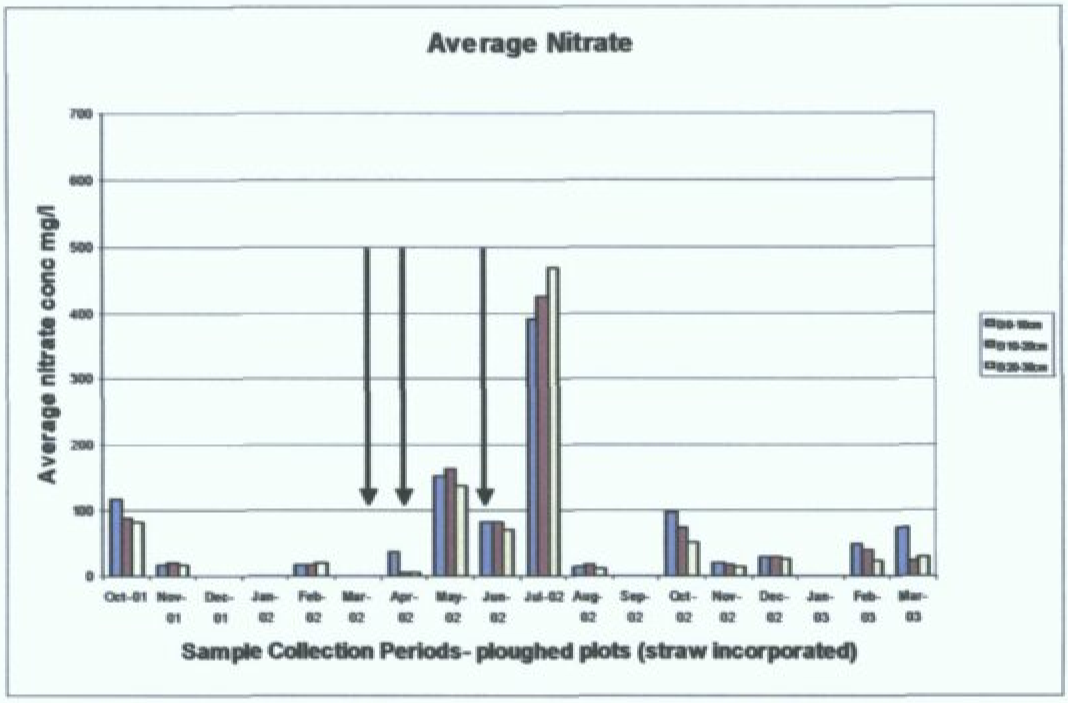
The arrows on the graph indicate the date of fertiliser nitrogen application.

Table 5.2.2. Nitrate concentration in the Ploughed treatments (straw incorporated) at different soil depths and on different dates (mg/l).

| Sample Depth | Oct 2001 | Nov 2001 | Feb 2002 | Apr 2002 | May 2002 | June 2002 | July 2002 | Aug 2002 | Oct 2002 | Nov 2002 | Dec 2002 | Feb 2003 | Mar 2003 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0-10 | 118 | 18 | 17.5 | 37.5 | 153 | 83 | 391.5 | 14.5 | 97.5 | 19 | 27.5 | 49 | 75.5 |
| 10-20 | 89 | 20 | 18.5 | 7 | 163 | 83.5 | 423.5 | 16.5 | 74.2 | 16 | 28.5 | 40 | 23.5 |
| 20-30 | 84.5 | 18 | 20 | 6.5 | 139 | 71.5 | 467.5 | 12 | 51.5 | 15.5 | 26.5 | 24 | 28.5 |
| Mean | 97.2 | 18.7 | 18.7 | 17 | 151.2 | 79.3 | 427.5 | 14.3 | 74.4 | 16.8 | 27.5 | 37.7 | 42.5 |
| Std Devi | 18.18 | 1.15 | 1.26 | 17.76 | 12.06 | 6.79 | 38.16 | 2.25 | 23.00 | 1.89 | 1 | 12.66 | 28.69 |
| Signif | ** | NS | ** | *** | ** | * | *** | * | *** | NS | NS | *** | *** |

Significance Key
| | |
|---|---|
| * | P<0.05 |
| ** | P<0.01 |
| *** | P<0.001 |
| NS | No Significant Difference |

Fig. 5.2.2. Nitrate concentration in the Ploughed treatments (straw incorporated) at different soil depths and on different dates (mg/l).



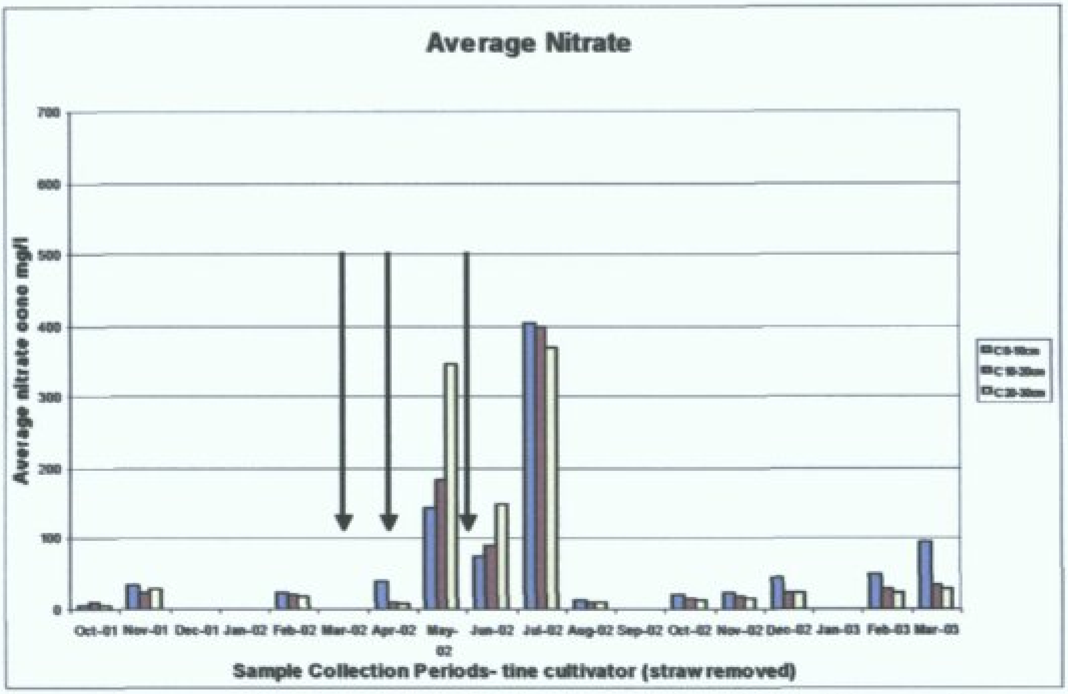
The arrows on the graph indicate the date of fertiliser nitrogen application.

Table 5.2.3. Nitrate concentration in the Reduced treatments (straw removed) at different soil depths and on different dates (mg/l).

| Sample Depth | Oct 2001 | Nov 2001 | Feb 2002 | Apr 2002 | May 2002 | June 2002 | July 2002 | Aug 2002 | Oct 2002 | Nov 2002 | Dec 2002 | Feb 2003 | Mar 2003 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0-10 | 6.5 | 34 | 23.5 | 41 | 144.5 | 74 | 404.5 | 12 | 20 | 23.5 | 44 | 50.5 | 95 |
| 10-20 | 9.5 | 25 | 21.5 | 9.5 | 183 | 89.5 | 400 | 10.5 | 16 | 18.5 | 24.5 | 29 | 35.5 |
| 20-30 | 5 | 29 | 19.5 | 8.5 | 345 | 150 | 370.5 | 10 | 12 | 17 | 25 | 24 | 29 |
| Mean | 7 | 29.3 | 21.5 | 19.7 | 224.2 | 104.5 | 391.7 | 10.8 | 16 | 19.7 | 31.2 | 34.5 | 53.2 |
| Std Devi | 2.29 | 4.51 | 2 | 18.48 | 106.01 | 40.16 | 18.47 | 1.04 | 4 | 3.40 | 11.12 | 14.08 | 36.37 |
| Signif | *** | *** | * | ** | *** | *** | ** | * | * | NS | ** | *** | *** |

Significance Key
* P<0.05
** P<0.01
*** P<0.001
NS No Significant Difference

Fig.5.2.3. Nitrate concentration in the Reduced treatments (straw removed) at different soil depths and on different dates (mg/l).



The arrows on the graph indicate the date of fertiliser nitrogen application.

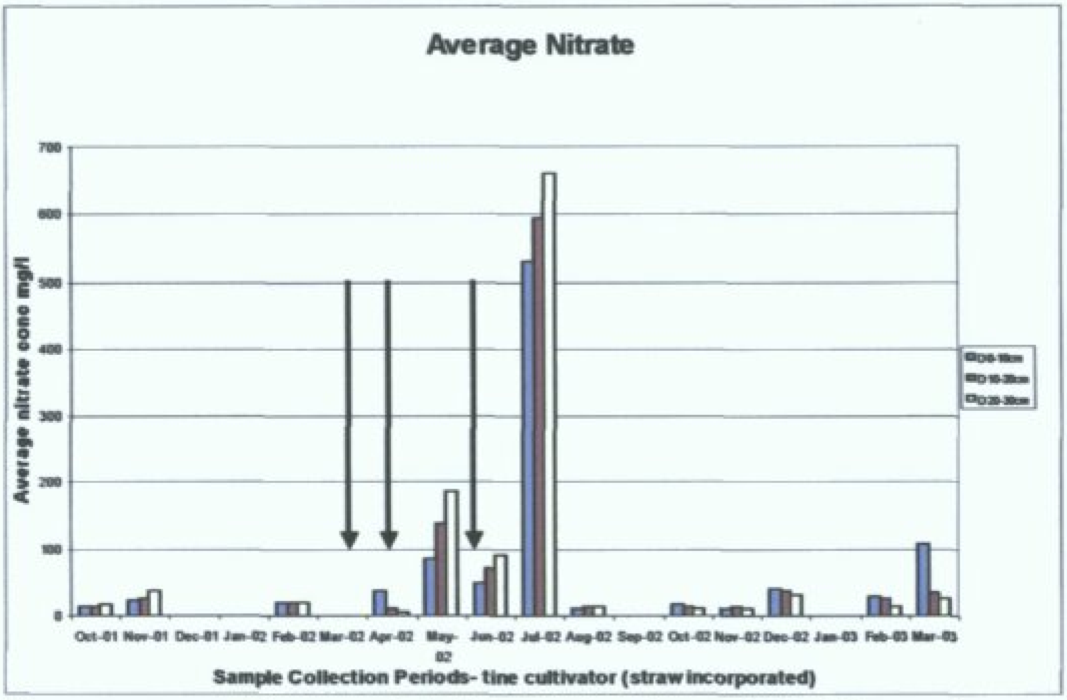
Table 5.2.4. Nitrate concentration in the Reduced treatments (straw incorporated) at different soil depths and on different dates (mg/l).

| Sample Depth | Oct 2001 | Nov 2001 | Feb 2002 | Apr 2002 | May 2002 | June 2002 | July 2002 | Aug 2002 | Oct 2002 | Nov 2002 | Dec 2002 | Feb 2003 | Mar 2003 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0-10 | 15 | 24 | 20.5 | 35.5 | 85 | 48.5 | 531 | 10.5 | 16 | 10.5 | 41 | 27 | 109 |
| 10-20 | 14 | 26 | 20.5 | 10.5 | 139 | 72 | 595.5 | 15 | 13 | 13 | 35.5 | 25.5 | 33.5 |
| 20-30 | 17 | 36 | 20.5 | 6.5 | 187.5 | 91.5 | 659 | 13 | 10 | 11 | 30.5 | 15.5 | 25.5 |
| Mean | 15.3 | 28.7 | 20.5 | 17.5 | 137.2 | 70.7 | 595.2 | 12.8 | 13 | 11.5 | 35.7 | 22.7 | 56 |
| Std Devi | 1.53 | 6.43 | 0 | 15.72 | 51.27 | 21.53 | 64.00 | 2.25 | 3 | 1.32 | 5.25 | 6.25 | 46.07 |
| Signif | NS | ** | NS | *** | *** | *** | *** | NS | * | NS | NS | * | *** |

Significance Key

| | |
|---|---|
| * | P<0.05 |
| ** | P<0.01 |
| *** | P<0.001 |
| NS | No Significant Difference |

Fig.5.2.4. Nitrate concentration in the Reduced treatments (straw incorporated) at different soil depths and on different dates (mg/l).



The arrows on the graph indicate the date of fertiliser nitrogen application.

***Nitrate concentration for each treatment.***

*Table 5.2.1.*

The concentration of nitrate-nitrogen available within the soil profile varies over the growing season, due to nitrogen mineralization rates, utilisation rate, fertiliser application and leaching. Through the winter months and into spring, the concentration of nitrate in soil is low in the ploughed treatments which have straw removed. This occurs at a time when crop requirement for nitrates is low, therefore available nitrate would not be utilised and leaching potential is greatest, due to weather conditions. The low soil temperature also ensures that nitrate mineralization is at a minimum. The application of nitrogen fertilisers occurred after samples were collected during the months of April and July, no samples were obtained in March due to unfavourable weather conditions. These applications did not increase the concentration of nitrate available significantly in March, this was possible due to wet soil conditions which would have caused some of the application to be lost as runoff. Nitrate mineralization reaches a peak in July, with the greatest concentration of nitrogen available at the lower sampling depth of 20-30cm due to leaching. Of the four treatments analysed the conventionally tilled plots with straw removed contain the lowest concentration of nitrate available over the summer period.

*Table 5.2.2.*

Nitrate availability followed the same pattern with and without the incorporation of straw in the ploughed treatments, although the concentration was greater during the period when nitrate mineralization was greatest, where straw was incorporated. Nitrate leaching was also evident in July in these plots, the difference in leaching between sample depths was reduced due to the greater concentration of nitrate available. However, the overall concentration leached was not reduced at the 20-30cm depth.

*Table 5.2.3.*

Thomas and Frye (1984) suggest that lower mineralization, higher leaching and higher denitrification (due to higher surface water content) in reduced tillage tended to lower the available nitrogen particularly in spring, when compared to conventional tillage. This was not determined in this study as the greatest concentration of nitrate fluctuated between treatments over the sampling period, the greatest concentration in spring being determined in the reduced treatments and not the conventional as suggested by Thomas and Frye.

*Table 5.2.4.*

The concentration remained low throughout the majority of the occasions sampled with the incorporation of straw. As had occurred previously at a sample depth of 10-20cm, on eight of the thirteen sampling occasions there was a statistical difference in nitrate concentration through the soil profile, but the greatest concentration was not always determined at a depth of 0-10cm ($P=< 0.001$). On the other five occasions there was no statistical difference in the median values determined for nitrate concentration.

Table. 5.2.5. Nitrate concentration for all four cultivation methods at 0-10cm sampling depth over the sampling period (mg/l).

| Plot Type | Oct 2001 | Nov 2001 | Feb 2002 | Apr 2002 | May 2002 | June 2002 | July 2002 | Aug 2002 | Oct 2002 | Nov 2002 | Dec 2002 | Feb 2003 | Mar 2003 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A | 183.5 | 16 | 16.5 | 18 | 133.5 | 11 | 123 | 29.5 | 125 | 26.5 | 25.5 | 33 | 144 |
| B | 118 | 18 | 17.5 | 37.5 | 153 | 83 | 391.5 | 14.5 | 97.5 | 19 | 27.5 | 49 | 75.5 |
| C | 6.5 | 34 | 23.5 | 41 | 144.5 | 74 | 404.5 | 12 | 20 | 23.5 | 44 | 50.5 | 95 |
| D | 15 | 24 | 20.5 | 35.5 | 85 | 48.5 | 531 | 10.5 | 16 | 10.5 | 41 | 27 | 109 |
| Std D | 85.21 | 8.08 | 3.16 | 10.26 | 30.40 | 32.25 | 171.62 | 8.74 | 55.02 | 6.97 | 9.35 | 11.68 | 28.89 |
| Signif | *** | *** | *** | NS | *** | *** | *** | ** | *** | ** | NS | *** | NS |

Key

A = Conventional tillage (straw removed)

B = Conventional tillage (straw incorporated)

C = Reduced tillage (straw removed)

D = Reduced tillage (straw incorporated)

Significance Key
* P<0.05
** P<0.01
*** P<0.001
NS No Significant Difference

Fig.5.2.5. Nitrate concentration for all four cultivation methods at 0-10cm sampling depth over the sampling period (mg/l).

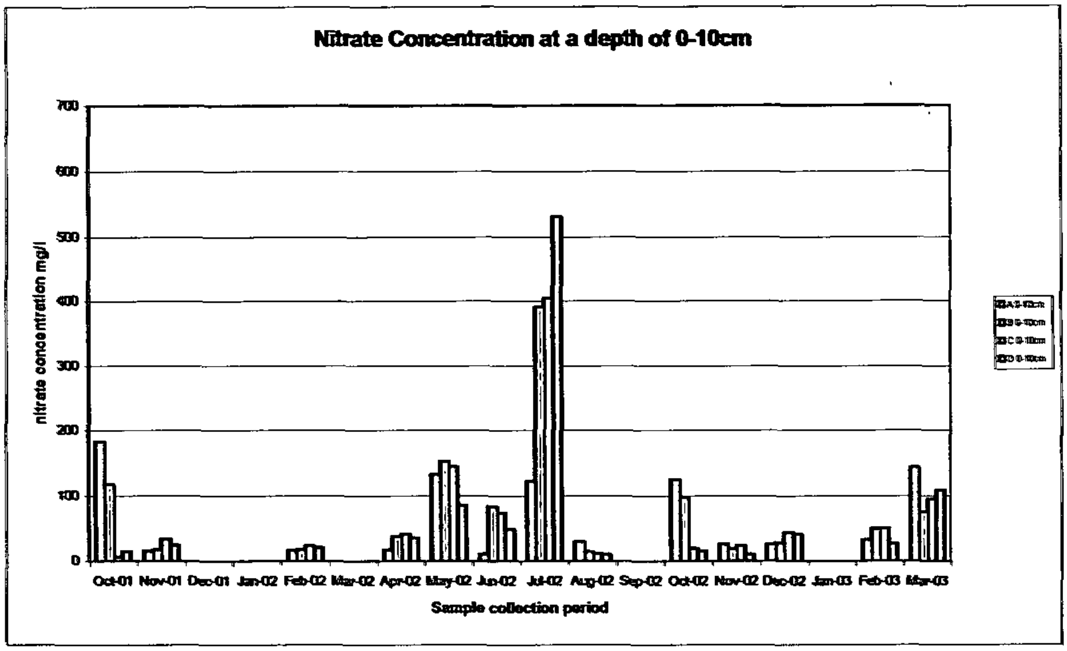


Table. 5.2.6. Nitrate concentration for all four cultivation methods at 10-20cm sampling depth over the sampling period (mg/l).

| Plot Type | Oct 2001 | Nov 2001 | Feb 2002 | Apr 2002 | May 2002 | June 2002 | July 2002 | Aug 2002 | Oct 2002 | Nov 2002 | Dec 2002 | Feb 2003 | Mar 2003 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A | 96.5 | 8 | 18.5 | 4.5 | 162.5 | 11 | 174 | 17.5 | 87.1 | 26 | 26.5 | 20.5 | 29 |
| B | 89 | 20 | 18.5 | 7 | 163 | 83.5 | 423.5 | 16.5 | 74.2 | 16 | 28.5 | 40 | 23.5 |
| C | 9.5 | 25 | 21.5 | 9.5 | 183 | 89.5 | 400 | 10.5 | 16 | 18.5 | 24.5 | 29 | 35.5 |
| D | 14 | 26 | 20.5 | 10.5 | 139 | 72 | 595.5 | 15 | 13 | 13 | 35.5 | 25.5 | 33.5 |
| Std D | 46.90 | 8.26 | 1.5 | 2.69 | 17.99 | 36.07 | 173.0 | 3.09 | 38.57 | 5.56 | 4.78 | 8.27 | 5.33 |
| Signif | *** | ** | NS | *** | *** | *** | *** | NS | *** | ** | ** | ** | ** |

Key

A = Conventional tillage (straw removed)

B = Conventional tillage (straw incorporated)

C = Reduced tillage (straw removed)

D = Reduced tillage (straw incorporated)

Significance Key

| | |
|---|---|
| * | P<0.05 |
| ** | P<0.01 |
| *** | P<0.001 |
| NS | No Significant Difference |

Fig.5.2.6. Nitrate concentration for all four cultivation methods at 10-20cm sampling depth over the sampling period (mg/l).

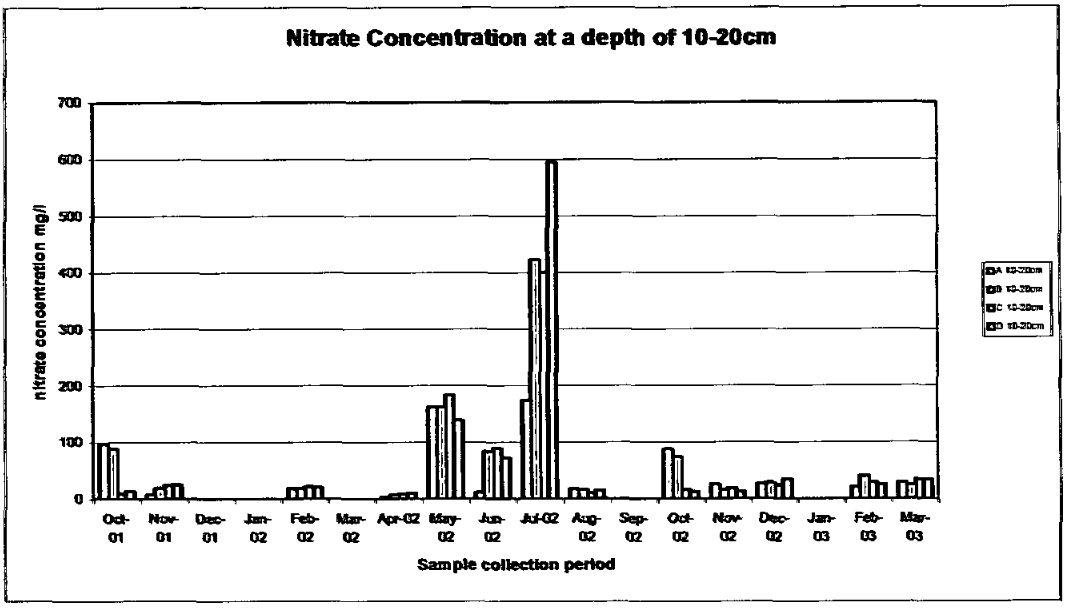


Table. 5.2.7. Nitrate concentration for all four cultivation methods at 20-30cm sampling depth over the sampling period (mg/l).

| Plot Type | Oct 2001 | Nov 2001 | Feb 2002 | Apr 2002 | May 2002 | June 2002 | July 2002 | Aug 2002 | Oct 2002 | Nov 2002 | Dec 2002 | Feb 2003 | Mar 2003 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A | 73.5 | 15 | 15.5 | 4.5 | 117 | 10 | 466.5 | 10 | 66.3 | 17 | 30 | 23.5 | 28 |
| B | 84.5 | 18 | 20 | 6.5 | 139 | 71.5 | 467.5 | 12 | 51.5 | 15.5 | 26.5 | 24 | 28.5 |
| C | 5 | 29 | 19.5 | 8.5 | 345 | 150 | 370.5 | 10 | 12 | 17 | 25 | 24 | 29 |
| D | 17 | 36 | 20.5 | 6.5 | 187.5 | 91.5 | 659 | 13 | 10 | 11 | 30.5 | 15.5 | 25.5 |
| Std D | 39.82 | 9.75 | 2.29 | 1.63 | 102.9 | 57.74 | 120.9 | 1.5 | 28.32 | 2.84 | 2.68 | 4.17 | 1.55 |
| Signif | *** | *** | *** | ** | *** | *** | *** | ** | *** | ** | * | ** | NS |

Key

A = Conventional tillage (straw removed)

B = Conventional tillage (straw incorporated)

C = Reduced tillage (straw removed)

D = Reduced tillage (straw incorporated)

Significance Key

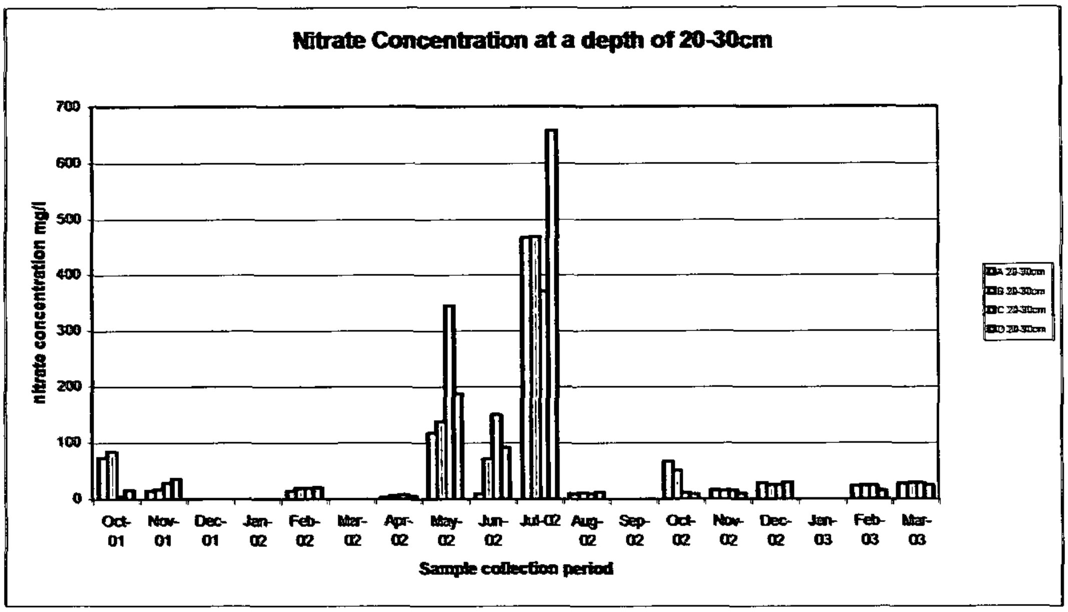
* $P<0.05$

** $P<0.01$

*** $P<0.001$

NS No Significant Difference

Fig.5.2.7. Nitrate concentration for all four cultivation methods at 20-30cm sampling depth over the sampling period (mg/l).



***Nitrate concentration. Comparing the three sample depths.***

*Table 5.2.5.*

The conventionally tilled plots contain higher concentration of nitrate during the autumn, as moisture contents increase and the soil temperature remains high. These plots are more prone to moisture stress during the summer months, therefore when the percentage moisture increase the rate of mineralization also increases.

The reduced cultivation plots contained a higher concentration of nitrate at a sampling depth of 0-10 cm both with and without the incorporation of straw than the plots, which were treated with the conventional *tillage treatment* during the summer. These plots retain a higher content of water, therefore moisture stress would not be as great and mineralization would not be affected.

*Table 5.2.6.*

At the lower sampling depth of 10-20cm the concentration of nitrate reduces throughout most of the crop growth season. As evident in the overlying soil layer, there is a higher concentration of nitrate during autumn for the conventionally tilled plots at 10-20cm, whereas the reduced cultivation treatments contain higher concentrations of nitrate during the summer months.

The greatest concentration of nitrate occurred in the reduced cultivation plots, which had incorporated straw. This can be attributed to the slower soil warming of the reduced cultivation plots early in the season, and the maintenance of higher soil water contents.

*Table 5.2.7.*

When treatments were compared at a sampling depth of 20-30cm the reduced cultivation plots continued to contain a higher concentration of nitrate during the summer months. At this sample depth this occurrence was due to leaching, as water infiltration rates increase under reduced cultivation. However, the incorporation of straw is expected to reduce the occurrence of leaching. The conventional tillage treatment also contain higher concentration of nitrate during October than the reduced treatment.

Table 5.2.8. Variation of Nitrate concentration at the three sample depths for each of the cultivation methods (mg/l).

| Plot Type | 0-10cm depth | 10-20cm depth | 20-30cm depth |
|---|---|---|---|
| A | 77.38 | 58.82 | 73.98 |
| B | 95.38 | 82.13 | 81.04 |
| C | 85.54 | 74.88 | 87.50 |
| D | 82.19 | 85.35 | 97.23 |

Key

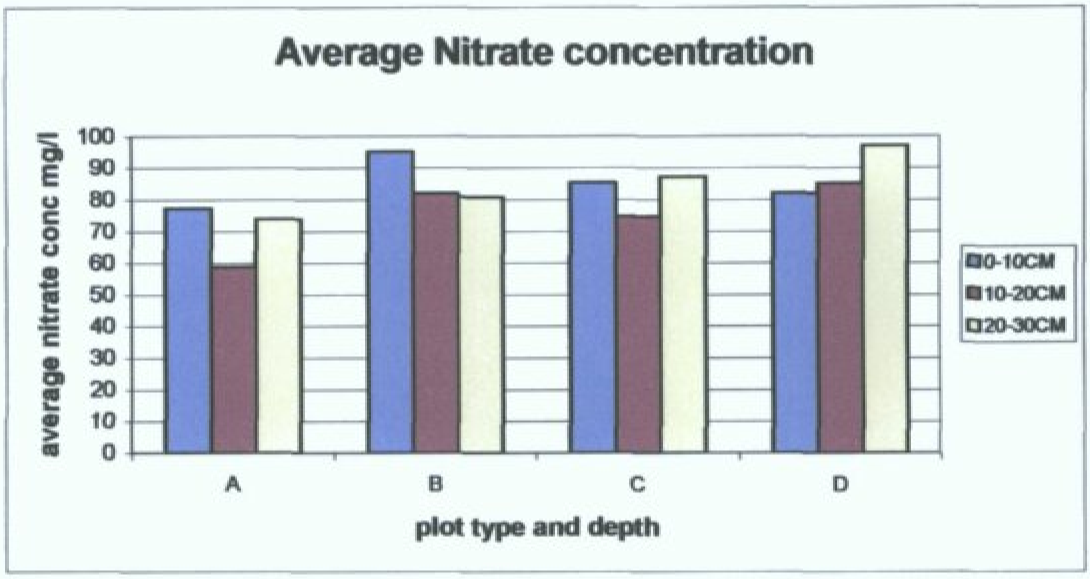
A = Conventional tillage (straw removed)

B = Conventional tillage (straw incorporated)

C = Reduced tillage (straw removed)

D = Reduced tillage (straw incorporated)

Fig.5.2.8. Variation of Nitrate concentration at the three sample depths for each of the cultivation methods (mg/l).



### ***Variation of Nitrate concentration at the three sample depths for each of the cultivation methods.***

From these results it is possible to determine that treatments of conventional tillage with straw incorporated contain the greatest concentration of nitrate in the top 10cm of soil, over the thirteen month sampling period. On comparison the reduced cultivation plots contain the greatest concentration on nitrates at the lowest sampling depth of 20-30cm with or without straw incorporation, which indicates that under this form of cultivation there is a greater quantity of nitrate leaching.

At a sample depth of 10-20cm both the conventional and reduced treatments, which had incorporated straw contained a higher concentration of nitrate than those which had removed straw.

## *5.3. PHOSPHORUS RESULTS*

The available phosphorus concentration of soils was determined by use of Morgans extracting reagent, as outlined previously. All analysis was carried out in triplicate on air-dried soil samples. The following results were determined by averaging six figures for each sample depth during each month, results are supplied in Appendix A.

Results are tabulated for each cultivation method over the sampling period, before each depth is viewed in greater detail.

Table 5.3.1. Represents the concentration of phosphorus available for the growing crops over the sampling period, under conventional tillage with straw removed.

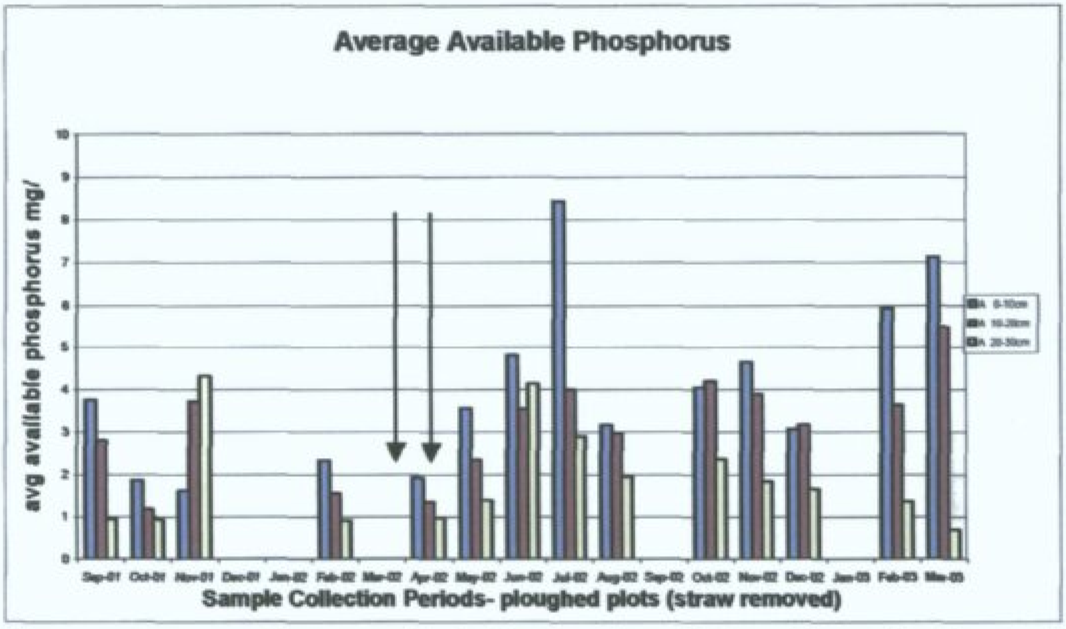
Table 5.3.1. Available Phosphorus concentration in the Ploughed treatments (straw removed) at different soil depths and on different sampling dates (mg/l).

| Sample Depth | Sept 2001 | Oct 2001 | Nov 2001 | Feb 2002 | Apr 2002 | May 2002 | June 2002 | July 2002 | Aug 2002 | Oct 2002 | Nov 2002 | Dec 2002 | Feb 2003 | Mar 2003 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0-10 | 3.77 | 1.87 | 1.62 | 2.34 | 1.93 | 3.57 | 4.81 | 8.43 | 3.17 | 4.06 | 4.65 | 3.07 | 5.94 | 7.14 |
| 10-20 | 2.81 | 1.18 | 3.72 | 1.56 | 1.36 | 2.35 | 3.55 | 4.01 | 2.97 | 4.2 | 3.89 | 3.17 | 3.64 | 5.49 |
| 20-30 | 0.95 | 0.95 | 4.32 | 0.92 | 0.98 | 1.39 | 4.14 | 2.91 | 1.97 | 2.37 | 1.83 | 1.67 | 1.37 | 0.7 |
| Mean | 2.51 | 1.33 | 3.22 | 1.61 | 1.42 | 2.44 | 4.17 | 5.12 | 2.70 | 3.54 | 3.46 | 2.64 | 3.65 | 4.44 |
| Std D | 1.433 | 0.478 | 2.55 | 0.711 | 0.478 | 1.09 | 0.630 | 2.921 | 0.643 | 1.019 | 2.534 | 0.838 | 2.285 | 3.345 |
| Signif | *** | *** | *** | NS | *** | *** | *** | *** | *** | *** | *** | *** | *** | *** |

Significance Key

| | |
|---|---|
| * | $P<0.05$ |
| ** | $P<0.01$ |
| *** | $P<0.001$ |
| NS | No Significant Difference |

Fig 5.3.1. Available Phosphorus concentration in the Ploughed treatments (straw removed) at different soil depths and on different sampling dates (mg/l).



The arrows on the graph indicate the date of application of phosphorus fertilisers.

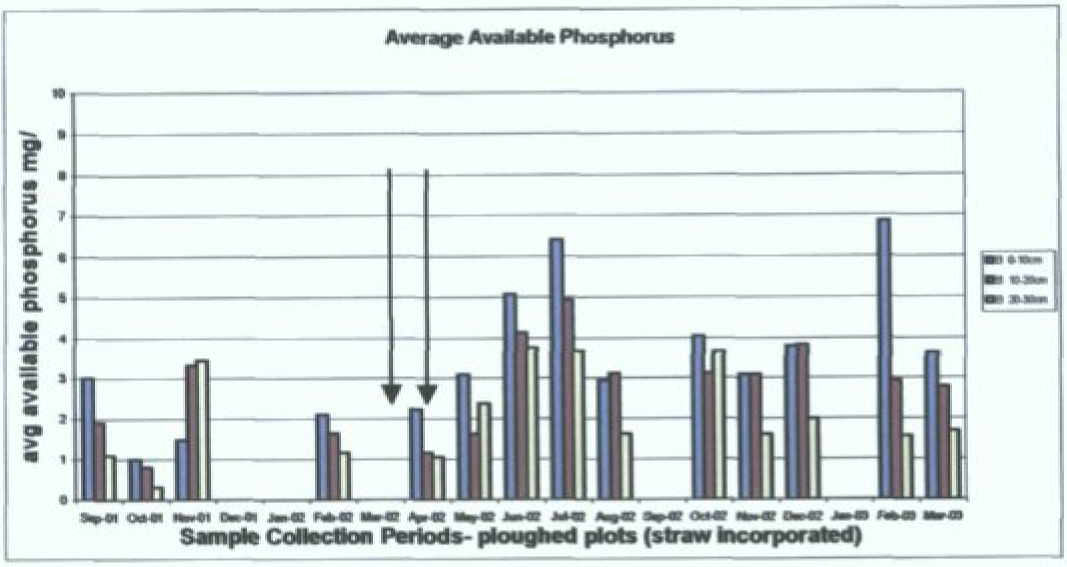
Table 5.3.2. Available Phosphorus concentration in the Ploughed treatments (straw incorporated) at different soil depths and on different sampling dates (mg/l).

| Sample Depth | Sept 2001 | Oct 2001 | Nov 2001 | Feb 2002 | Apr 2002 | May 2002 | June 2002 | July 2002 | Aug 2002 | Oct 2002 | Nov 2002 | Dec 2002 | Feb 2003 | Mar 2003 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0-10 | 3.01 | 1.01 | 1.48 | 2.11 | 2.23 | 3.09 | 5.07 | 6.4 | 2.95 | 4.06 | 3.08 | 3.81 | 6.86 | 3.63 |
| 10-20 | 1.92 | 0.81 | 3.32 | 1.64 | 1.16 | 1.62 | 4.16 | 4.93 | 3.12 | 3.13 | 3.09 | 3.83 | 2.93 | 2.78 |
| 20-30 | 1.1 | 0.32 | 3.45 | 1.16 | 1.1 | 2.37 | 3.75 | 3.67 | 1.62 | 3.66 | 1.6 | 1.99 | 1.57 | 1.68 |
| Mean | 2.01 | 0.71 | 2.75 | 1.64 | 1.50 | 2.36 | 4.33 | 5 | 2.56 | 3.62 | 2.59 | 3.21 | 3.79 | 2.70 |
| Std D | 0.958 | 0.355 | 1.017 | 0.475 | 0.636 | 0.735 | 0.676 | 1.366 | 0.821 | 0.466 | 0.857 | 1.056 | 2.747 | 0.977 |
| Signif | *** | *** | *** | NS | *** | *** | *** | *** | *** | *** | ** | *** | *** | *** |

Significance Key

| | |
|---|---|
| * | $P<0.05$ |
| ** | $P<0.01$ |
| *** | $P<0.001$ |
| NS | No Significant Difference |

Fig. 5.3.2. Available Phosphorus concentration in the Ploughed treatments (straw incorporated) at different soil depths and on different sampling dates (mg/l).



The arrows on the graph indicate the date of application of phosphorus fertilisers.

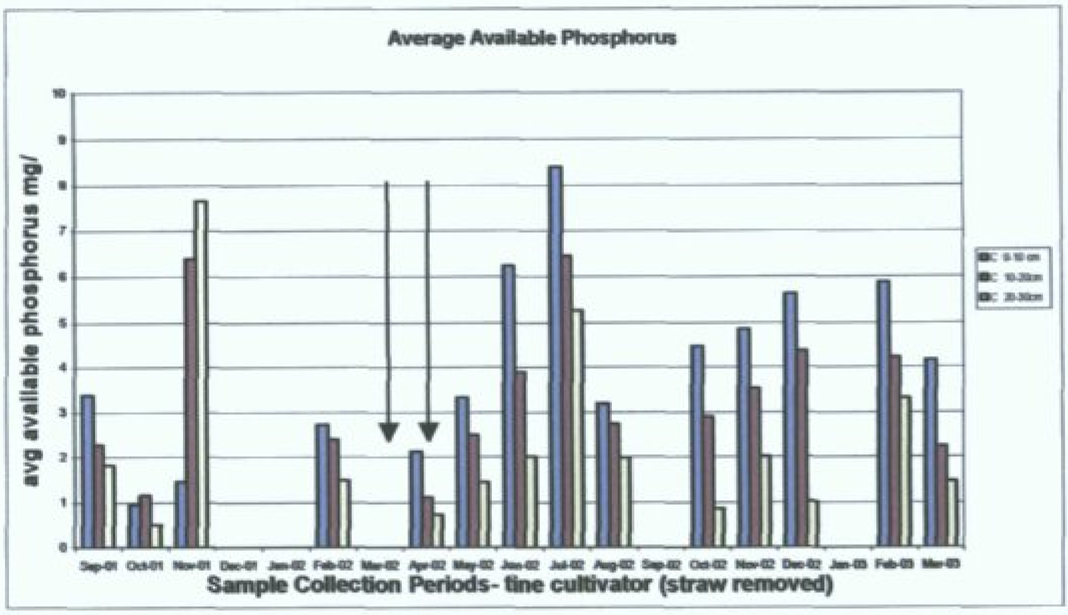
Table 5.3.3. Available Phosphorus concentration in the Reduced treatments (straw removed) at different soil depths and on different sampling dates (mg/l).

| Sample Depth | Sept 2001 | Oct 2001 | Nov 2001 | Feb 2002 | Apr 2002 | May 2002 | June 2002 | July 2002 | Aug 2002 | Oct 2002 | Nov 2002 | Dec 2002 | Feb 2003 | Mar 2003 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0-10 | 3.39 | 0.97 | 1.46 | 2.73 | 2.13 | 3.32 | 6.24 | 8.4 | 3.19 | 4.47 | 4.85 | 5.64 | 5.89 | 4.16 |
| 10-20 | 2.28 | 1.16 | 6.39 | 2.4 | 1.13 | 2.5 | 3.9 | 6.45 | 2.74 | 2.9 | 3.52 | 4.37 | 4.23 | 2.25 |
| 20-30 | 1.84 | 0.51 | 7.66 | 1.5 | 0.73 | 1.45 | 2.02 | 5.28 | 1.99 | 0.87 | 2.02 | 1.02 | 3.31 | 1.46 |
| Mean | 2.50 | 0.88 | 5.17 | 2.21 | 1.33 | 2.42 | 4.05 | 6.71 | 2.64 | 2.75 | 3.46 | 3.67 | 4.48 | 2.62 |
| Std D | 0.798 | 0.334 | 3.275 | 0.636 | 0.721 | 0.937 | 2.114 | 1.576 | 0.606 | 1.804 | 1.415 | 2.386 | 1.307 | 1.388 |
| Signif | *** | *** | *** | NS | *** | *** | *** | *** | *** | *** | *** | *** | *** | *** |

Significance Key

| | |
|---|---|
| * | P<0.05 |
| ** | P<0.01 |
| *** | P<0.001 |
| NS | No Significant Difference |

Fig 5.3.3. Available Phosphorus concentration in the Reduced treatments (straw removed) at different soil depths and on different sampling dates (mg/l).



The arrows on the graph indicate the date of application of phosphorus fertilisers.

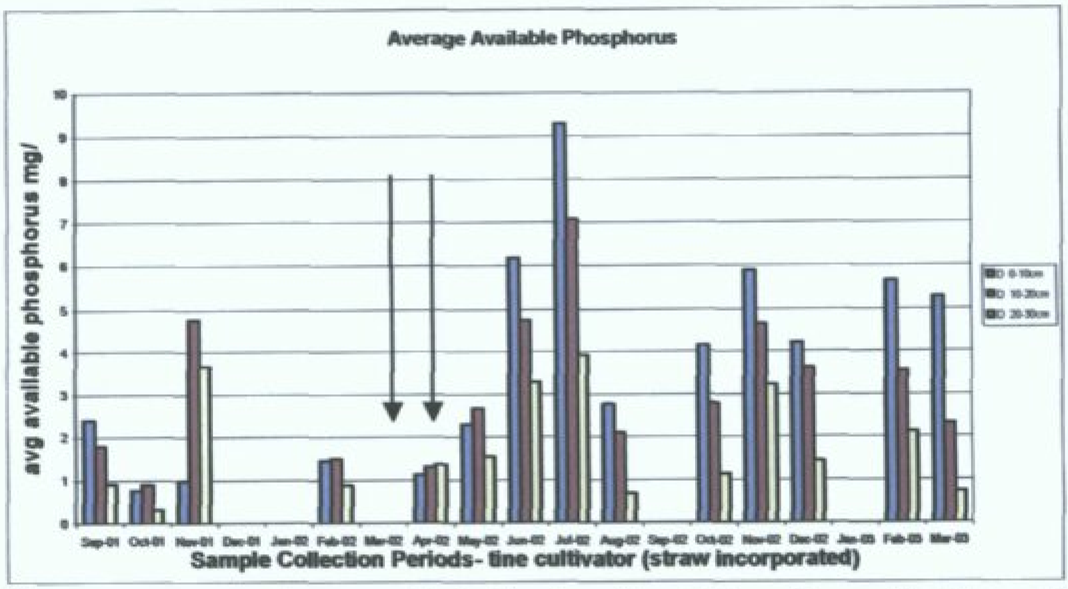
Table 5.3.4. Available Phosphorus concentration in the Reduced treatments (straw incorporated) at different soil depths and on different sampling dates (mg/l).

| Sample Depth | Sept 2001 | Oct 2001 | Nov 2001 | Feb 2002 | Apr 2002 | May 2002 | June 2002 | July 2002 | Aug 2002 | Oct 2002 | Nov 2002 | Dec 2002 | Feb 2003 | Mar 2003 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0-10 | 2.41 | 0.77 | 0.99 | 1.46 | 1.16 | 2.3 | 6.18 | 9.3 | 2.77 | 4.15 | 5.9 | 4.21 | 5.65 | 5.27 |
| 10-20 | 1.8 | 0.9 | 4.78 | 1.5 | 1.31 | 2.68 | 4.77 | 7.08 | 2.1 | 2.79 | 4.67 | 3.62 | 3.56 | 2.31 |
| 20-30 | 0.92 | 0.32 | 3.67 | 0.89 | 1.37 | 1.55 | 3.29 | 3.91 | 0.68 | 1.15 | 3.23 | 1.44 | 2.11 | 0.73 |
| Mean | 1.71 | 0.66 | 3.15 | 1.28 | 1.28 | 2.18 | 4.75 | 6.76 | 1.85 | 2.70 | 4.6 | 3.09 | 3.77 | 2.77 |
| Std D | 0.749 | 0.304 | 1.948 | 0.341 | 0.108 | 0.575 | 1.445 | 2.708 | 1.067 | 1.502 | 1.336 | 1.459 | 1.779 | 2.304 |
| Signif | *** | ** | *** | *** | *** | *** | *** | *** | *** | *** | *** | *** | *** | *** |

Significance Key

| | |
|---|---|
| * | P<0.05 |
| ** | P<0.01 |
| *** | P<0.001 |
| NS | No Significant Difference |

Fig 5.3.4. Available Phosphorus concentration in the Reduced treatments (straw incorporated) at different soil depths and on different sampling dates (mg/l).



The arrows on the graph indicate the date of application of phosphorus fertilisers.

### *Available Phosphorus concentration for each treatment.*

*Table 5.3.1.*

The concentration of phosphorus can be seen to fluctuate through the sampling period in the conventional treatments which had straw removed. An increase in phosphorus concentration occurs after the application of fertiliser, until a peak is reached in July. This increase is not only due to fertiliser application but also due to the increased quantity of phosphorus mineralization in the soil as soil temperature increased.

*Table 5.3.2.*

Available phosphorus concentration can be seen to follow the same pattern of distribution both with and without the incorporation of straw under conventional tillage. However, the rate of mineralization of soil phosphorus was greater where straw was removed, as these plots contained a greater concentration of phosphorus in July. The incorporation of straw into plots may have slowed down the processes of soil warming, therefore reducing the concentration of phosphorus made available through mineralization. The distribution of available phosphorus through the soil profile after the crop was resown was greater where straw was incorporated (as observed in autumn 2002).

*Table 5.3.3.*

The loss of phosphorus in soils is greatest through soil erosion and runoff, however in November of 2001 a large concentration of available phosphorus was present at the lower sampling depths in the soil profile due to leaching. These levels were statistically greater under reduced tillage than under conventional tillage at this time. The reduction in the quantity of soil disturbance in this tillage system, leads to a distinct reduction in phosphorus concentration throughout the sampling period.

*Table 5.3.4.*

The pattern of phosphorus availability remained the same for all four treatments. However, the incorporation of straw to the plots treated with reduced cultivation reduced the concentration of available phosphorus leached significantly, at the lower sampling depths in November when compared to the reduced cultivation plots with straw removed.

Mineralization of soil phosphorus was slowest in this treatment system but peaked at the highest concentration in July, the incorporation of straw slowing down the rate of soil warming in early summer. The concentration of available phosphorus can be seen to increase over time in all four treatments, as the application of fertiliser phosphorus does not have an immediate impact on the soil but is released gradually over time, which allows it to become built up in the soil profile (Tunney et al., 2000).

Table 5.3.5. Available Phosphorus concentration for all four cultivation methods at 0-10cm sampling depth over the sampling period (mg/l).

| Plot Type | Sep 2001 | Oct 2001 | Nov 2001 | Feb 2002 | Apr 2002 | May 2002 | June 2002 | July 2002 | Aug 2002 | Oct 2002 | Nov 2002 | Dec 2002 | Feb 2003 | Mar 2003 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A | 3.77 | 1.87 | 1.62 | 2.34 | 1.93 | 3.57 | 4.81 | 8.43 | 3.17 | 4.06 | 4.65 | 3.07 | 5.94 | 7.14 |
| B | 3.01 | 1.01 | 1.48 | 2.1 | 2.23 | 3.09 | 5.07 | 6.4 | 2.95 | 4.06 | 3.08 | 3.81 | 6.86 | 3.63 |
| C | 3.39 | 0.97 | 1.46 | 2.73 | 2.13 | 3.32 | 6.24 | 8.4 | 3.19 | 4.47 | 4.85 | 5.64 | 5.89 | 4.16 |
| D | 2.41 | 0.77 | 0.99 | 1.46 | 1.16 | 2.3 | 6.18 | 9.3 | 2.77 | 4.15 | 5.9 | 4.21 | 5.65 | 5.27 |
| Std D | 0.579 | 0.488 | 0.274 | 0.532 | 0.484 | 0.549 | 0.741 | 1.228 | 0.199 | 0.195 | 1.164 | 1.080 | 0.532 | 1.552 |
| Signif | *** | *** | NS | *** | NS | *** | ** | NS | NS | NS | *** | *** | NS | *** |

Key

A = Conventional tillage (straw removed)

B = Conventional tillage (straw incorporated)

C = Reduced tillage (straw removed)

D = Reduced tillage (straw incorporated)

Significance Key

| | |
|---|---|
| * | P<0.05 |
| ** | P<0.01 |
| *** | P<0.001 |
| NS | No Significant Difference |

Fig 5.3.5. Available Phosphorus concentration for all four cultivation methods at 0-10cm sampling depth over the sampling period(mg/l).

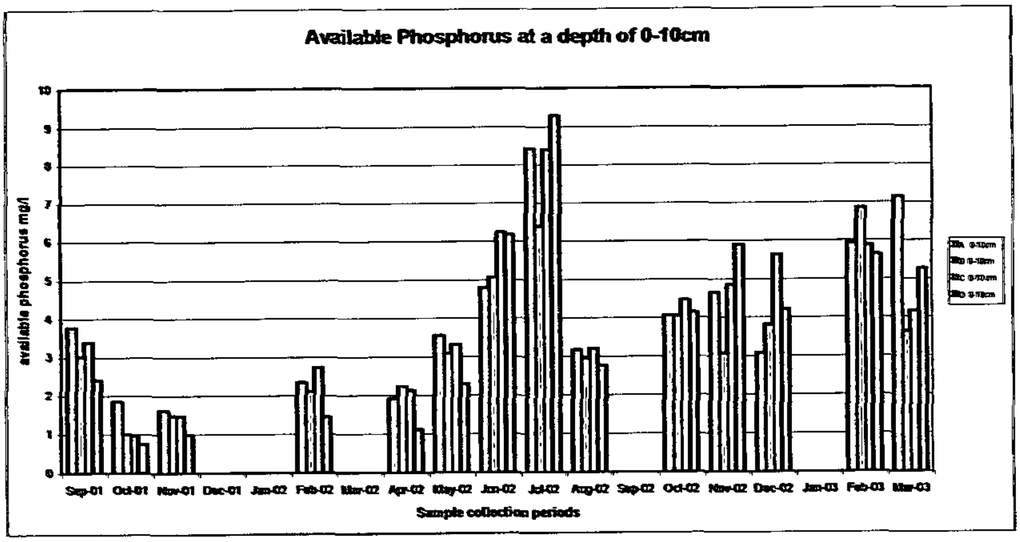


Table 5.3.6. Available Phosphorus concentration for all four cultivation methods at 10-20cm sampling depth over the sampling period (mg/l).

| Plot Type | Sep 2001 | Oct 2001 | Nov 2001 | Feb 2002 | Apr 2002 | May 2002 | June 2002 | July 2002 | Aug 2002 | Oct 2002 | Nov 2002 | Dec 2002 | Feb 2003 | Mar 2003 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A | 2.81 | 1.18 | 3.72 | 1.56 | 1.36 | 2.35 | 3.55 | 4.01 | 2.97 | 4.2 | 3.89 | 3.17 | 3.64 | 5.49 |
| B | 1.92 | 0.81 | 3.32 | 1.64 | 1.16 | 1.62 | 4.16 | 4.93 | 3.16 | 3.13 | 3.09 | 3.83 | 2.93 | 2.78 |
| C | 2.28 | 1.16 | 6.39 | 2.4 | 1.13 | 2.5 | 3.9 | 6.45 | 2.74 | 2.9 | 3.52 | 4.37 | 4.23 | 2.25 |
| D | 1.8 | 0.9 | 4.78 | 1.5 | 1.31 | 2.68 | 4.77 | 7.08 | 2.1 | 2.79 | 4.67 | 3.62 | 3.56 | 2.31 |
| Std D | 0.453 | 0.185 | 1.371 | 0.421 | 0.112 | 0.465 | 0.515 | 1.401 | 0.461 | 0.646 | 0.671 | 0.498 | 0.532 | 1.540 |
| Signif | NS | NS | ** | ** | NS | *** | *** | ** | NS | NS | NS | NS | ** | *** |

Key

A = Conventional tillage (straw removed)

B = Conventional tillage (straw incorporated)

C = Reduced tillage (straw removed)

D = Reduced tillage (straw incorporated)

Significance Key

* P<0.05

** P<0.01

*** P<0.001

NS No Significant Difference

Fig 5.3.6. Available Phosphorus concentration for all four cultivation methods at 10-20cm sampling depth over the sampling period (mg/l).

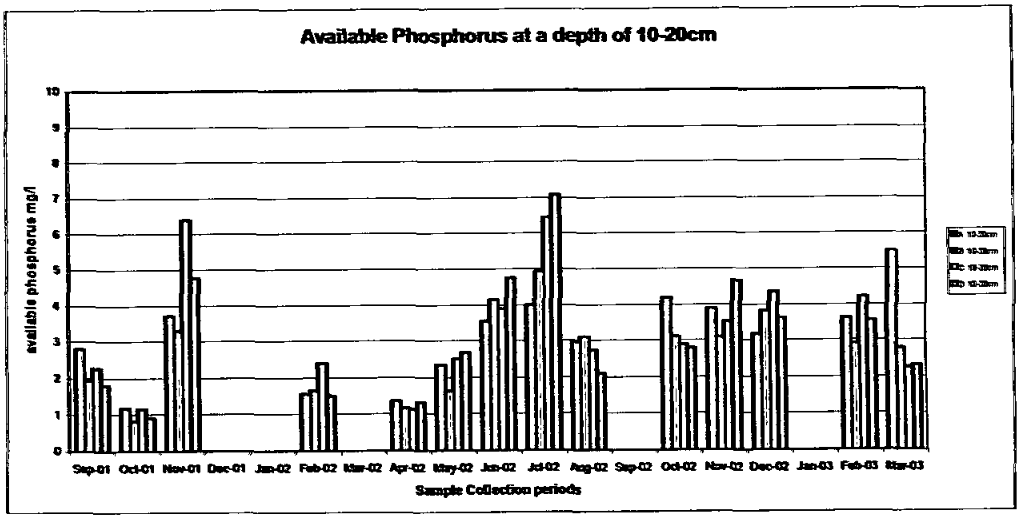


Table 5.3.7. Available Phosphorus concentration for all four cultivation methods at 20-30cm sampling depth over the sampling period (mg/l).

| Plot Type | Sep 2001 | Oct 2001 | Nov 2001 | Feb 2002 | Apr 2002 | May 2002 | June 2002 | July 2002 | Aug 2002 | Oct 2002 | Nov 2002 | Dec 2002 | Feb 2003 | Mar 2003 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A | 0.95 | 0.95 | 4.32 | 0.92 | 0.98 | 1.39 | 4.14 | 2.91 | 1.97 | 2.37 | 1.83 | 1.67 | 1.37 | 0.7 |
| B | 1.1 | 0.32 | 3.45 | 1.16 | 1.06 | 2.37 | 3.75 | 3.67 | 1.62 | 3.66 | 1.6 | 1.99 | 1.57 | 1.68 |
| C | 1.84 | 0.51 | 7.66 | 1.5 | 0.73 | 1.46 | 2.02 | 5.28 | 1.99 | 0.87 | 2.02 | 1.02 | 3.31 | 1.46 |
| D | 0.92 | 0.32 | 3.67 | 0.89 | 1.37 | 1.55 | 3.29 | 3.91 | 0.68 | 1.15 | 3.23 | 1.44 | 2.11 | 0.73 |
| Std D | 0.432 | 0.297 | 1.958 | 0.282 | 0.263 | 0.456 | 0.921 | 0.988 | 0.614 | 1.277 | 0.727 | 0.408 | 0.871 | 0.502 |
| Signif | * | NS | *** | *** | NS | *** | *** | NS | * | *** | ** | * | *** | *** |

Key

A = Conventional tillage (straw removed)

B = Conventional tillage (straw incorporated)

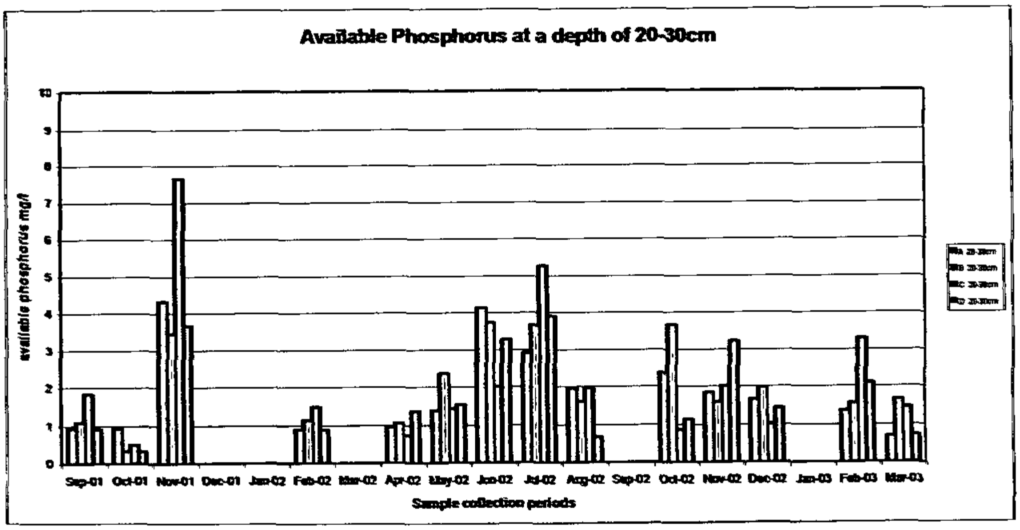
C = Reduced tillage (straw removed)

D = Reduced tillage (straw incorporated)

Significance Key

| | |
|---|---|
| * | P<0.05 |
| ** | P<0.01 |
| *** | P<0.001 |
| NS | No Significant Difference |

Fig 5.3.7. Available Phosphorus concentration for all four cultivation methods at 20-30cm sampling depth over the sampling period (mg/l).



### *Available Phosphorus. Comparing the three sample depths.*

*Table 5.3.5.*

The concentration of available phosphorus is greater in the treatments which had removed straw, than those which had incorporated straw, although these differences are not great enough to be statistically different. Previous studies have determined that over time the concentration of phosphorus increases in the top 10cm under reduced cultivation, and reduce in concentration below this sampling depth (Triplett and Van Doren, 1969). This was not evident in the early stages of this project but may develop over time.

*Table 5.3.6.*

Throughout most of the sampling period at a sampling depth of 10-20cm there was no statistical difference in available phosphorus concentration. On five occasions however, the concentration of phosphorus was statistically greater in the plots which were treated by reduced cultivation. These increases in concentration occurred during the wetter sampling periods (i.e. November 2001, 2002 and February) and during the summer months of June and July when mineralization was greater in these treatments.

The incorporation of straw in the reduced cultivation plots appeared to reduce the concentration of phosphorus leached through the soil profile in November of 2001.

*Table 5.3.7.*

As had occurred at a sampling depth of 10-20cm, during wetter periods the concentration of available phosphorus increased in the reduced cultivation plots to levels greater than those observed under conventional tillage.

The following table contains average values for available phosphorus determined by averaging all previous results tabulated (over the fourteen month sampling period).

Table 5.3.8. Variation of Available Phosphorus concentration at the three sample depths for each of the cultivation methods (mg/l).

| Plot Type | 0-10cm depth | 10-20cm depth | 20-30cm depth |
|---|---|---|---|
| A | 4.03 | 3.14 | 1.89 |
| B | 3.48 | 2.75 | 2.07 |
| C | 4.06 | 3.30 | 2.26 |
| D | 3.75 | 3.13 | 1.80 |

Key

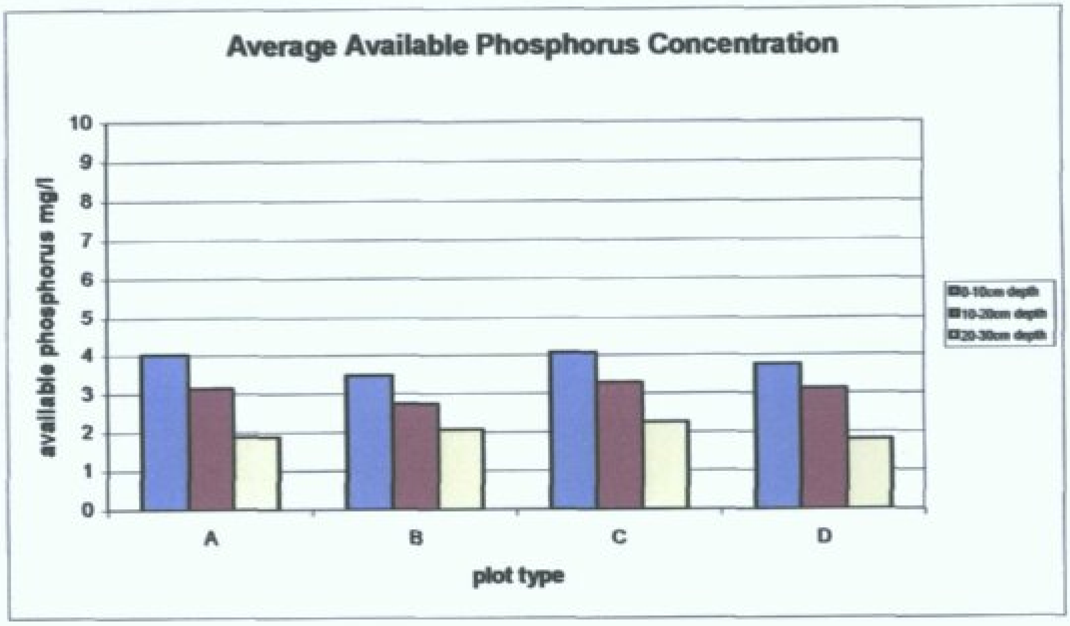
A = Conventional tillage (straw removed)

B = Conventional tillage (straw incorporated)

C = Reduced tillage (straw removed)

D = Reduced tillage (straw incorporated)

Fig 5.3.8. Variation of Available Phosphorus concentration at the three sample depths for each of the cultivation methods (mg/l).



## *5.4. POTASSIUM RESULTS*

Flame photometry analysis was used to determine the concentration of exchangeable potassium in air-dried soil samples, by extraction in "Morgans" solution. All analysis was carried out in triplicate and each value tabulated was determined by the averaging of 6 results.

The following tables contain values for exchangeable potassium present in the soil samples of each of the four treatments over the fourteen-month period, at each of the three sample depths.
Results are also included for all four treatments when directly compared at the three sample depths, as well as the average concentration of potassium over the sampling programme.

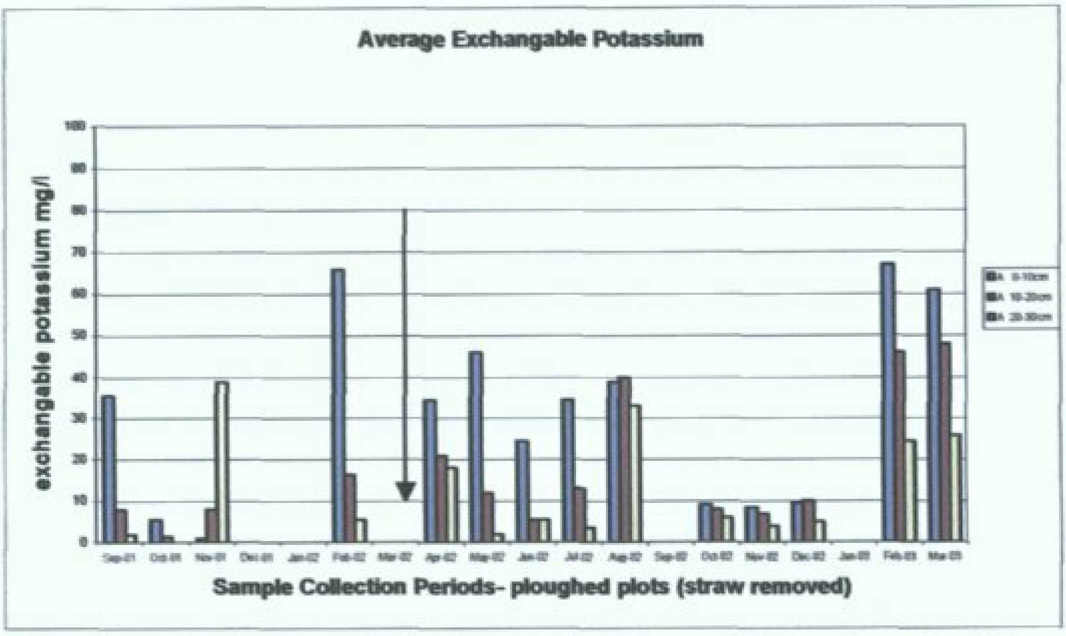
Table 5.4.1. Exchangeable Potassium concentration in the Ploughed treatments (straw removed) at different soil depths and on different sampling dates (mg/l).

| Sample Depth | Sept 2001 | Oct 2001 | Nov 2001 | Feb 2002 | Apr 2002 | May 2002 | June 2002 | July 2002 | Aug 2002 | Oct 2002 | Nov 2002 | Dec 2002 | Feb 2003 | Mar 2003 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0-10 | 35.5 | 5.5 | 1 | 66 | 34.5 | 46 | 24.5 | 34.5 | 39 | 9 | 8.5 | 9.5 | 67 | 61 |
| 10-20 | 8 | 1.5 | 8 | 16.5 | 21 | 12 | 5.5 | 13 | 40 | 8 | 7 | 10 | 46 | 48 |
| 20-30 | 2 | 0 | 39 | 5.5 | 18 | 2 | 5.5 | 3.5 | 33 | 6 | 4 | 5 | 24.5 | 26 |
| Mean | 15.16 | 2.33 | 16 | 29.33 | 24.5 | 20 | 11.83 | 17 | 37.33 | 7.66 | 6.5 | 8.16 | 45.83 | 45 |
| Std D | 17.87 | 2.84 | 20.22 | 32.22 | 8.79 | 23.07 | 10.97 | 15.88 | 3.79 | 1.53 | 2.29 | 2.75 | 21.25 | 17.69 |
| Signif | *** | *** | *** | *** | *** | *** | *** | *** | ** | NS | NS | * | *** | *** |

Significance Key

| | |
|---|---|
| * | P<0.05 |
| ** | P<0.01 |
| *** | P<0.001 |
| NS | No Significant Difference |

Fig 5.4.1. Exchangeable Potassium concentration in the Ploughed treatments (straw removed) at different soil depths and on different sampling dates (mg/l).



The arrow on the graph indicates the date of potassium fertiliser application.

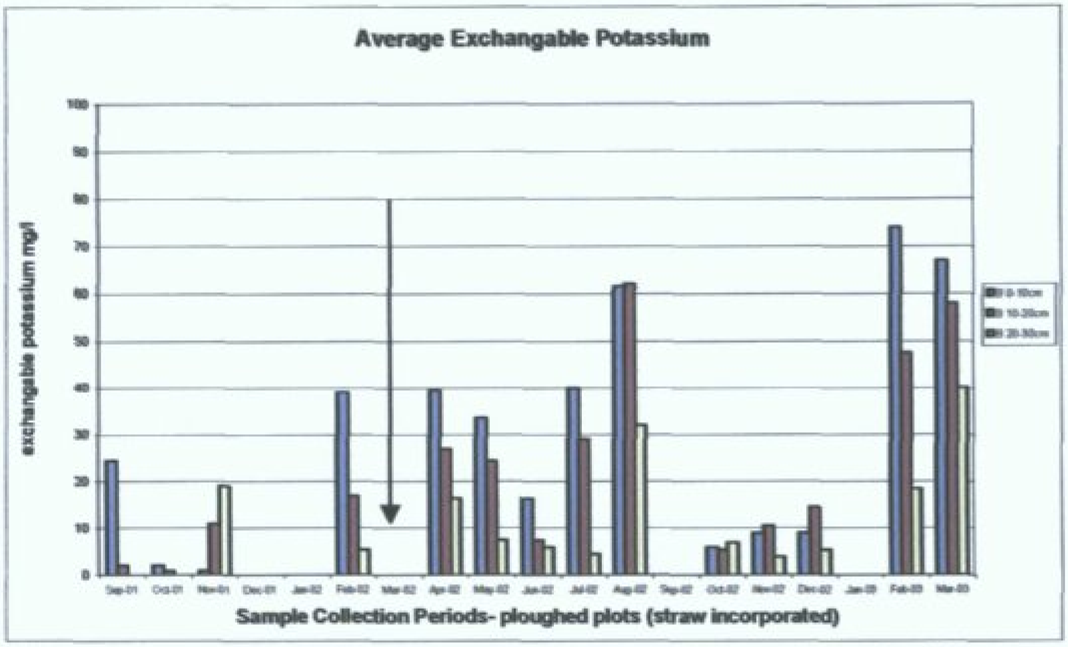
Table 5.4.2. Exchangeable Potassium concentration in the Ploughed treatments (straw incorporated) at different soil depths and on different sampling dates (mg/l).

| Sample Depth | Sept 2001 | Oct 2001 | Nov 2001 | Feb 2002 | Apr 2002 | May 2002 | June 2002 | July 2002 | Aug 2002 | Oct 2002 | Nov 2002 | Dec 2002 | Feb 2003 | Mar 2003 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0-10 | 24.5 | 2 | 1 | 39 | 39.5 | 33.5 | 16.5 | 40 | 61.5 | 6 | 9 | 9 | 74 | 67 |
| 10-20 | 2 | 1 | 11 | 17 | 27 | 24.5 | 7.5 | 29 | 62 | 5.5 | 10.5 | 14.5 | 47.5 | 58 |
| 20-30 | 0 | 0 | 9 | 5.5 | 16.5 | 7.5 | 6 | 4.5 | 32 | 7 | 4 | 5.5 | 18.5 | 40 |
| Mean | 8.83 | 1 | 7 | 20.5 | 27.7 | 21.8 | 10 | 24.5 | 51.8 | 6.17 | 7.83 | 9.67 | 46.7 | 55 |
| Std D | 13.6 | 1 | 5.29 | 17.0 | 11.5 | 13.2 | 5.67 | 18.2 | 17.8 | 0.76 | 3.40 | 4.54 | 27.8 | 13.7 |
| Signif | *** | * | * | *** | *** | *** | *** | *** | *** | * | ** | *** | *** | *** |

Significance Key

| | |
|---|---|
| * | P<0.05 |
| ** | P<0.01 |
| *** | P<0.001 |
| NS | No Significant Difference |

Fig. 5.4.2. Exchangeable Potassium concentration in the Ploughed treatments (straw incorporated) at different soil depths and on different sampling dates (mg/l).



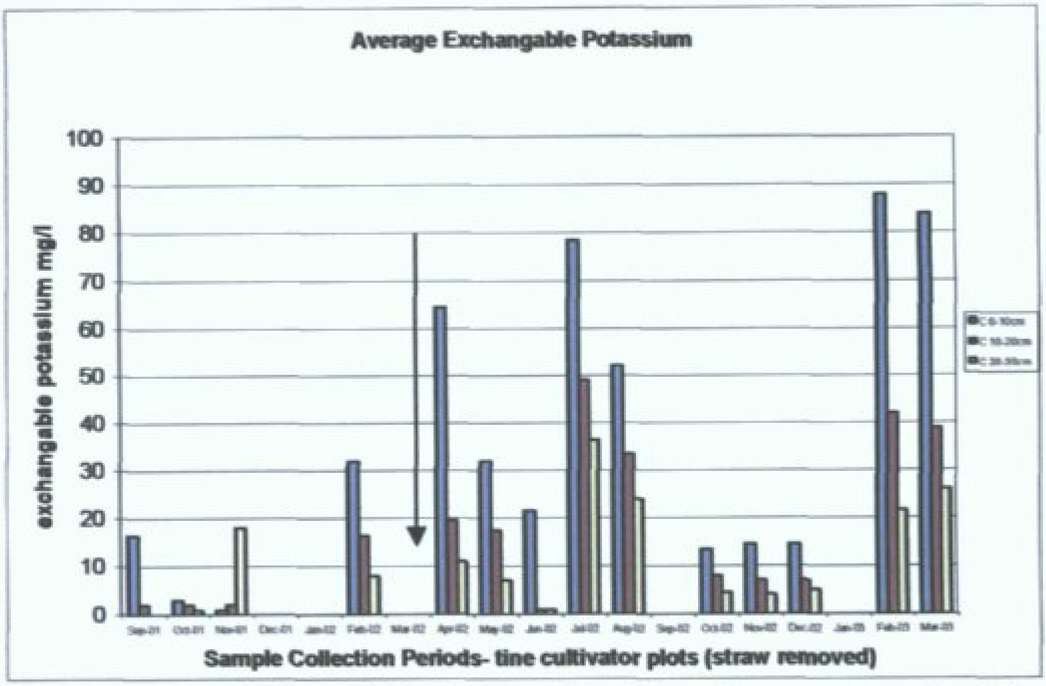
The arrow on the graph indicates the date of potassium fertiliser application.

Table 5.4.3. Exchangeable Potassium concentration in the Reduced cultivation treatments (straw removed) at different soil depths and on different sampling dates (mg/l).

| Sample Depth | Sept 2001 | Oct 2001 | Nov 2001 | Feb 2002 | Apr 2002 | May 2002 | June 2002 | July 2002 | Aug 2002 | Oct 2002 | Nov 2002 | Dec 2002 | Feb 2003 | Mar 2003 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0-10 | 16.5 | 3 | 1 | 32 | 64.5 | 32 | 21.5 | 78.5 | 52 | 13.5 | 14.5 | 14.5 | 88 | 84 |
| 10-20 | 2 | 2 | 2 | 16.5 | 19.5 | 17.5 | 1 | 49 | 33.5 | 8 | 7 | 7 | 42 | 39 |
| 20-30 | 0 | 1 | 18 | 8 | 11 | 7 | 1 | 36.5 | 24 | 4.5 | 4 | 5 | 21.5 | 26 |
| Mean | 6.17 | 2 | 7 | 18.8 | 31.7 | 18.8 | 7.8 | 54.7 | 36.5 | 8.7 | 8.5 | 8.8 | 50.5 | 49.7 |
| StdD | 9.00 | 1.00 | 9.53 | 12.2 | 28.8 | 12.6 | 11.8 | 21.6 | 14.2 | 4.53 | 5.41 | 5.00 | 34.1 | 30.4 |
| Signif | *** | ** | *** | *** | *** | *** | *** | *** | *** | *** | *** | *** | *** | *** |

Significance Key
- * P<0.05
- ** P<0.01
- *** P<0.001
- NS No Significant Difference

Fig.5.4.3. Exchangeable Potassium concentration in the Reduced cultivation treatments (straw removed) at different soil depths and on different sampling dates (mg/l).



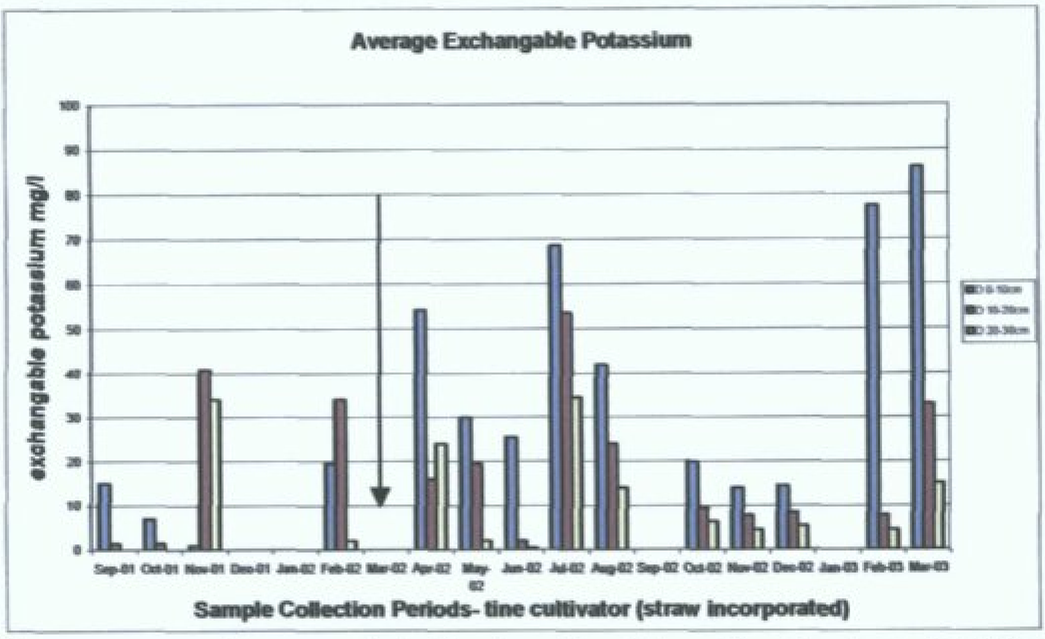
The arrow on the graph indicates the date of potassium fertiliser application.

Table 5.4.4. Exchangeable Potassium concentration in the Reduced cultivation treatments (straw incorporated) at different soil depths and on different sampling dates (mg/l).

| Sample Depth | Sept 2001 | Oct 2001 | Nov 2001 | Feb 2002 | Apr 2002 | May 2002 | June 2002 | July 2002 | Aug 2002 | Oct 2002 | Nov 2002 | Dec 2002 | Feb 2003 | Mar 2003 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0-10 | 15 | 7 | 1 | 19.5 | 54 | 30 | 25.5 | 68.5 | 42 | 20 | 14 | 14.5 | 77.5 | 86 |
| 10-20 | 1.5 | 1.5 | 41 | 34 | 16 | 19.5 | 2 | 53.5 | 24 | 9.5 | 8 | 8.5 | 8 | 33 |
| 20-30 | 0 | 0 | 34 | 2 | 24 | 2 | 0.5 | 34.5 | 14 | 6.5 | 4.5 | 5.5 | 4.5 | 15 |
| Mean | 5.5 | 2.8 | 25.3 | 18.5 | 31.3 | 17.2 | 9.3 | 52.2 | 26.7 | 12 | 8.8 | 9.5 | 30 | 44.7 |
| StdD | 8.26 | 3.68 | 21.4 | 16.0 | 20.0 | 14.1 | 14.0 | 17.0 | 14.2 | 7.09 | 4.80 | 4.58 | 41.2 | 36.9 |
| Signif | *** | *** | *** | *** | *** | *** | *** | *** | *** | *** | *** | *** | *** | *** |

Significance Key
*     P<0.05
**    P<0.01
***  P<0.001
NS   No Significant Difference

Fig.5.4.4. Exchangeable Potassium concentration in the Reduced cultivation treatments (straw incorporated) at different soil depths and on different sampling dates (mg/l).



The arrow on the graph indicates the date of potassium fertiliser application.

***Exchangeable Potassium concentration for each treatment.***

*Table 5.4.1.*

The concentration of exchangeable potassium can be seen to fluctuate throughout the sampling period at each sample depth in the soil horizon. The application of potassium fertiliser does not appear to have an immediate impact on exchangeable potassium concentration in the soil. This may be due to the "luxury consumption" of potassium by the growing plants during the summer months, and as the crop consumes potassium in quantities in excess of its requirements, this consumption does not increase crop yield. Moisture stress may also have limited potassium mineralization. The concentration of exchangeable potassium peaks in February when crop requirements are low and therefore the potassium is not being utilised. During November 2001 the exchangeable potassium leaches through the soil profile, this nutrient movement was also observed to occur for phosphorus.

*Table 5.4.2.*

The incorporation of straw in the conventionally tilled plots did not limit the fluctuations in exchangeable potassium concentration throughout the sampling period, although the concentration of potassium leached during the month of November was reduced (this was also evident for phosphorus). "Luxury consumption" did not appear to be affected by the incorporation of straw, as potassium continued to remain low after the application of fertiliser.

The concentration of exchangeable potassium appeared to be greater in these plots, however this difference was not statistically significant.

*Table 5.4.3.*

Although the concentration of exchangeable potassium continues to decrease through the soil profile, the pattern of potassium available differs between conventional and reduced tillage systems.

In this treatment the exchangeable potassium increases after the application of fertiliser, is then utilised during the months of May and June (for crop ripening), and leaves a large surplus of exchangeable potassium in July and August when the crop no longer requires it.

*Table 5.4.4.*

The incorporation of straw in the reduced cultivation plots did not alter the pattern of available exchangeable potassium over time. The application of fertiliser also increased the concentration of exchangeable potassium present, which was then utilised before leaving surplus quantities in July. However, the concentration of exchangeable potassium present in this treatment was less than that which was present in the reduced plots, which had removed straw. The reduced cultivation treatments, with and without straw incorporation, showed greater fluctuations in concentration of exchangeable potassium over time than the conventionally tilled plots.

Table. 5.4.5. Exchangeable Potassium concentration for all four Cultivation methods at 0-10cm Sampling depth over the sampling period (mg/l).

| Plot Type | Sep 2001 | Oct 2001 | Nov 2001 | Feb 2002 | Apr 2002 | May 2002 | June 2002 | July 2002 | Aug 2002 | Oct 2002 | Nov 2002 | Dec 2002 | Feb 2003 | Mar 2003 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A | 35.5 | 5.5 | 1 | 66 | 34.5 | 46 | 24.5 | 34.5 | 39 | 9 | 8.5 | 9.5 | 67 | 61 |
| B | 24.5 | 2 | 1 | 39 | 39.5 | 33.5 | 16.5 | 40 | 61.5 | 6 | 9 | 9 | 74 | 67 |
| C | 16.5 | 3 | 1 | 32 | 64.5 | 32 | 21.5 | 78.5 | 52 | 13.5 | 14.5 | 14.5 | 88 | 84 |
| D | 15 | 7 | 1 | 19.5 | 54 | 30 | 25.5 | 68.5 | 42 | 20 | 14 | 14.5 | 77.5 | 86 |
| StdD | 9.39 | 2.28 | 0 | 19.6 | 13.7 | 7.22 | 4.04 | 21.4 | 10.2 | 6.09 | 3.18 | 3.04 | 8.75 | 12.4 |
| Signi | *** | NS | NS | *** | *** | *** | * | *** | ** | *** | ** | ** | *** | ** |

Key

A = Conventional tillage (straw removed)

B = Conventional tillage (straw incorporated)

C = Reduced tillage (straw removed)

D = Reduced tillage (straw incorporated)

Significance Key

| | |
|---|---|
| * | $P<0.05$ |
| ** | $P<0.01$ |
| *** | $P<0.001$ |
| NS | No Significant Difference |

Fig.5.4.5. Exchangeable Potassium concentration for all four Cultivation methods at 0-10cm sampling depth over the sampling period (mg/l).

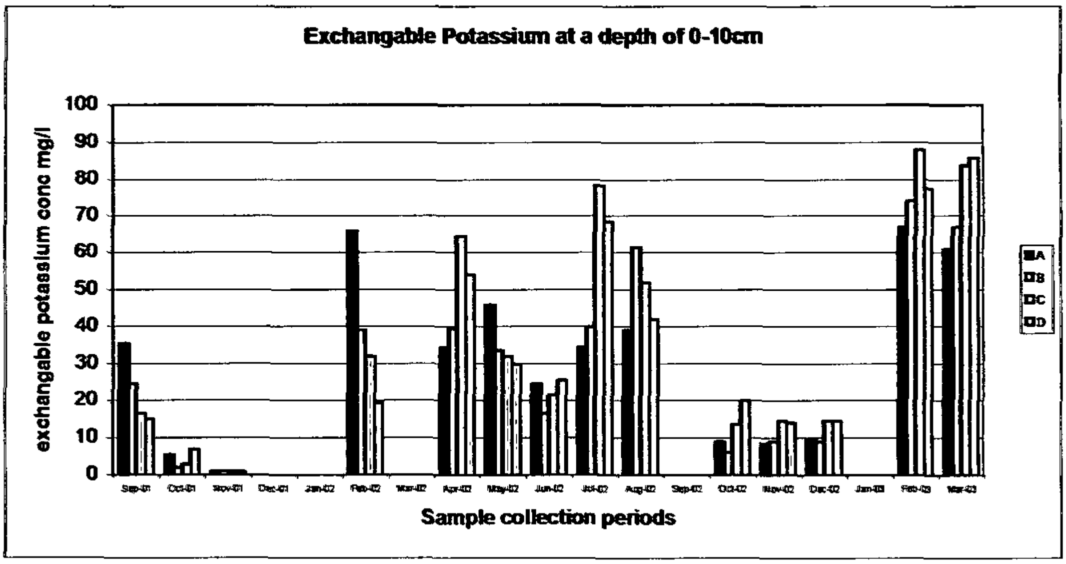


Table. 5.4.6. Exchangeable Potassium concentration for all four Cultivation methods at 10-20cm sampling depth over the sampling period (mg/l).

| Plot Type | Sep 2001 | Oct 2001 | Nov 2001 | Feb 2002 | Apr 2002 | May 2002 | June 2002 | July 2002 | Aug 2002 | Oct 2002 | Nov 2002 | Dec 2002 | Feb 2003 | Mar 2003 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A | 8 | 1.5 | 8 | 16.5 | 21 | 12 | 5.5 | 13 | 40 | 8 | 7 | 10 | 46 | 48 |
| B | 2 | 1 | 11 | 17 | 27 | 24.5 | 7.5 | 29 | 62 | 5.5 | 10.5 | 14.5 | 47.5 | 58 |
| C | 2 | 2 | 2 | 16.5 | 19.5 | 17.5 | 1 | 49 | 33.5 | 8 | 7 | 7 | 42 | 39 |
| D | 1.5 | 1.5 | 41 | 34 | 16 | 19.5 | 2 | 53.5 | 24 | 9.5 | 8 | 8.5 | 8 | 33 |
| StdD | 3.09 | 0.41 | 17.4 | 8.67 | 4.58 | 5.17 | 3.03 | 18.7 | 16.1 | 1.66 | 1.65 | 3.24 | 18.7 | 10.9 |
| Signi | * | NS | ** | * | NS | NS | * | *** | *** | ** | * | * | NS | *** |

Key

A = Conventional tillage (straw removed)

B = Conventional tillage (straw incorporated)

C = Reduced tillage (straw removed)

D = Reduced tillage (straw incorporated)

Significance Key

| | |
|---|---|
| * | P<0.05 |
| ** | P<0.01 |
| *** | P<0.001 |
| NS | No Significant Difference |

Fig.5.4.6. Exchangeable Potassium concentration for all four Cultivation methods at 10-20cm sampling depth over the sampling period (mg/l).

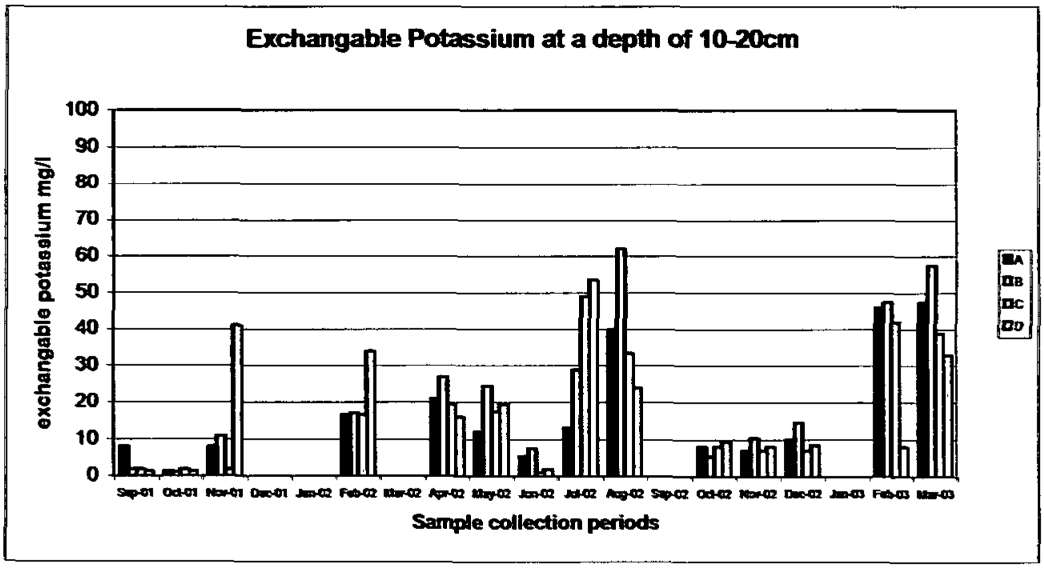


Table. 5.4.7. Exchangeable Potassium concentration for all four Cultivation methods at 20-30cm sampling depth over the sampling period (mg/l).

| Plot Type | Sep 2001 | Oct 2001 | Nov 2001 | Feb 2002 | Apr 2002 | May 2002 | June 2002 | July 2002 | Aug 2002 | Oct 2002 | Nov 2002 | Dec 2002 | Feb 2003 | Mar 2003 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A | 2 | 0 | 39 | 5.5 | 18 | 2 | 5.5 | 3.5 | 33 | 6 | 4 | 5 | 24.5 | 25 |
| B | 0 | 0 | 19 | 5.5 | 16.5 | 7.5 | 6 | 4.5 | 32 | 7 | 4 | 5.5 | 18.5 | 40 |
| C | 0 | 1 | 18 | 8 | 11 | 7 | 1 | 36.5 | 24 | 4.5 | 4 | 5 | 21.5 | 25 |
| D | 0 | 0 | 34 | 2 | 24 | 2 | 0.5 | 34.5 | 14 | 6.5 | 4.5 | 5.5 | 4.5 | 14 |
| StdD | 1.0 | 0.5 | 10.6 | 2.47 | 5.34 | 3.04 | 2.90 | 18.2 | 8.80 | 1.08 | 0.25 | 0.29 | 8.85 | 10.7 |
| Signi | NS | NS | *** | NS | NS | * | *** | *** | *** | NS | NS | NS | NS | ** |

Key

A = Conventional tillage (straw removed)

B = Conventional tillage (straw incorporated)

C = Reduced tillage (straw removed)

D = Reduced tillage (straw incorporated)

Significance Key

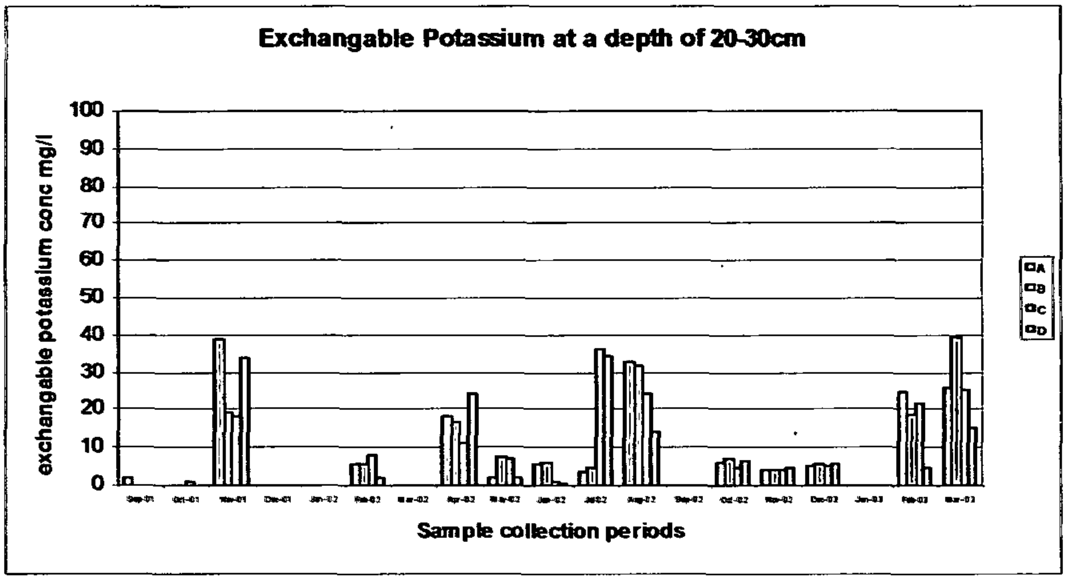
* P<0.05

** P<0.01

*** P<0.001

NS No Significant Difference

Fig.5.4.7. Exchangeable Potassium concentration for all four Cultivation methods at 20-30cm sampling depth over the sampling period(mg/l).



***Exchangeable Potassium. Comparing the three sample depths.***

*Table 5.4.5.*

The fluctuating patterns of exchangeable potassium concentration are easily distinguished between treatments on this graph. When statistical analysis was carried out the differences in the mean values among the treatment groups are greater than would be expected by chance. The reduced cultivation plots contained a higher concentration of exchangeable potassium at a sampling depth of 0-10 cm both with and without the incorporation of straw than the plots which were treated with the conventional tillage treatment.

*Table 5.4.6.*

The concentration of exchangeable potassium was reduced at this sample depth under both cultivation methods. The cultivation methods, which had incorporated straw contained higher concentrations of exchangeable potassium than those which had removed straw at this sampling depth of 10-20 cm, the conventional tillage system containing the highest concentration of potassium on average.

*Table 5.4.7.*

The deepest depth sampled in the soil profile was at a depth of 20-30cm. At this depth the differences in the median values among the different groups were not great enough to exclude the possibility that the difference was due to random sampling variability on the majority of occasions during the crop-growing season. Therefore at these times there is not a statistically significant difference in the concentration of exchangeable potassium between the four different treatment types at a sampling depth of 20-30 cm. The plots, which had removed straw contained slightly higher concentrations than those which had incorporated straw.

Table 5.4.8. Variation of Exchangeable Potassium concentration at the three sample depths for each of the cultivation methods (mg/l).

| Plot Type | 0-10cm depth | 10-20cm depth | 20-30cm depth |
|---|---|---|---|
| A | 29 | 15 | 11 |
| B | 27 | 20 | 10 |
| C | 32 | 16 | 11 |
| D | 30 | 17 | 10 |

Key

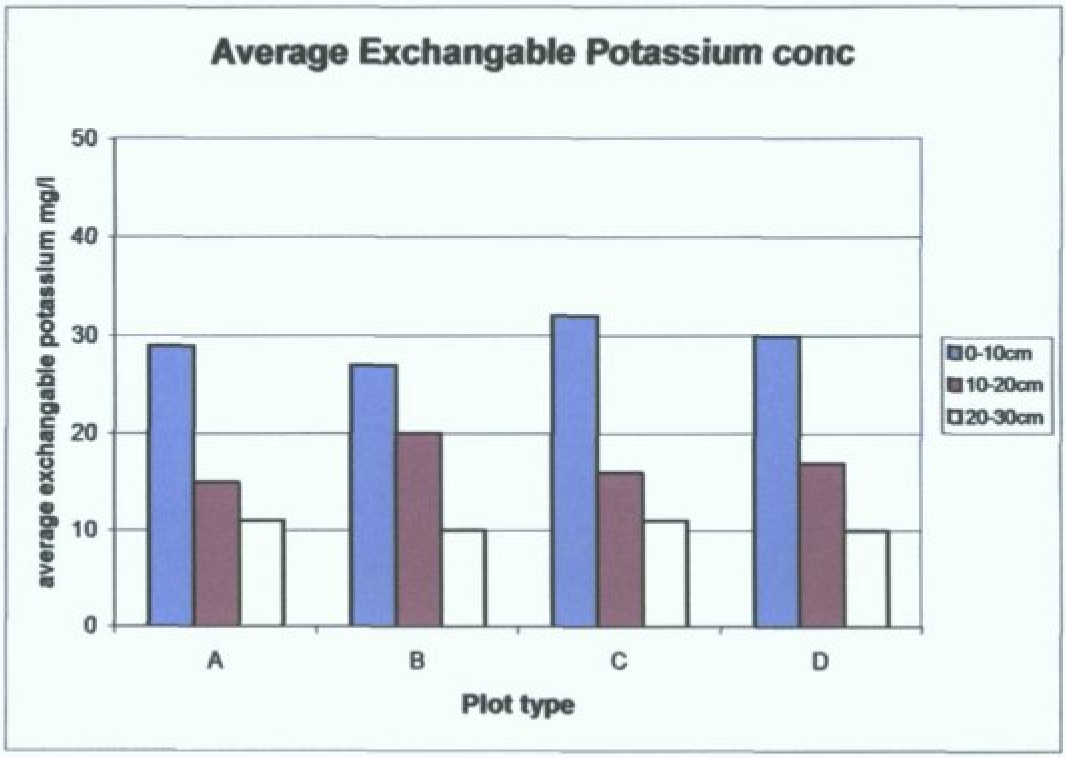
A = Conventional tillage (straw removed)

B = Conventional tillage (straw incorporated)

C = Reduced tillage (straw removed)

D = Reduced tillage (straw incorporated)

Fig.5.4.8. Variation of Exchangeable Potassium concentration at the three sample depths for each of the cultivation methods (mg/l).



***Variation of Exchangeable Potassium concentration at the three sample depths for each of the cultivation methods.***

Statistical analysis carried out on potassium concentration through the soil profile has shown that there is a significant statistical difference in potassium concentration between all three sample depths, the greatest concentration of potassium being determined in the top 10cm of soil, and decreasing with increasing sampling depth, as outlined in Tables 5.4.1. to 5.4.4. The differences in the mean values among the treatment groups are not always great enough to exclude the possibility of random sampling variability; however the reduced tillage treatments did contain higher concentrations of potassium in the top 10cm of soil (Table 5.4.5.). Cultivation methods, which had removed straw contained slightly higher concentrations of potassium in the 0-10cm of soil but these were not great enough to be statistically significant.

## *5.5. ORGANIC CARBON RESULTS*

The quality of agricultural soils is largely a function of soil organic matter. Tillage and crop management impacts soil organic matter dynamics, by modification of the soil environment and quantity and quality of carbon input.

The following results aim to determine if organic carbon concentration is affected by tillage intensity, or by the incorporation or removal of straw. Table 5.5.1. contains the average values for organic carbon determined over the sampling period, for the conventionally tilled plots with straw removed.

Each value tabulated, was determined by the averaging of six values obtained for organic carbon on each occasion. All four treatments are presented in this manner, before being directly compared at each of the three depths sampled in the soil profile.

Table 5.5.1. Percentage Organic Carbon concentration in the ploughed treatment (straw removed) at different soil depths and on different sampling dates.

| Sample Depth | Sept 2001 | Oct 2001 | Nov 2001 | Feb 2002 | Apr 2002 | May 2002 | June 2002 | July 2002 | Aug 2002 | Oct 2002 | Nov 2002 | Dec 2002 | Feb 2003 | Mar 2003 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0-10 | 1.11 | 1.37 | 0.62 | 1.17 | 1.02 | 1.82 | 0.86 | 1.25 | 0.77 | 0.84 | 1.14 | 0.91 | 1.03 | 1.08 |
| 10-20 | 0.91 | 1.12 | 1.03 | 1.00 | 0.97 | 1.19 | 0.84 | 0.99 | 0.73 | 0.75 | 1.05 | 0.95 | 0.99 | 1.08 |
| 20-30 | 0.43 | 0.55 | 1.01 | 0.81 | 0.70 | 0.69 | 0.84 | 0.92 | 0.68 | 0.59 | 0.65 | 0.62 | 0.57 | 0.71 |
| Mean | 0.82 | 1.01 | 0.89 | 0.99 | 0.90 | 1.23 | 0.85 | 1.05 | 0.73 | 0.73 | 0.95 | 0.83 | 0.86 | 0.96 |
| Std D | 0.349 | 0.420 | 0.231 | 0.180 | 0.172 | 0.566 | 0.011 | 0.174 | 0.045 | 0.127 | 0.261 | 0.180 | 0.255 | 0.214 |
| Signif | *** | *** | *** | *** | *** | *** | * | *** | * | *** | *** | *** | *** | *** |

Significance Key
* P<0.05
** P<0.01
*** P<0.001
NS No Significant Difference

Fig 5.4.1. Percentage Organic Carbon concentration in the ploughed treatment (straw removed) at different soil depths and on different sampling dates.

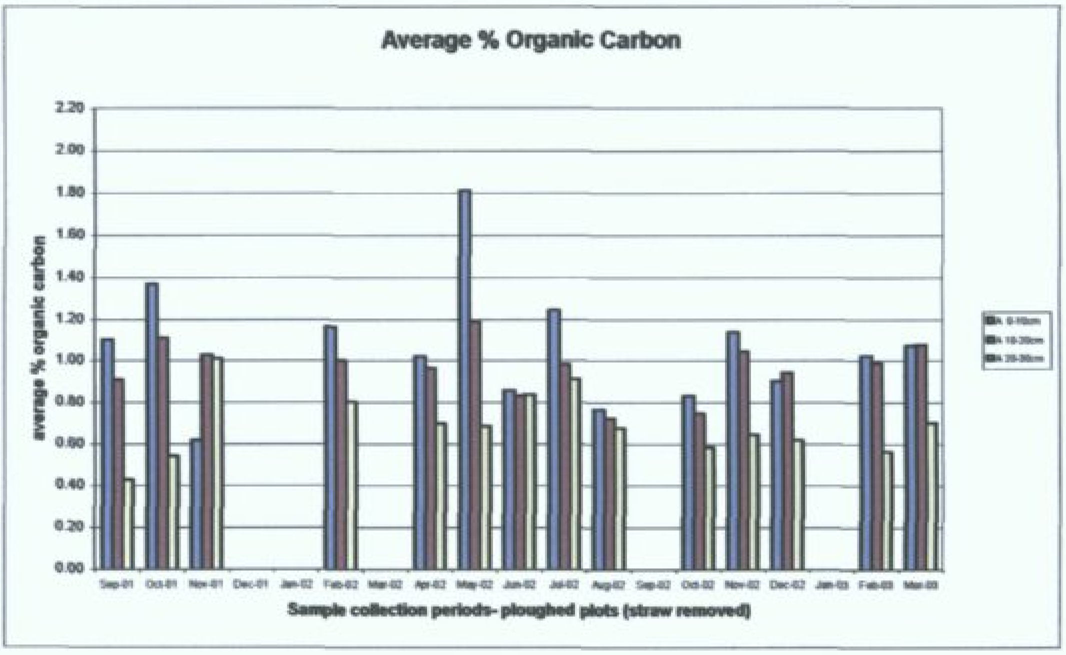


Table 5.5.2. Percentage Organic Carbon concentration in the ploughed treatment (straw incorporated), at different soil depths, and on different sampling dates.

| Sample Depth | Sept 2001 | Oct 2001 | Nov 2001 | Feb 2002 | Apr 2002 | May 2002 | June 2002 | July 2002 | Aug 2002 | Oct 2002 | Nov 2002 | Dec 2002 | Feb 2003 | Mar 2003 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0-10 | 0.84 | 0.97 | 0.52 | 1.22 | 1.16 | 0.93 | 1.01 | 1.00 | 0.74 | 1.08 | 1.04 | 1.05 | 0.98 | 2.06 |
| 10-20 | 0.96 | 0.80 | 1.09 | 1.25 | 1.13 | 0.73 | 0.88 | 0.93 | 0.70 | 0.78 | 0.94 | 0.99 | 0.91 | 1.92 |
| 20-30 | 0.58 | 0.54 | 1.16 | 0.85 | 0.99 | 0.86 | 0.79 | 0.79 | 0.61 | 0.73 | 0.55 | 0.52 | 0.69 | 1.39 |
| Mean | 0.79 | 0.77 | 0.92 | 1.11 | 1.09 | 0.84 | 0.89 | 0.91 | 0.68 | 0.86 | 0.84 | 0.85 | 0.86 | 1.79 |
| Std D | 0.194 | 0.217 | 0.351 | 0.222 | 0.091 | 0.101 | 0.111 | 0.107 | 0.067 | 0.189 | 0.259 | 0.290 | 0.151 | 0.353 |
| Signif | *** | *** | *** | *** | * | * | *** | *** | ** | *** | *** | *** | *** | *** |

Significance Key

| | |
|---|---|
| * | P<0.05 |
| ** | P<0.01 |
| *** | P<0.001 |
| NS | No Significant Difference |

Fig. 5.5.2. Percentage Organic Carbon concentration in the ploughed treatment (straw incorporated), at different soil depths, and on different sampling dates.

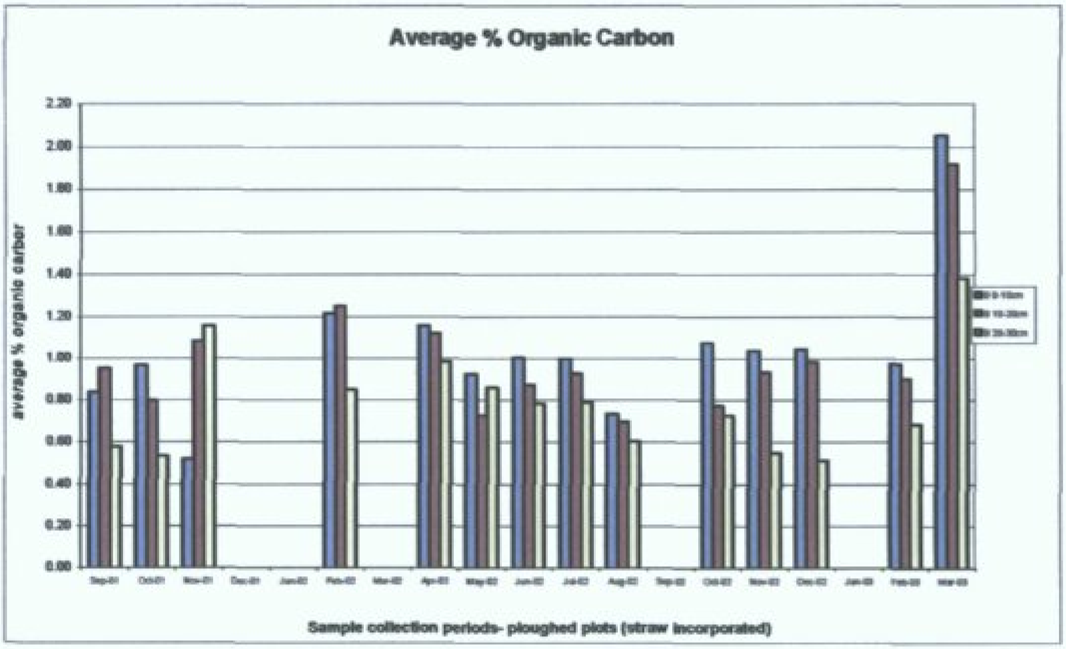


Table 5.5.3. Percentage Organic Carbon concentration in the reduced tillage treatment (straw removed) at different soil depths and on different sampling dates.

| Sample Depth | Sept 2001 | Oct 2001 | Nov 2001 | Feb 2002 | Apr 2002 | May 2002 | June 2002 | July 2002 | Aug 2002 | Oct 2002 | Nov 2002 | Dec 2002 | Feb 2003 | Mar 2003 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0-10 | 1.14 | 1.15 | 0.50 | 1.12 | 1.28 | 0.91 | 1.07 | 1.04 | 0.89 | 1.19 | 1.02 | 1.17 | 1.26 | 1.31 |
| 10-20 | 1.03 | 1.04 | 0.50 | 1.09 | 1.18 | 0.87 | 0.95 | 0.87 | 0.82 | 1.02 | 0.93 | 0.99 | 1.10 | 1.20 |
| 20-30 | 1.01 | 0.63 | 0.50 | 0.90 | 0.81 | 0.53 | 0.64 | 0.71 | 0.62 | 0.65 | 0.80 | 0.60 | 0.65 | 0.98 |
| Mean | 1.06 | 0.94 | 0.50 | 1.04 | 1.09 | 0.77 | 0.89 | 0.87 | 0.78 | 0.95 | 0.92 | 0.92 | 1.00 | 1.16 |
| Std D | 0.070 | 0.274 | 0 | 0.119 | 0.248 | 0.209 | 0.222 | 0.165 | 0.140 | 0.276 | 0.111 | 0.292 | 0.316 | 0.168 |
| Signif | ** | *** | NS | *** | *** | *** | *** | *** | *** | *** | *** | *** | *** | *** |

Significance Key
* P<0.05
** P<0.01
*** P<0.001
NS No Significant Difference

Fig.5.5.3. Percentage Organic Carbon concentration in the reduced tillage treatment (straw removed) at different soil depths and on different sampling dates

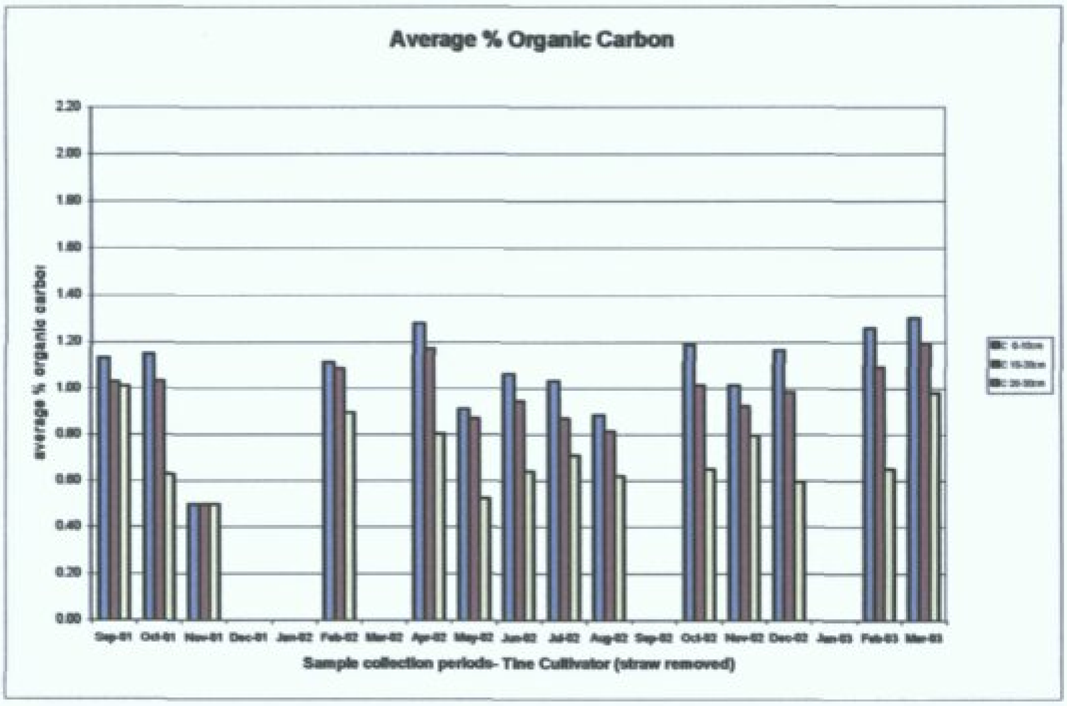
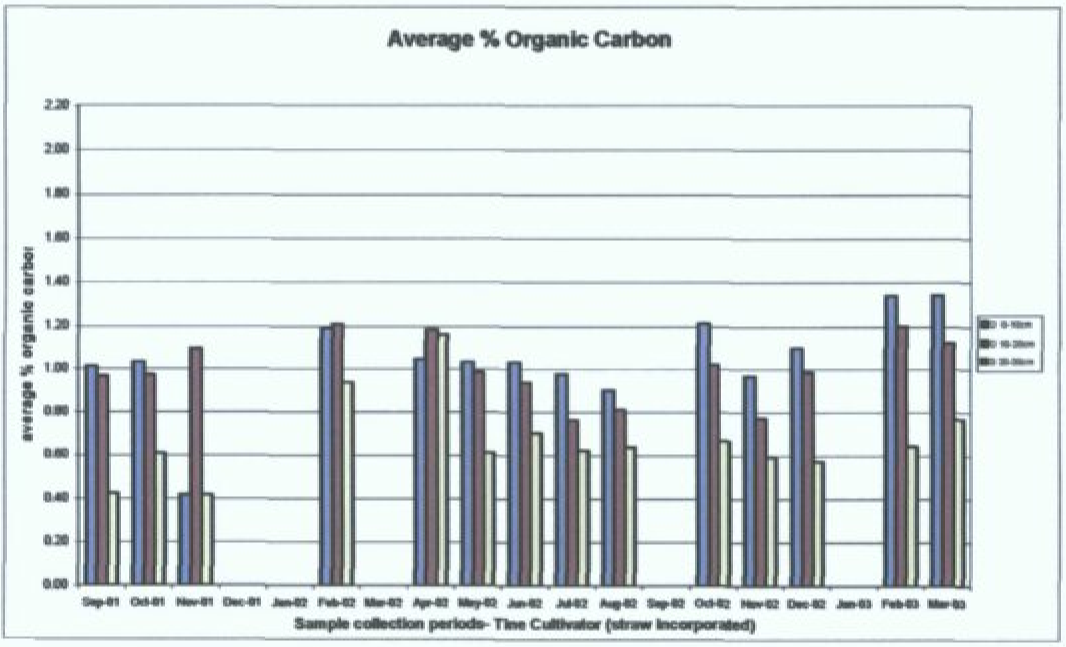


Table 5.5.4. Percentage Organic Carbon concentration in the reduced tillage treatment (straw incorporated) at different soil depths and on different sampling dates.

| Sample Depth | Sept 2001 | Oct 2001 | Nov 2001 | Feb 2002 | Apr 2002 | May 2002 | June 2002 | July 2002 | Aug 2002 | Oct 2002 | Nov 2002 | Dec 2002 | Feb 2003 | Mar 2003 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0-10 | 1.02 | 1.04 | 0.42 | 1.19 | 1.05 | 1.04 | 1.04 | 0.98 | 0.91 | 1.22 | 0.97 | 1.11 | 1.34 | 1.35 |
| 10-20 | 0.97 | 0.98 | 1.10 | 1.21 | 1.19 | 0.99 | 0.94 | 0.77 | 0.82 | 1.02 | 0.78 | 0.99 | 1.21 | 1.13 |
| 20-30 | 0.43 | 0.61 | 0.42 | 0.94 | 1.17 | 0.62 | 0.71 | 0.63 | 0.64 | 0.67 | 0.60 | 0.58 | 0.65 | 0.77 |
| Mean | 0.81 | 0.88 | 0.65 | 1.11 | 1.14 | 0.88 | 0.90 | 0.79 | 0.79 | 0.97 | 0.78 | 0.89 | 1.07 | 1.08 |
| Std D | 0.327 | 0.233 | 0.393 | 0.150 | 0.076 | 0.229 | 0.169 | 0.176 | 0.137 | 0.278 | 0.185 | 0.278 | 0.367 | 0.293 |
| Signif | *** | *** | * | *** | ** | *** | *** | *** | *** | *** | *** | *** | *** | *** |

Significance Key
* P<0.05
** P<0.01
*** P<0.001
NS No Significant Difference

Fig.5.5.4. Percentage Organic Carbon concentration in the reduced tillage treatment (straw incorporated), at different soil depths, and on different sampling dates.



### *Organic Carbon concentration for each treatment.*

*Table 5.5.1.*

The concentration of organic carbon decreased through the soil profile during the majority of the sampling programme, although some exceptions were observed. During November 2001 all four treatments contained higher concentrations of organic carbon at lower depths in the soil profile, this occured after a period of heavy rainfall (and was also evident in results determined for phosphorus Fig.5.3.1. and potassium Fig.5.4.1.), therefore organic carbon concentration can be leached through the soil during heavy rainfall events.

The concentration of organic carbon did not deviate greatly over the sampling period, although slightly lower concentrations were determined during the second year of sampling. The greatest concentration of organic carbon occurred in May due to mineralization of organic matter.

*Table 5.5.2.*

The concentration of organic carbon determined under conventional tillage with straw incorporated throughout the sampling period, was less than that determined where straw was removed, particularly in the top 10cm of soil. The concentration of organic carbon continued to decrease down through the soil profile. The previous set of results for conventional tillage (no straw) reached a peak for organic carbon in May, whereas when straw was incorporated the greatest concentration of organic carbon occurred at an earlier stage in the season (February 2002 and March 2003).

*Table 5.5.3.*

When compared to the conventionally tilled treatments, the concentration of organic carbon did not fluctuate to any great extent from September 2001 to March 2003, and there was a clear reduction of organic carbon concentration through the soil profile.

*Table 5.5.4.*

Haslin et al (1990) determined that reducing tillage and maintaining surface residues in a long- term study increased soil organic carbon in the surface 2.5cm of soil. This however, is not immediately apparent in these results.

The incorporation or removal of straw in the reduced cultivation treatments, did not greatly effect the concentration of organic carbon available in the soil. The initial samples obtained from the treatments, which had incorporated straw were lower than for those, which had removed straw (as was determined in the conventional treatments). This may be due to slower soil warming in these treatments and could possibly change over time.

During this period there was no statistical difference in organic carbon concentration in the top two sample depths in these treatments. By May of 2002 there was a reduction in organic carbon concentration with depth for each of the three sample depths.

Table. 5.5.5. Percentage Organic Carbon concentration for all of the four cultivation methods, at 0-10cm sampling depth, over the sampling period.

| Plot Type | Sep 2001 | Oct 2001 | Nov 2001 | Feb 2002 | Apr 2002 | May 2002 | June 2002 | July 2002 | Aug 2002 | Oct 2002 | Nov 2002 | Dec 2002 | Feb 2003 | Mar 2003 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A | 1.11 | 1.37 | 0.62 | 1.17 | 1.02 | 1.82 | 0.86 | 1.25 | 0.77 | 0.84 | 1.14 | 0.91 | 1.03 | 1.08 |
| B | 0.84 | 0.97 | 0.52 | 1.22 | 1.16 | 0.93 | 1.01 | 1.00 | 0.74 | 1.08 | 1.04 | 1.05 | 0.98 | 2.06 |
| C | 1.14 | 1.15 | 0.50 | 1.12 | 1.28 | 0.91 | 1.07 | 1.04 | 0.89 | 1.19 | 1.02 | 1.17 | 1.26 | 1.31 |
| D | 1.02 | 1.04 | 0.42 | 1.19 | 1.05 | 1.04 | 1.04 | 0.98 | 0.91 | 1.22 | 0.97 | 1.11 | 1.34 | 1.35 |
| Std D | 0.135 | 0.175 | 0.082 | 0.042 | 0.118 | 0.434 | 0.093 | 0.124 | 0.085 | 0.173 | 0.071 | 0.111 | 0.175 | 0.424 |
| Signif | *** | *** | ** | NS | NS | ** | ** | NS | ** | *** | ** | ** | *** | *** |

Key

A = Conventional tillage (straw removed)

B = Conventional tillage (straw incorporated)

C = Reduced tillage (straw removed)

D = Reduced tillage (straw incorporated)

Significance Key
- * P<0.05
- ** P<0.01
- *** P<0.001
- NS No Significant Difference

Fig.5.5.5. Percentage Organic Carbon concentration for all of the four cultivation methods at 0-10cm sampling depth over the sampling period.

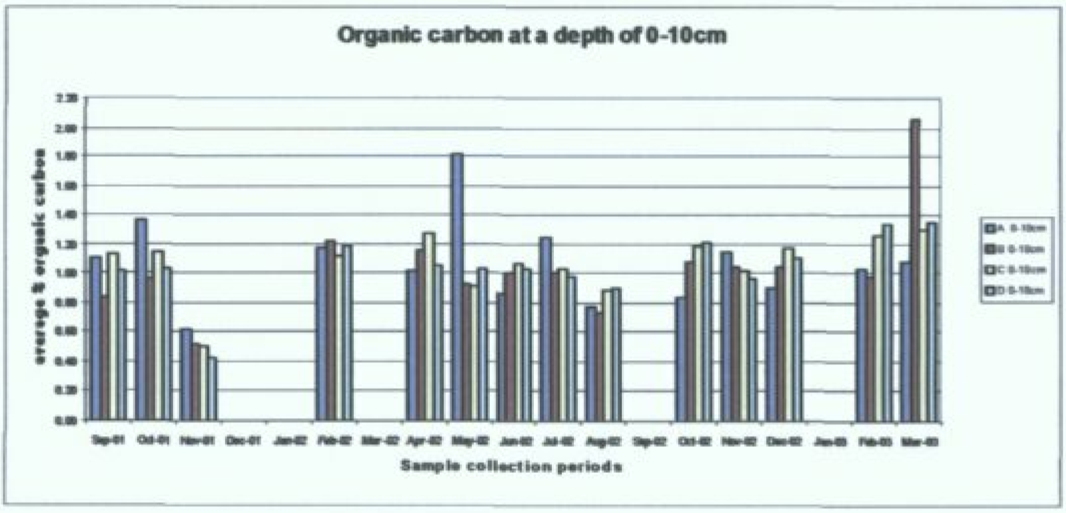


Table. 5.5.6. Percentage Organic Carbon concentration for all of the four cultivation methods, at 10-20cm sampling depth, over the sampling period.

| Plot Type | Sep 2001 | Oct 2001 | Nov 2001 | Feb 2002 | Apr 2002 | May 2002 | June 2002 | July 2002 | Aug 2002 | Oct 2002 | Nov 2002 | Dec 2002 | Feb 2002 | Mar 2002 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A | 0.91 | 1.12 | 1.03 | 1.00 | 0.97 | 1.19 | 0.84 | 0.99 | 0.73 | 0.75 | 1.05 | 0.95 | 0.99 | 1.08 |
| B | 0.96 | 0.80 | 1.09 | 1.25 | 1.13 | 0.73 | 0.88 | 0.93 | 0.70 | 0.78 | 0.94 | 0.99 | 0.91 | 1.92 |
| C | 1.03 | 1.04 | 0.50 | 1.09 | 1.18 | 0.87 | 0.95 | 0.87 | 0.82 | 1.02 | 0.93 | 0.99 | 1.10 | 1.20 |
| D | 0.97 | 0.98 | 1.10 | 1.21 | 1.19 | 0.99 | 0.94 | 0.77 | 0.82 | 1.02 | 0.78 | 0.99 | 1.21 | 1.13 |
| Std D | 0.049 | 0.136 | 0.288 | 0.114 | 0.102 | 0.195 | 0.052 | 0.094 | 0.062 | 0.148 | 0.111 | 0.02 | 0.131 | 0.395 |
| Signif | ** | *** | ** | NS | NS | ** | NS | *** | NS | *** | *** | NS | ** | *** |

Key

A = Conventional tillage (straw removed)

B = Conventional tillage (straw incorporated)

C = Reduced tillage (straw removed)

D = Reduced tillage (straw incorporated)

Significance Key

* P<0.05

** P<0.01

*** P<0.001

NS No Significant Difference

Fig.5.5.6. Percentage Organic Carbon concentration for all of the four cultivation methods at 10-20cm sampling depth over the sampling period.

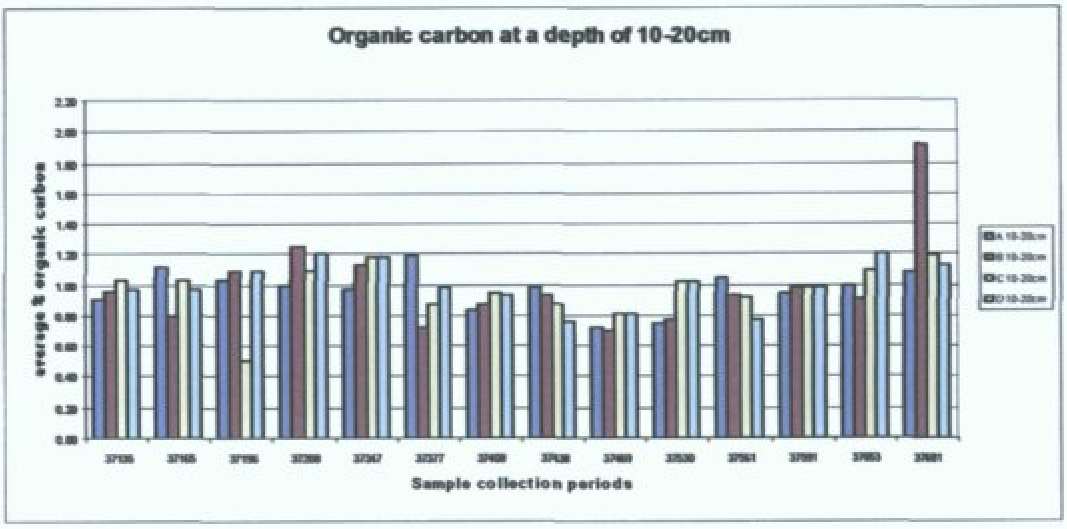


Table. 5.5.7. Percentage Organic Carbon concentration for all of the four cultivation methods, at 20-30cm sampling depth, over the sampling period.

| Plot Type | Sep 2001 | Oct 2001 | Nov 2001 | Feb 2002 | Apr 2002 | May 2002 | June 2002 | July 2002 | Aug 2002 | Oct 2002 | Nov 2002 | Dec 2002 | Feb 2002 | Mar 2002 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A | 0.43 | 0.55 | 1.01 | 0.81 | 0.70 | 0.69 | 0.84 | 0.92 | 0.68 | 0.59 | 0.65 | 0.62 | 0.57 | 0.71 |
| B | 0.58 | 0.54 | 1.16 | 0.85 | 0.99 | 0.86 | 0.79 | 0.79 | 0.61 | 0.73 | 0.55 | 0.52 | 0.69 | 1.39 |
| C | 1.01 | 0.63 | 0.50 | 0.90 | 0.81 | 0.53 | 0.64 | 0.71 | 0.62 | 0.65 | 0.80 | 0.60 | 0.65 | 0.98 |
| D | 0.43 | 0.61 | 0.42 | 0.94 | 1.17 | 0.62 | 0.71 | 0.63 | 0.64 | 0.67 | 0.60 | 0.58 | 0.65 | 0.77 |
| Std D | 0.274 | 0.044 | 0.367 | 0.057 | 0.206 | 0.140 | 0.088 | 0.124 | 0.031 | 0.058 | 0.108 | 0.043 | 0.050 | 0.308 |
| Signif | *** | NS | *** | NS | *** | *** | NS | *** | NS | NS | *** | NS | NS | *** |

Key

A = Conventional tillage (straw removed)

B = Conventional tillage (straw incorporated)

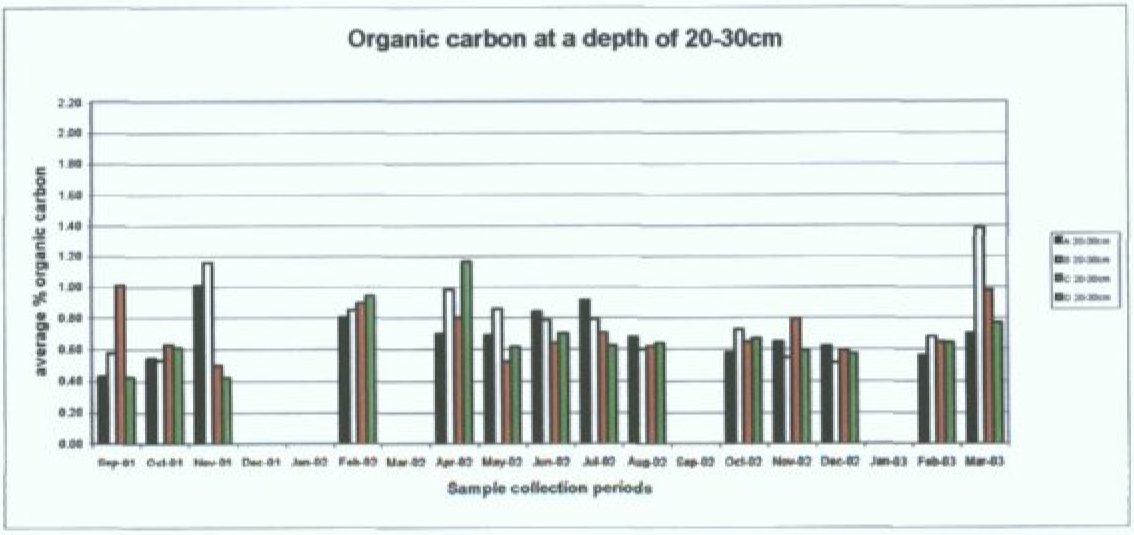
C = Reduced tillage (straw removed)

D = Reduced tillage (straw incorporated)

Significance Key

| | |
|---|---|
| * | P<0.05 |
| ** | P<0.01 |
| *** | P<0.001 |
| NS | No Significant Difference |

Fig.5.5.7. Percentage Organic Carbon concentration for all of the four cultivation methods, at 20-30cm sampling depth, over the sampling period.



### *Organic Carbon. Comparing the three sample depths.*

*Table 5.5.5.*

Over the fourteen-month sampling period, there were differences in organic carbon concentration between cultivation methods at a sample depth of 0-10cm. These differences occurred in eleven of the fourteen months sampled, and were largely during the autumn/winter seasons. On five of these occasions the conventionally tilled treatments contained a greater concentration of organic matter, which mainly occurred during the early stages of sample collection. On the other six occasions the reduced cultivation treatments contained a higher concentration of organic carbon. Therefore there was no obvious bias in the organic carbon distribution under reduced versus conventional tillage in the ten centimetres of soil after immediate implementation of these cultivation methods.

*Table 5.5.6.*

Differences in organic carbon concentration were not as great at a sample depth of 10-20cm, as was previously evident in the overlying ten centimetres. At this depth there were nine occasions when differences were determined for organic carbon between cultivation methods. The conventionally tilled treatments contained a higher concentration of organic carbon than the reduced tillage treatment, which had incorporated straw, for both cultivation methods.

*Table 5.5.7.*

At a sample depth of 20-30cm there were differences between cultivation methods on seven of the fourteen months sampled. These differences indicated that there was a greater concentration of organic carbon in the conventionally tilled plots. On the other seven occassions there were no differences between treatments.

Table 5.5.8. Variation of Percentage Organic Carbon concentration at the three sample depths for each of the cultivation methods.

| Plot Type | 0-10cm depth | 10-20cm depth | 20-30cm depth |
|---|---|---|---|
| A | 1.07 | 0.97 | 0.70 |
| B | 1.04 | 1.00 | 0.79 |
| C | 1.08 | 0.84 | 0.72 |
| D | 1.05 | 1.01 | 0.67 |

Key

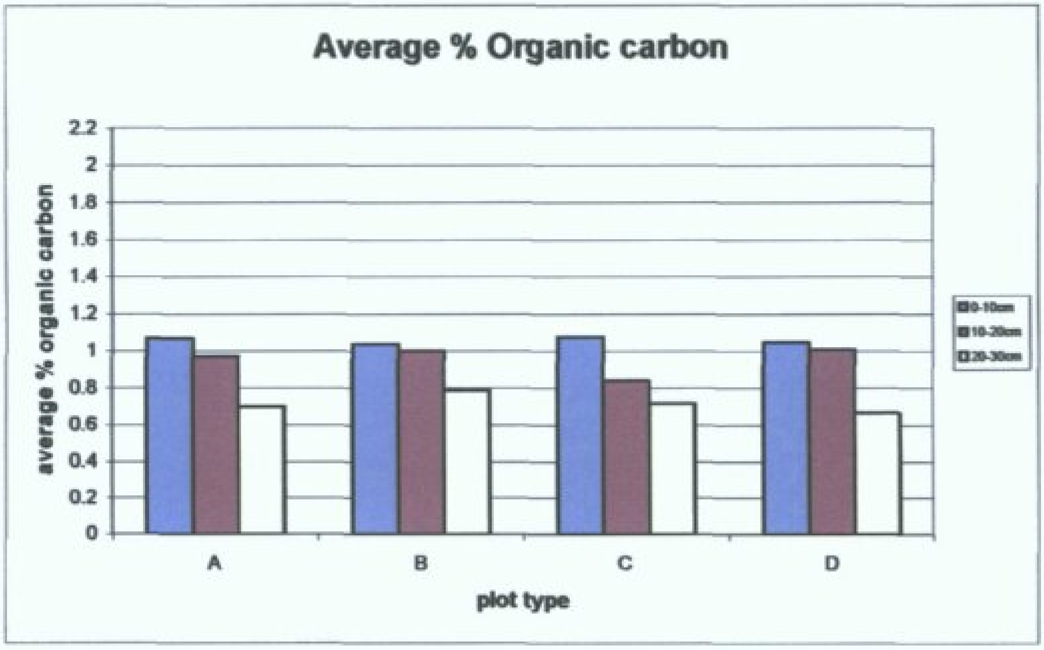
A = Conventional tillage (straw removed)

B = Conventional tillage (straw incorporated)

C = Reduced tillage (straw removed)

D = Reduced tillage (straw incorporated)

Fig.5.5.8. Variation of Percentage Organic Carbon concentration at the three sample depths for each of the cultivation methods.



***Variation of Percentage Organic Carbon concentration at the three sample depths for each of the cultivation methods.***

Soil organic carbon concentration decreased with increasing depth under both conventional and reduced tillage (as was evident in Tables 5.5.1. to 5.5.4.). There was no statistical difference in the average organic carbon concentration available over the fourteen-month sampling period, for the four treatments in the top 30cm of soil.

From this it is evident that cultivation methods did not greatly impact on the concentration of organic carbon or its distribution in the soil profile.

## *5.6. pH Results*

Soil pH is generally regarded as a very important soil property since it tends to correlate with other properties such as the degree of base saturation.

Differences in soil pH are often noted from one portion of soil to that only a few inches away. Such variations result from local microbial action and the uneven distribution of organic residues in the soil.

The pH of a soil is stabilised by its buffering capacity. A marked change in pH indicates a radical modification in soil environment, especially in respect to the availability of plant nutrients. And if this environment should fluctuate too widely higher plants and microorganisms undoubtedly would suffer seriously before they could make adequate adjustments. Not only would they be affected directly by the change in hydrogen ion concentration, but the indirect influences on nutrient elements might prove to be exceedingly unsatisfactory. The stabilization of soil pH through buffering seems to be an effective guard against these difficulties.

pH analysis was carried out on air-dried soil samples by use of an 'orion' ion selective electrode. Six pH readings were averaged to obtain the following pH values tabulated, the purpose of which was to determine if variations in pH occurred due to the different treatments, as this would enhance differences in nutrient availability for the subsequent crops. PH results for all treatment types were also compared at each of the depths sampled.

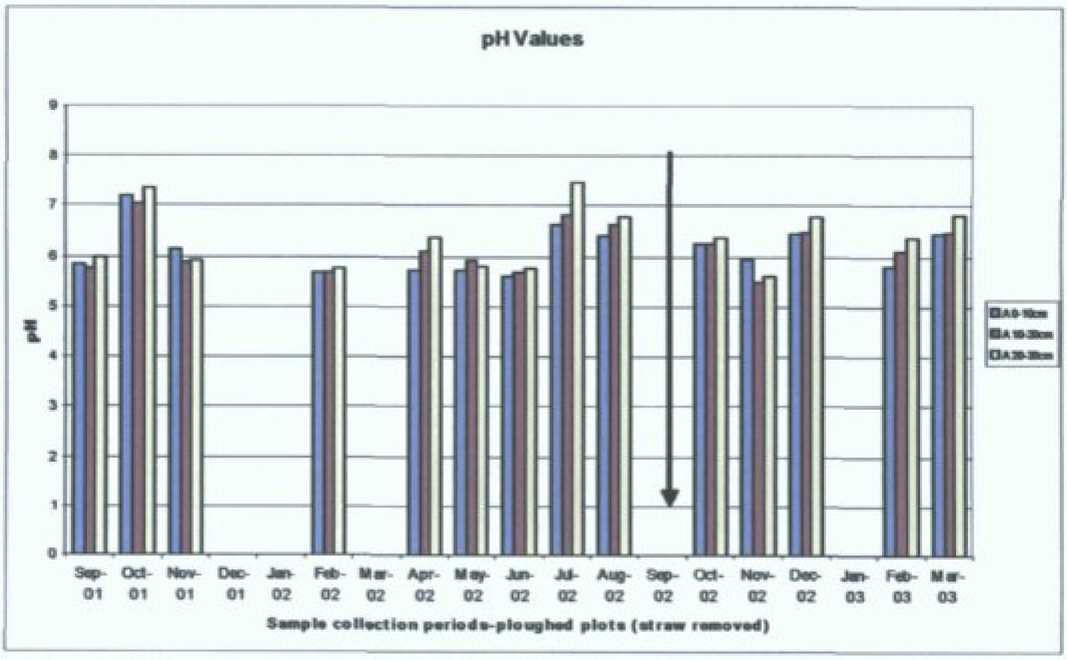
Table 5.6.1. pH readings in the ploughed treatments (straw removed) at different soil depths and on different sampling dates.

| Sample Depth | Sept 2001 | Oct 2001 | Nov 2001 | Feb 2002 | Apr 2002 | May 2002 | June 2002 | July 2002 | Aug 2002 | Oct 2002 | Nov 2002 | Dec 2002 | Feb 2003 | Mar 2003 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0-10 | 5.85 | 7.21 | 6.14 | 5.69 | 5.71 | 5.73 | 5.62 | 6.63 | 6.41 | 6.27 | 5.95 | 6.46 | 5.81 | 6.46 |
| 10-20 | 5.76 | 7.07 | 5.89 | 5.67 | 6.1 | 5.91 | 5.69 | 6.84 | 6.62 | 6.27 | 5.49 | 6.50 | 6.10 | 6.50 |
| 20-30 | 6 | 7.37 | 5.9 | 5.77 | 6.38 | 5.79 | 5.77 | 7.47 | 6.77 | 6.36 | 5.61 | 6.81 | 6.38 | 6.81 |
| Std D | 0.121 | 0.150 | 0.141 | 0.053 | 0.336 | 0.091 | 0.075 | 0.437 | 0.180 | 0.052 | 0.239 | 0.192 | 0.285 | 0.192 |
| Signif | * | *** | * | * | *** | NS | *** | *** | *** | NS | *** | ** | *** | ** |

Significance Key

| | |
|---|---|
| * | P<0.05 |
| ** | P<0.01 |
| *** | P<0.001 |
| NS | No Significant Difference |

Fig 5.6.1. pH readings in the ploughed treatments (straw removed) at different soil depths, and on different sampling dates.



The arrow on the graph indicates the date of lime application.

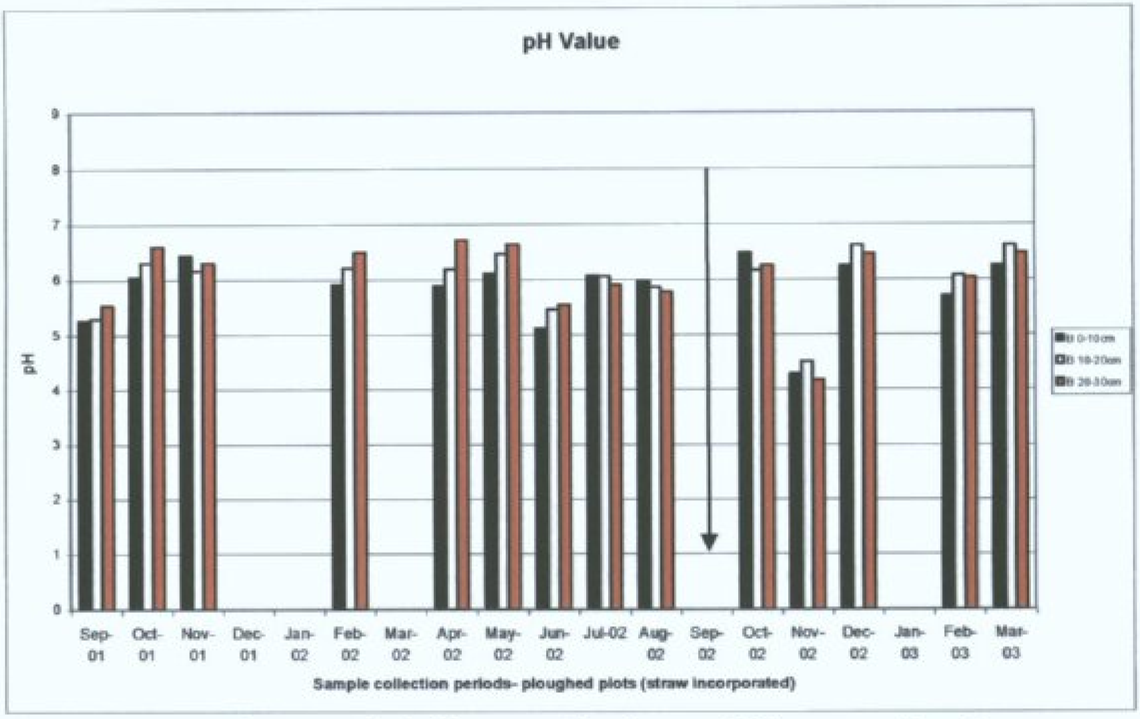
Table 5.6.2. pH readings in the ploughed treatments (straw incorporated) at different soil depths, and on different sampling dates.

| Sample Depth | Sept 2001 | Oct 2001 | Nov 2001 | Feb 2002 | Apr 2002 | May 2002 | June 2002 | July 2002 | Aug 2002 | Oct 2002 | Nov 2002 | Dec 2002 | Feb 2003 | Mar 2003 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0-10 | 5.23 | 6.10 | 6.44 | 5.91 | 5.89 | 6.12 | 5.14 | 6.08 | 5.97 | 6.49 | 4.28 | 6.25 | 5.70 | 6.25 |
| 10-20 | 5.32 | 6.31 | 6.17 | 6.22 | 6.20 | 6.47 | 5.47 | 6.07 | 5.87 | 6.17 | 4.51 | 6.61 | 6.07 | 6.61 |
| 20-30 | 5.55 | 6.60 | 6.31 | 6.50 | 6.72 | 6.64 | 5.55 | 5.91 | 5.78 | 6.26 | 4.17 | 6.47 | 6.04 | 6.47 |
| Std D | 0.165 | 0.251 | 0.135 | 0.295 | 0.419 | 0.265 | 0.217 | 0.095 | 0.095 | 0.165 | 0.173 | 0.181 | 0.205 | 0.181 |
| Signif | *** | *** | *** | *** | *** | *** | *** | ** | *** | *** | ** | *** | *** | *** |

Significance Key

| | |
|---|---|
| * | P<0.05 |
| ** | P<0.01 |
| *** | P<0.001 |
| NS | No Significant Difference |

Fig 5.6.2. pH readings in the ploughed treatments (straw incorporated) at different soil depths and on different sampling dates.



The arrow on the graph indicates the date of lime application.

Table .5.6.3. pH readings in the reduced tillage treatments (straw removed) at different soil depths and on different sampling dates.

| Sample Depth | Sept 2001 | Oct 2001 | Nov 2001 | Feb 2002 | Apr 2002 | May 2002 | June 2002 | July 2002 | Aug 2002 | Oct 2002 | Nov 2002 | Dec 2002 | Feb 2003 | Mar 2003 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0-10 | 6.10 | 6.61 | 8.04 | 6.50 | 6.10 | 5.89 | 4.97 | 5.34 | 5.78 | 6.28 | 5.00 | 6.91 | 6.34 | 6.91 |
| 10-20 | 6.28 | 6.34 | 7.73 | 6.63 | 6.47 | 6.48 | 5.69 | 5.30 | 6.19 | 5.73 | 5.12 | 6.67 | 6.10 | 6.67 |
| 20-30 | 6.21 | 6.53 | 7.69 | 6.83 | 6.41 | 6.52 | 5.69 | 5.34 | 6.66 | 5.91 | 5.02 | 6.72 | 6.23 | 6.72 |
| Std D | 0.091 | 0.139 | 0.192 | 0.166 | 0.199 | 0.353 | 0.415 | 0.023 | 0.440 | 0.280 | 0.064 | 0.127 | 0.120 | 0.127 |
| Signif | *** | *** | *** | *** | *** | *** | *** | * | *** | *** | ** | ** | *** | *** |

Significance Key

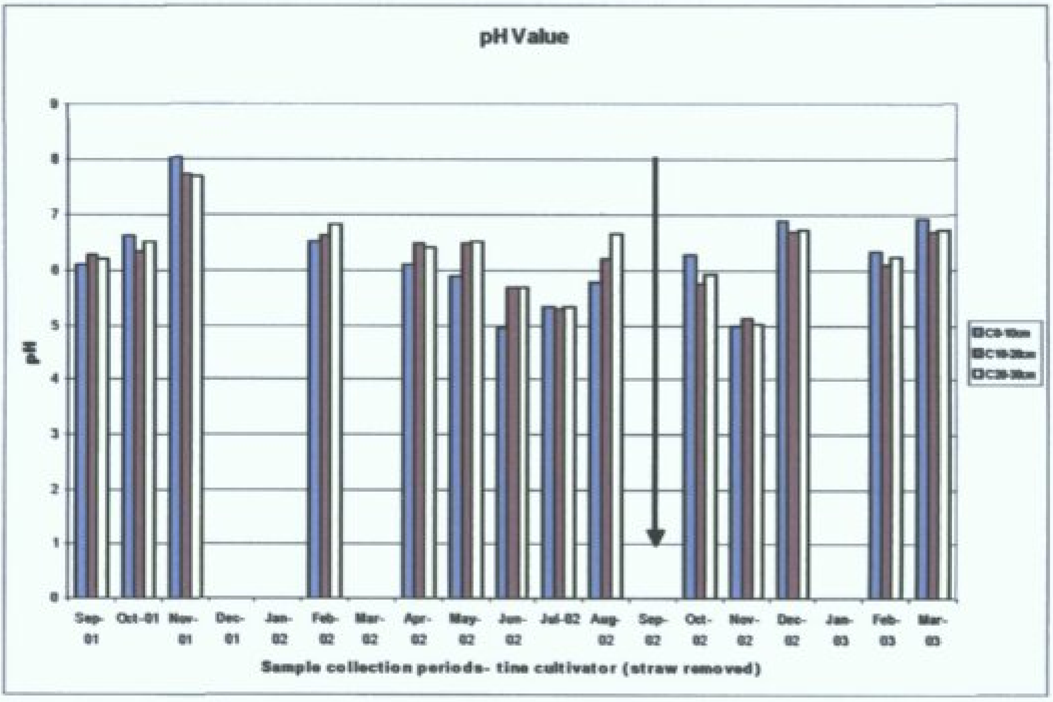
* P<0.05

** P<0.01

*** P<0.001

NS No Significant Difference

Fig 5.6.3. pH readings in the reduced tillage treatments (straw removed) at different soil depths and on different sampling dates.



The arrow on the graph indicates the date of lime application.

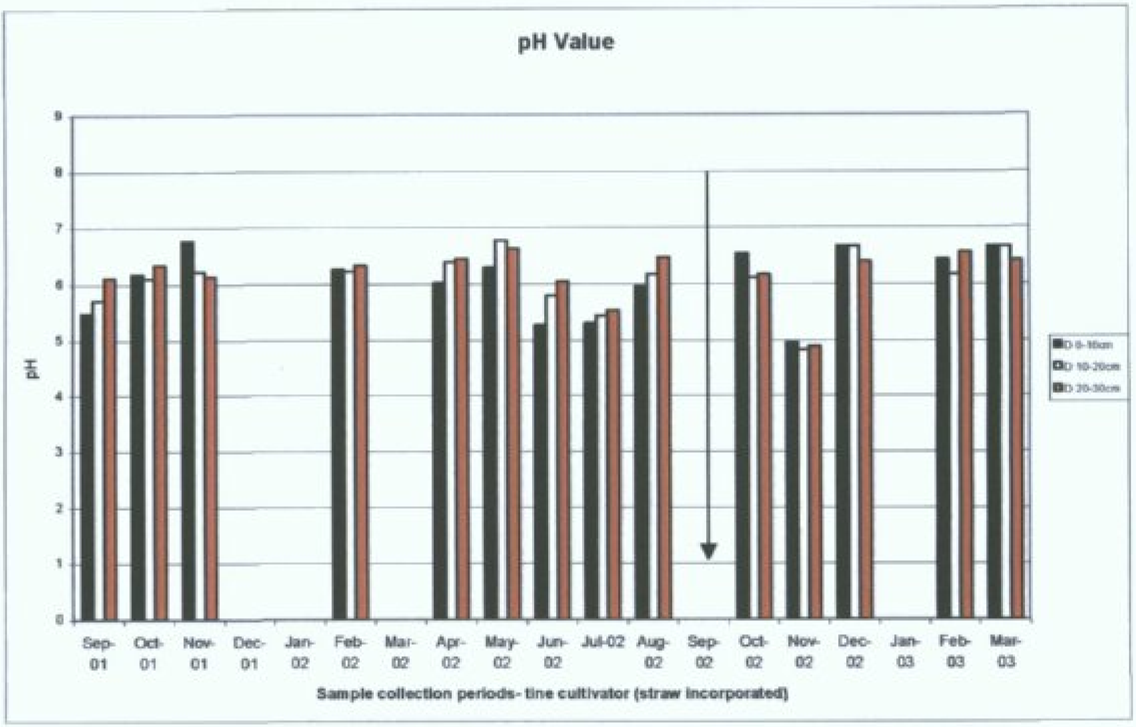
Table .5.6.4. pH readings in the reduced tillage treatments (straw incorporated) at different soil depths and on different sampling dates.

| Sample Depth | Sept 2001 | Oct 2001 | Nov 2001 | Feb 2002 | Apr 2002 | May 2002 | June 2002 | July 2002 | Aug 2002 | Oct 2002 | Nov 2002 | Dec 2002 | Feb 2003 | Mar 2003 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0-10 | 5.48 | 6.19 | 6.77 | 6.27 | 6.02 | 6.30 | 5.27 | 5.31 | 5.96 | 6.54 | 4.95 | 6.66 | 6.44 | 6.66 |
| 10-20 | 5.71 | 6.11 | 6.23 | 6.23 | 6.40 | 6.77 | 5.79 | 5.44 | 6.18 | 6.12 | 4.82 | 6.67 | 6.17 | 6.67 |
| 20-30 | 6.12 | 6.35 | 6.14 | 6.33 | 6.46 | 6.64 | 6.05 | 5.53 | 6.47 | 6.17 | 4.89 | 6.41 | 6.56 | 6.41 |
| Std D | 0.324 | 0.122 | 0.341 | 0.050 | 0.239 | 0.243 | 0.397 | 0.111 | 0.256 | 0.230 | 0.065 | 0.147 | 0.200 | 0.147 |
| Signif | *** | *** | *** | * | *** | *** | *** | *** | *** | *** | NS | * | *** | * |

Significance Key

| | |
|---|---|
| * | P<0.05 |
| ** | P<0.01 |
| *** | P<0.001 |
| NS | No Significant Difference |

Fig .5.6.4. pH readings in the reduced tillage treatments (straw incorporated) at different soil depths and on different sampling dates.



The arrow on the graph indicates the date of lime application.

***pH results for each treatment.***

*Table 5.6.1.*

The pH values determined in the soil did not appear to vary greatly between the three sampled depths. These differences indicated that the hydrogen ion concentration fluctuated slightly through the soil horizon. The addition of lime to the treatment increased the soil pH during the summer months, where the greatest increase occurred during July at the lower sampled depths.

*Table 5.6.2.*

In general the pH values determined in the soil for the conventionally tilled treatments, which had incorporated straw, were slightly less than for the treatments which had removed straw. These treatments were also subjected to greater fluctuations in soil pH values over the sampling period. Although the treatments, which had removed straw yielded higher values for soil pH, these figures were not statistically different to those which had incorporated straw.

*Table 5.6.3.*

This treatment yielded the greatest fluctuations in soil pH of the four (the pH ranged from 8.04 to 5.00). Throughout most of the sampling period there were no differences in pH values between this treatment and the conventionally tilled. The statistical differences observed by Dick (1983) etc were not evident over the 20 month sampling period of this research.

*Table 5.6.4.*

The reduced tillage treatment yielded the greater differences in pH values through the soil profile (both with and without the straw). Of the four treatments analysed for pH this treatment showed the least amount of fluctuations in pH over the sampling period.

Table 5.6.5. pH readings for all four cultivation methods at the 0-10cm sampling depth over the sampling period.

| Plot Type | Sep 2001 | Oct 2001 | Nov 2001 | Feb 2002 | Apr 2002 | May 2002 | June 2002 | July 2002 | Aug 2002 | Oct 2002 | Nov 2002 | Dec 2002 | Feb 2003 | Mar 2003 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A | 5.85 | 7.21 | 6.14 | 5.69 | 5.71 | 5.73 | 5.62 | 6.63 | 6.41 | 6.27 | 5.95 | 6.46 | 5.81 | 6.46 |
| B | 5.29 | 6.10 | 6.44 | 5.91 | 5.89 | 6.12 | 5.14 | 6.08 | 5.97 | 6.49 | 4.28 | 6.25 | 5.70 | 6.25 |
| C | 6.10 | 6.61 | 8.04 | 6.50 | 6.10 | 5.89 | 4.97 | 5.34 | 5.78 | 6.28 | 5.00 | 6.91 | 6.34 | 6.91 |
| D | 5.48 | 6.19 | 6.77 | 6.27 | 6.02 | 6.30 | 5.27 | 5.31 | 5.96 | 6.54 | 4.95 | 6.66 | 6.44 | 6.66 |
| Std D | 0.364 | 0.506 | 0.836 | 0.362 | 0.170 | 0.251 | 0.276 | 0.636 | 0.268 | 0.140 | 0.687 | 0.282 | 0.372 | 0.282 |
| Signif | *** | *** | *** | *** | NS | *** | ** | *** | *** | *** | *** | *** | *** | *** |

Key

A = Conventional tillage (straw removed)

B = Conventional tillage (straw incorporated)

C = Reduced tillage (straw removed)

D = Reduced tillage (straw incorporated)

Significance Key

| | |
|---|---|
| * | P<0.05 |
| ** | P<0.01 |
| *** | P<0.001 |
| NS | No Significant Difference |

Fig. 5.6.5. pH readings for all four cultivation methods at the 0-10cm sampling depth over the sampling period.

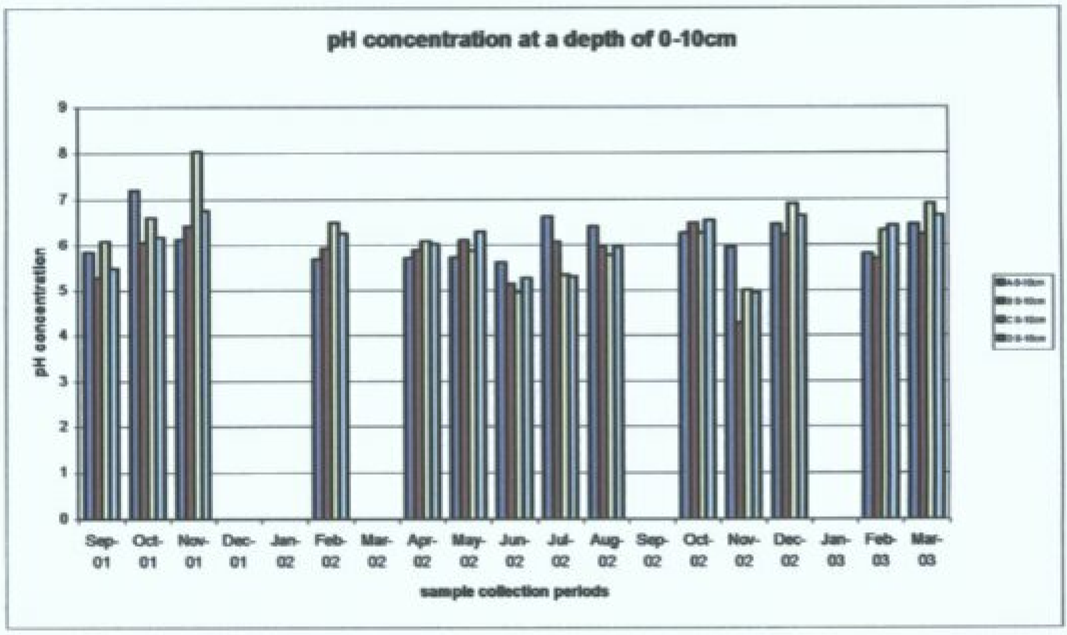


Table .5.6.6. pH readings for all four cultivation methods at the 10-20cm sampling depth over the sampling period.

| Plot Type | Sep 2001 | Oct 2001 | Nov 2001 | Feb 2002 | Apr 2002 | May 2002 | June 2002 | July 2002 | Aug 2002 | Oct 2002 | Nov 2002 | Dec 2002 | Feb 2003 | Mar 2003 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A | 5.76 | 7.07 | 5.89 | 5.67 | 6.10 | 5.91 | 5.69 | 6.84 | 6.62 | 6.27 | 5.49 | 6.50 | 6.10 | 6.50 |
| B | 5.32 | 6.31 | 6.17 | 6.22 | 6.20 | 6.47 | 5.47 | 6.10 | 5.87 | 6.17 | 4.51 | 6.61 | 6.07 | 6.61 |
| C | 6.28 | 6.34 | 7.73 | 6.63 | 6.47 | 6.48 | 5.69 | 5.30 | 6.19 | 5.73 | 5.12 | 6.67 | 6.10 | 6.67 |
| D | 5.71 | 6.11 | 6.23 | 6.23 | 6.40 | 6.77 | 5.79 | 5.44 | 6.18 | 6.12 | 4.82 | 6.67 | 6.17 | 6.67 |
| Std D | 0.394 | 0.421 | 0.83 | 0.394 | 0.172 | 0.359 | 0.135 | 0.706 | 0.308 | 0.237 | 0.419 | 0.080 | 0.042 | 0.080 |
| Signif | *** | *** | *** | *** | NS | ** | NS | *** | *** | *** | NS | NS | NS | NS |

Key

A = Conventional tillage (straw removed)

B = Conventional tillage (straw incorporated)

C = Reduced tillage (straw removed)

D = Reduced tillage (straw incorporated)

Significance Key

| | |
|---|---|
| * | P<0.05 |
| ** | P<0.01 |
| *** | P<0.001 |
| NS | No Significant Difference |

Fig. 5.6.6. pH readings for all four cultivation methods at the 10-20cm sampling depth over the sampling period.

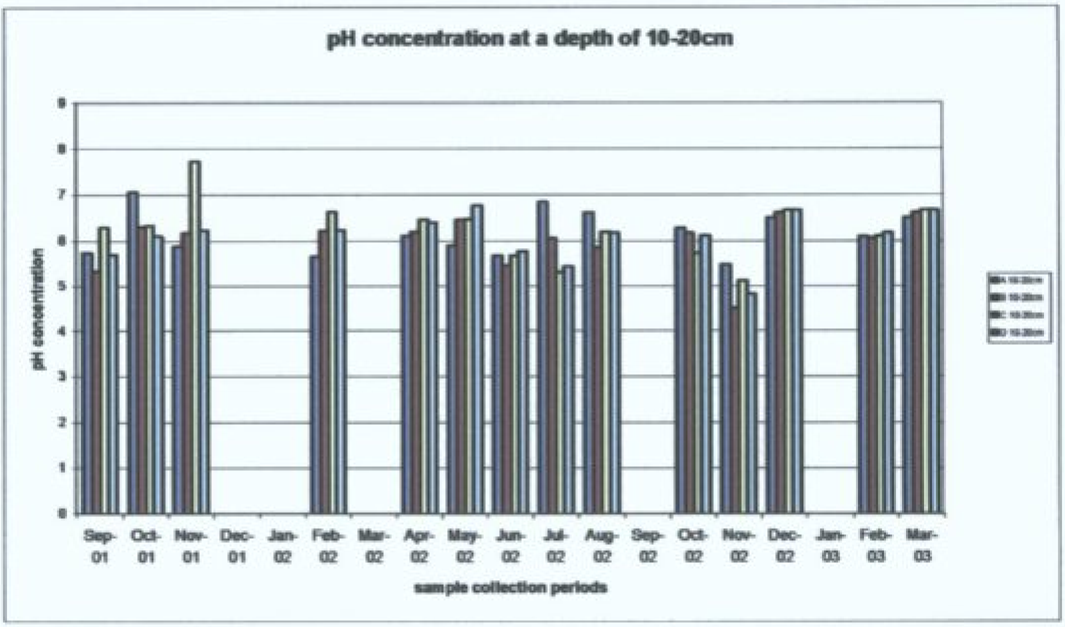


Table 5.6.7. pH readings for all four cultivation methods at the 20-30cm sampling depth over the sampling period.

| Plot Type | Sep 2001 | Oct 2001 | Nov 2001 | Feb 2002 | Apr 2002 | May 2002 | June 2002 | July 2002 | Aug 2002 | Oct 2002 | Nov 2002 | Dec 2002 | Feb 2002 | Mar 2002 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A | 5.76 | 7.07 | 5.89 | 5.67 | 6.10 | 5.91 | 5.69 | 6.84 | 6.62 | 6.27 | 5.49 | 6.50 | 6.10 | 6.50 |
| B | 5.32 | 6.31 | 6.17 | 6.22 | 6.20 | 6.47 | 5.47 | 6.10 | 5.87 | 6.17 | 4.51 | 6.61 | 6.07 | 6.61 |
| C | 6.28 | 6.34 | 7.73 | 6.63 | 6.47 | 6.48 | 5.69 | 5.30 | 6.19 | 5.73 | 5.12 | 6.67 | 6.10 | 6.67 |
| D | 5.71 | 6.11 | 6.23 | 6.23 | 6.40 | 6.77 | 5.79 | 5.44 | 6.18 | 6.12 | 4.82 | 6.67 | 6.17 | 6.67 |
| Std D | 0.394 | 0.421 | 0.83 | 0.394 | 0.172 | 0.359 | 0.135 | 0.706 | 0.308 | 0.237 | 0.419 | 0.080 | 0.042 | 0.080 |
| Signif | *** | *** | *** | *** | NS | *** | ** | *** | *** | NS | NS | NS | NS | NS |

Key

A = Conventional tillage (straw removed)

B = Conventional tillage (straw incorporated)

C = Reduced tillage (straw removed)

D = Reduced tillage (straw incorporated)

Significance Key

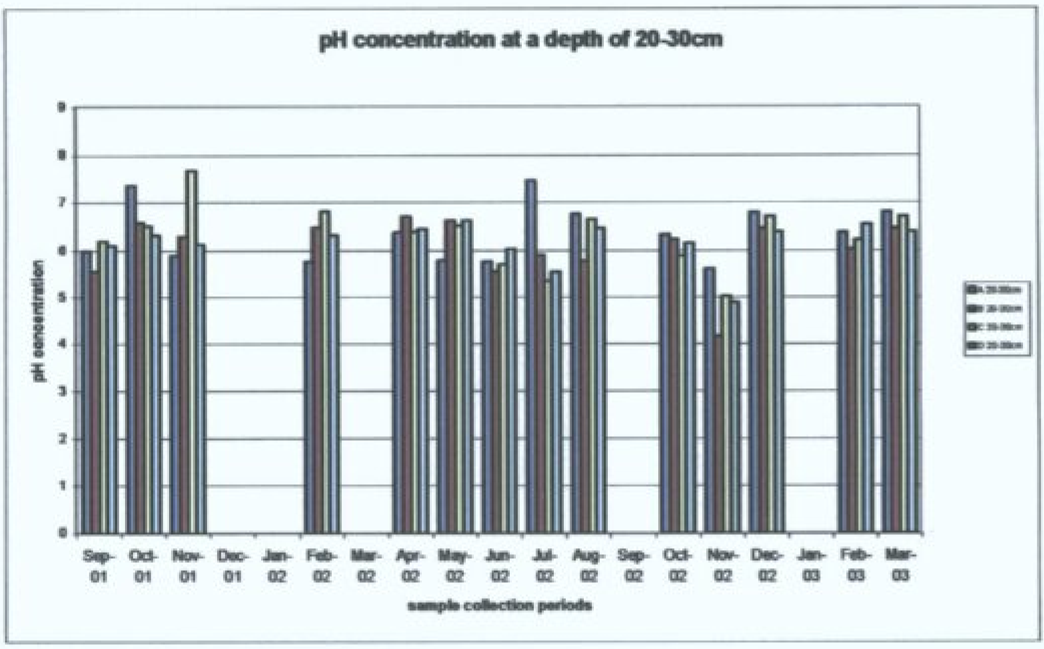
* P<0.05

** P<0.01

*** P<0.001

NS No Significant Difference

Fig. 5.6.7. pH readings for all four cultivation methods at the 20-30cm sampling depth over the sampling period.



***pH. Comparing the three sample depths.***

*Table 5.6.5.*

When values for pH were compared for the four treatments at a sample depth of 0-10cm, the differences in readings determined were statistically significant. During the wetter months from October through until March, there were slightly higher values determined for pH in the reduced cultivation treatments while during the summer months the conventionally tilled treatments contained higher values.

*Table 5.6.6.*

The concentration of pH at a sample depth of 10-20cm follows a similar trend initially to the overlying layer of soil, in that, from September 2001 until May 2002 the reduced tillage treatment in general contains higher values of pH, than the conventionally tilled treatments. This is then reverted over the summer months. However, the slightly higher pH values of the reduced cultivation treatment, which occurred during the first autumn/ winter period, were not evident from December 2002 onwards to March 2003. During this sampling period there were no differences in pH values between any of the four treatments. Although at times it appeared that one treatment dominated another in regard to pH determined.

*Table 5.6.7.*

As was determined previously there were very little differences determined in pH values at the lowest sampling depth of 20-30cm between treatments. At various stages throughout the sampling period one treatment appeared to contain higher pH values than the other but these differences were not statistically significant. Throughout the autumn and winter months there were no differences determined in the values for pH between the four cultivation methods.

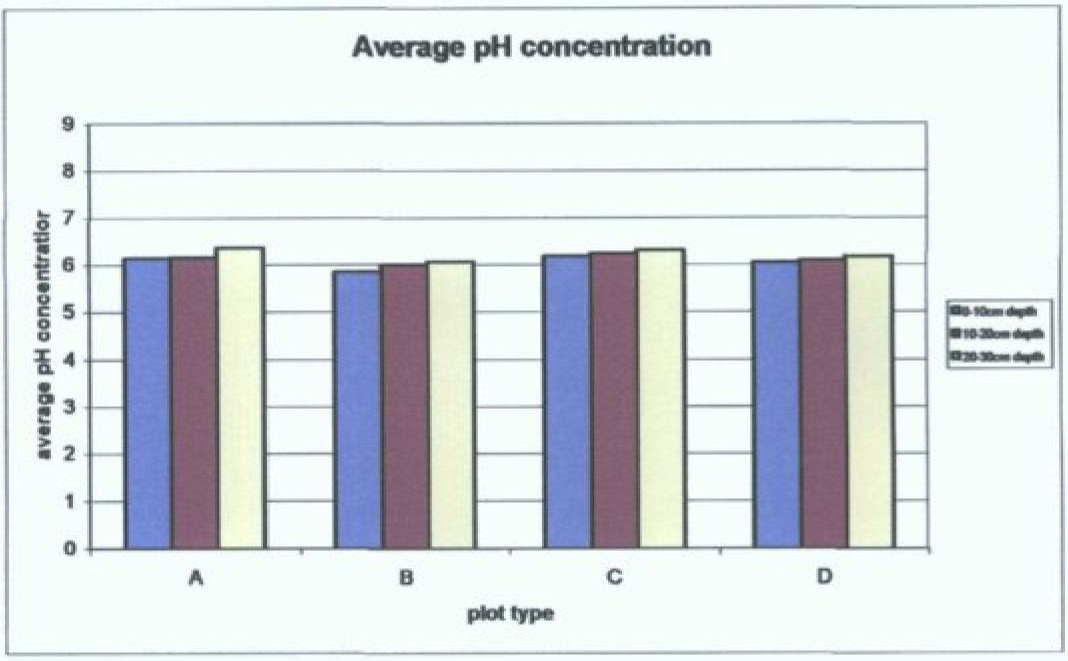
Table. 5.6.8. Variation of pH readings at the three sample depths for each of the cultivation methods.

| Plot Type | 0-10cm depth | 10-20cm depth | 20-30cm depth |
|---|---|---|---|
| A | 6.14 | 6.17 | 5.96 |
| B | 5.85 | 6.00 | 6.07 |
| C | 6.19 | 6.24 | 6.32 |
| D | 6.06 | 6.09 | 6.18 |

Key

A = Conventional tillage (straw removed)
B = Conventional tillage (straw incorporated)
C = Reduced tillage (straw removed)
D = Reduced tillage (straw incorporated)

Fig. 5.6.8. Variation of pH readings at the three sample depths for each of the cultivation methods.



Having graphed each of the average values determined for pH over the sampling period, it is evident that the differences in cultivation methods carried out did not initially impact on the pH of the soil through the soil profile, as all four treatments contain similar values for pH at each of the three depths sampled.

## *5.7. SHEAR STRENGTH RESULTS*

The following tables present the resultant changes in soil shear strength between two different cultivation methods, conventional and reduced tillage (with and without the incorporation of straw). The conventional tillage treatment disturbed the soil to a depth of 25cm whereas the reduced tillage treatment disturbed the top 10cm of soil. Forty individual measurements were obtained from each plot type and then averaged to give the values in the tables below. Appendix A contains the complete set of measurements.

The comparison of shear strength values from trials with different cultivation methods is possible since all sampling of the soil strength was performed simultaneously, thus eliminating the effect of changing soil moisture.

Table 5.7.1. Soil Shear strength values determined on 19/03/02 for all treatments.

| ***Cultivation Method*** | ***Shear strength at 4cm (kPa)*** | ***Shear strength at 12cm (kPa)*** |
|---|---|---|
| Conventional tillage + straw | 23 | 27 |
| Conventional tillage - straw | 19 | 24 |
| Reduced tillage + straw | 34 | 53 |
| Reduced tillage - straw | 37 | 52 |

Fig.5.7.1. Soil Shear strength as affected by cultivation methods (19/03/02).

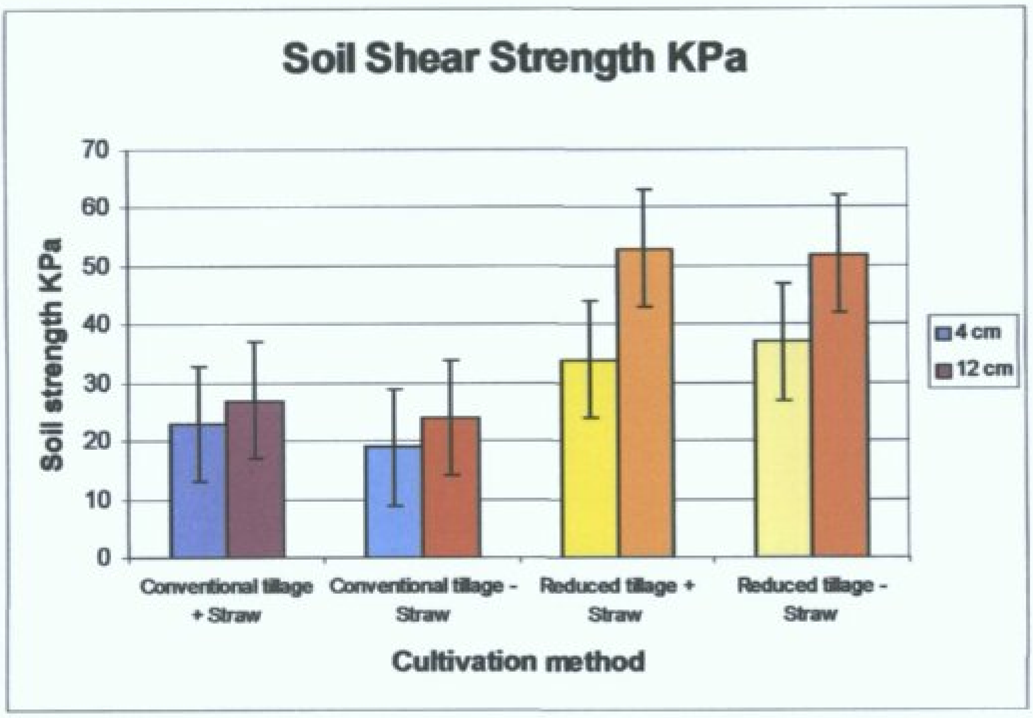


Table .5.7.2. Soil Shear strength values determined on 16/04/02.

| ***Cultivation Method*** | ***Shear strength at 4cm (kPa)*** | ***Shear strength at 12cm (kPa)*** |
|---|---|---|
| Conventional tillage + straw | 57 | 57 |
| Conventional tillage - straw | 58 | 59 |
| Reduced tillage + straw | 59 | 63 |
| Reduced tillage - straw | 63 | 67 |

Fig.5.7.2. Soil Shear strength as affected by cultivation method.

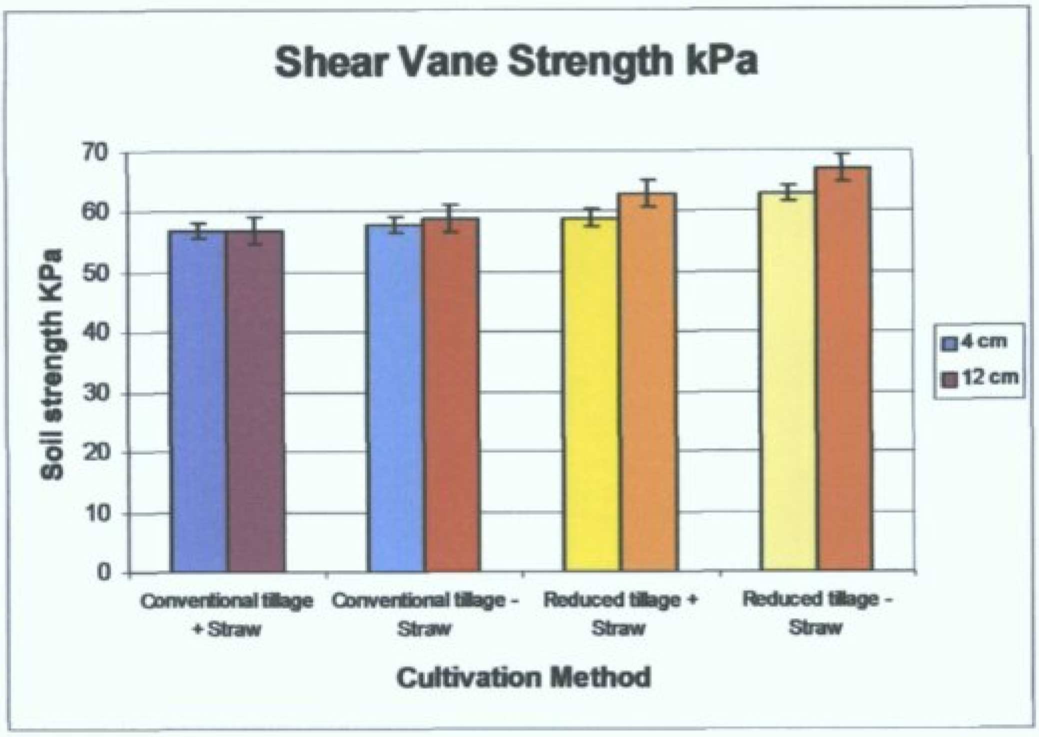
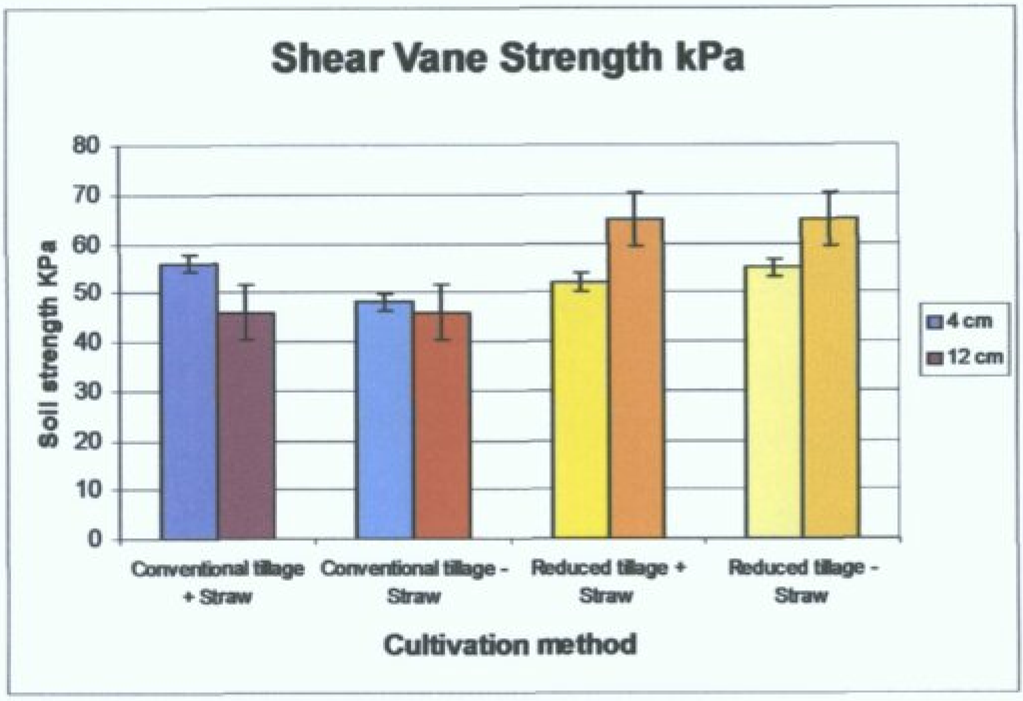


Table. 5.7.3. Soil Shear strength values determined on 24/03/03.

| ***Cultivation Method*** | ***Shear strength at 4cm (kPa)*** | ***Shear strength at 12cm (kPa)*** |
|---|---|---|
| Conventional tillage + straw | 56 | 46 |
| Conventional tillage - straw | 48 | 46 |
| Reduced tillage + straw | 52 | 65 |
| Reduced tillage - straw | 55 | 65 |

Fig.5.7.3. Soil Shear strength as affected by cultivation method.



### *Shear Strength Results.*

*Table 5.7.1.*

In fig 5.7.1. the shear strength of the soil can be seen to be influenced by tillage practices. Under reduced tillage the shear strength of the soil is greater at both 4 and 12cm. This may be due to the reduction in soil disturbance associated with this form of tillage. The shear strength of the soil is greater, deeper into the soil profile in all treatments.

Table 5.7.2.

A second set of data was obtained in April of 2002, when soil conditions were considered more favourable than previously in March. On this occasion soil moisture content was reduced through the profile. The reduction in soil moisture between March and April can be seen to affect the soil shear strength of the soil to a depth of 12cm. By reducing the moisture content of the soil the soil shear strength can be seen to increase.

The reduced cultivation plots still contain slightly higher shear strength values, but these may be due to random sampling variability. These plots also vary in shear strength at 4 and 12cm, unlike the conventionally tilled plots.

*Table 5.7.3.*

A third set of shear vane results were obtained in March of 2003.

As in previous sets of data, the shear strength of the soil is greater in the plots which, were cultivated by reduced cultivation. The incorporation or removal of straw did not greatly affect the shear strength of the soil under either of the cultivation methods used.

On this sampling occasion the shear strength of the soil was higher at the 4cm point in the conventionally tilled plots, on all other sampling dates the shear strength was higher further into the soil profile at 12cm.

## *5.8. CONE PENETROMETER RESULTS*

Ten separate profiles were measured with the cone penetrometer, and these were averaged to give one sample profile as shown in tables Appendix A. There were four sample profiles measured for each trial, Conventional and Reduced tillage (with and without the incorporation of straw). The average figures for soil profiles shown in the following tables is the average value obtained for the four sample profiles measured, therefore each profile shown below is an average resistance taken from forty individual measurements in the field. The Kilo Paschal (Kpa) is the unit of measure for penetration resistance.

It is not accurate to directly compare results for soil resistance using a cone penetrometer on different sampling dates due to differences in the soil moisture content. However, for the purpose of this study it may be a useful tool to determine patterns in soil penetration resistance within cultivation methods.
Tables 5.8.5., 5.8.7., 5.8.9. and 5.8.11. compare penetration resistance for each of the four treatments, conventional and reduced tillage (with and without straw), on the four dates sampled. As already outlined each value for soil resistance was averaged from forty individual measurements in the field.

The following table represents the results of the cone penetration analysis, carried out on the 19th of March 2002 for all four treatments. Measurements were taken simultaneously for the different cultivation methods as cone penetration results are affected by soil moisture content.

Fig.5.8.1. Cone Penetration Resistance determined on 19/03/02 for all treatments.

| Sample Depth (cm) | kPa Treatment A | kPa Treatment B | kPa Treatment C | kPa Treatment D |
|---|---|---|---|---|
| 3.5 | 8 | 6 | 6 | 7 |
| 7.0 | 10 | 9 | 10 | 12 |
| 10.5 | 12 | 10 | 15 | 17 |
| 14.0 | 12 | 11 | 18 | 20 |
| 17.5 | 12 | 10 | 18 | 20 |
| 21.0 | 12 | 11 | 20 | 20 |
| 24.5 | 13 | 12 | 22 | 21 |
| 28.0 | 16 | 17 | 23 | 24 |
| 31.5 | 22 | 23 | 26 | 27 |
| 34.0 | 27 | 25 | 26 | 28 |
| 37.5 | 29 | 27 | 27 | 28 |
| 41.0 | 31 | 28 | 28 | 28 |
| 44.5 | 32 | 30 | 29 | 30 |
| 48.0 | 33 | 29 | 29 | 30 |
| 51.5 | 31 | 28 | 29 | 28 |

Key

A = Conventional tillage (straw removed)

B = Conventional tillage (straw incorporated)

C = Reduced tillage (straw removed)

D = Reduced tillage (straw incorporated)

Fig. 5.8.1. Cone Penetration Resistance determined on 19/03/02 for all treatments.

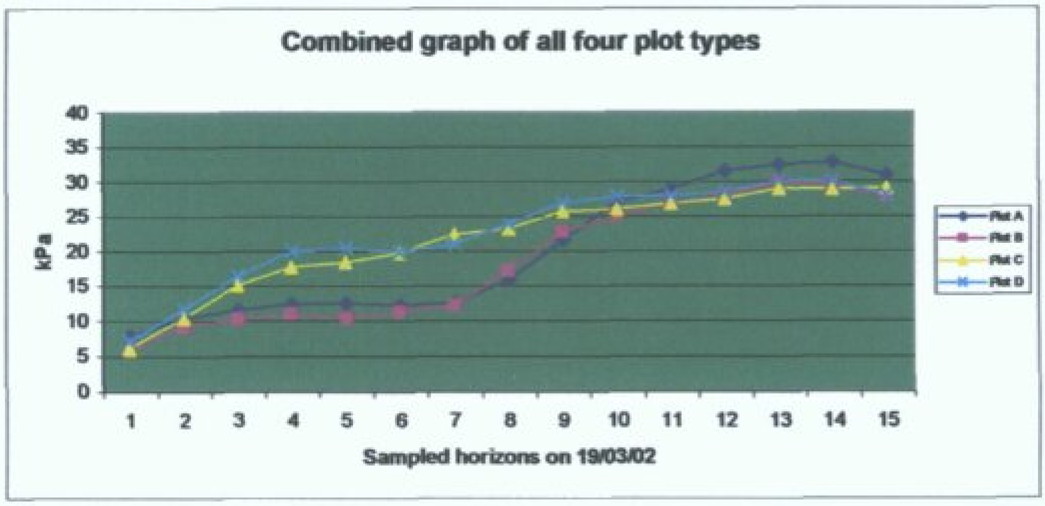


Table.5.8.2. Cone Penetration Resistance determined on 16/04/02 for all treatments.

| **Sample Depth (cm)** | **kPa Treatment A** | **kPa Treatment B** | **kPa Treatment C** | **kPa Treatment D** |
|---|---|---|---|---|
| **3.5** | 3 | 3 | 4 | 4 |
| **7.0** | 21 | 19 | 26 | 26 |
| **10.5** | 20 | 18 | 32 | 30 |
| **14.0** | 15 | 15 | 29 | 28 |
| **17.5** | 14 | 12 | 27 | 24 |
| **21.0** | 14 | 11 | 24 | 22 |
| **24.5** | 14 | 13 | 23 | 24 |
| **28.0** | 17 | 16 | 25 | 26 |
| **31.5** | 22 | 21 | 29 | 30 |
| **34.0** | 26 | 26 | 29 | 30 |
| **37.5** | 28 | 29 | 30 | 30 |
| **41.0** | 28 | 29 | 31 | 30 |
| **44.5** | 29 | 31 | 32 | 29 |
| **48.0** | 29 | 30 | 32 | 29 |
| **51.5** | 30 | 31 | 29 | 28 |

Key

A = Conventional tillage (straw removed)

B = Conventional tillage (straw incorporated)

C = Reduced tillage (straw removed)

D = Reduced tillage (straw incorporated)

Fig.5.8.2. Cone Penetration Resistance determined on 16/04/02 for all treatments.

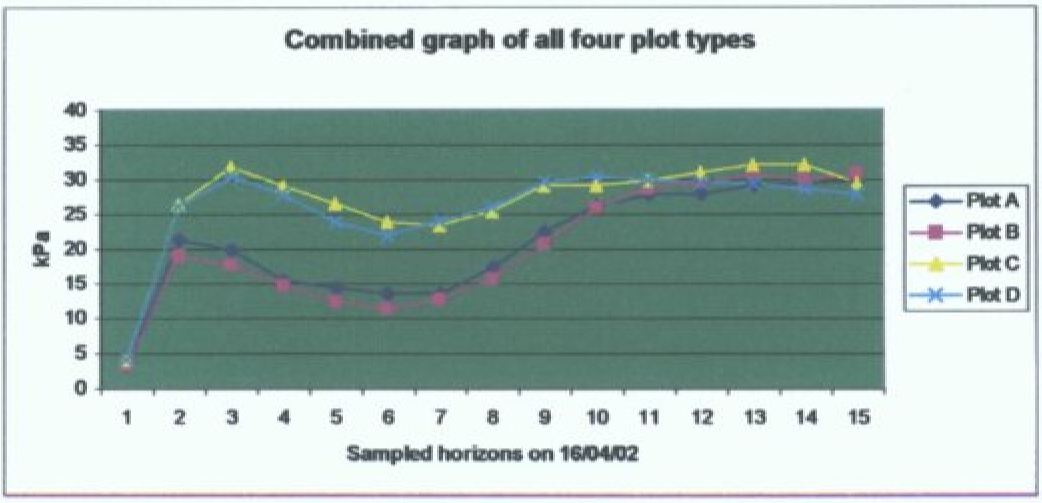


Table.5.8.3. Cone Penetration Resistance determined on 13/11/02 for all treatments.

| **Sample Depth (cm)** | **kPa Treatment A** | **kPa Treatment B** | **kPa Treatment C** | **kPa Treatment D** |
|---|---|---|---|---|
| **3.5** | 5 | 4 | 4 | 4 |
| **7.0** | 7 | 7 | 8 | 6 |
| **10.5** | 9 | 8 | 13 | 13 |
| **14.0** | 10 | 9 | 16 | 19 |
| **17.5** | 10 | 10 | 18 | 20 |
| **21.0** | 12 | 11 | 20 | 20 |
| **24.5** | 14 | 14 | 21 | 21 |
| **28.0** | 18 | 17 | 24 | 27 |
| **31.5** | 24 | 23 | 26 | 27 |
| **34.0** | 27 | 25 | 29 | 30 |
| **37.5** | 28 | 26 | 29 | 30 |
| **41.0** | 31 | 28 | 32 | 34 |
| **44.5** | 31 | 30 | 33 | 30 |
| **48.0** | 32 | 32 | 34 | 32 |
| **51.5** | 33 | 33 | 36 | 33 |

Key

A = Conventional tillage (straw removed)

B = Conventional tillage (straw incorporated)

C = Reduced tillage (straw removed)

D = Reduced tillage (straw incorporated)

Fig.5.8.3. Cone Penetration Resistance determined on 13/11/02 for all treatments.

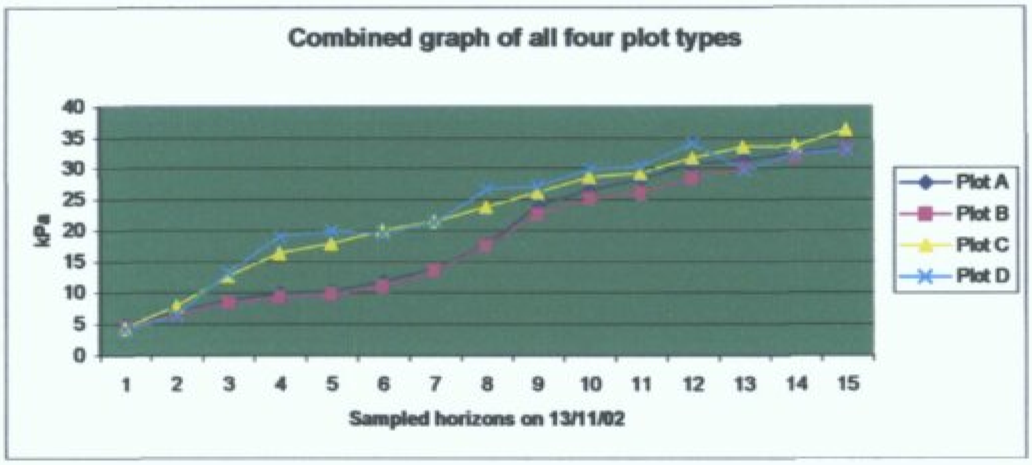


Table.5.8.4. Cone Penetration Resistance determined on 24/03/03 for all treatments.

| Sample Depth (cm) | kPa Treatment A | kPa Treatment B | kPa Treatment C | kPa Treatment D |
|---|---|---|---|---|
| 3.5 | 4 | 3 | 3 | 3 |
| 7.0 | 5 | 5 | 6 | 5 |
| 10.5 | 7 | 7 | 10 | 10 |
| 14.0 | 8 | 7 | 13 | 15 |
| 17.5 | 8 | 8 | 14 | 15 |
| 21.0 | 9 | 9 | 15 | 15 |
| 24.5 | 11 | 10 | 17 | 16 |
| 28.0 | 14 | 13 | 18 | 21 |
| 31.5 | 19 | 17 | 20 | 21 |
| 34.0 | 21 | 19 | 22 | 23 |
| 37.5 | 22 | 20 | 23 | 23 |
| 41.0 | 24 | 22 | 24 | 26 |
| 44.5 | 24 | 23 | 26 | 23 |
| 48.0 | 25 | 25 | 26 | 25 |
| 51.5 | 26 | 26 | 28 | 25 |

Key

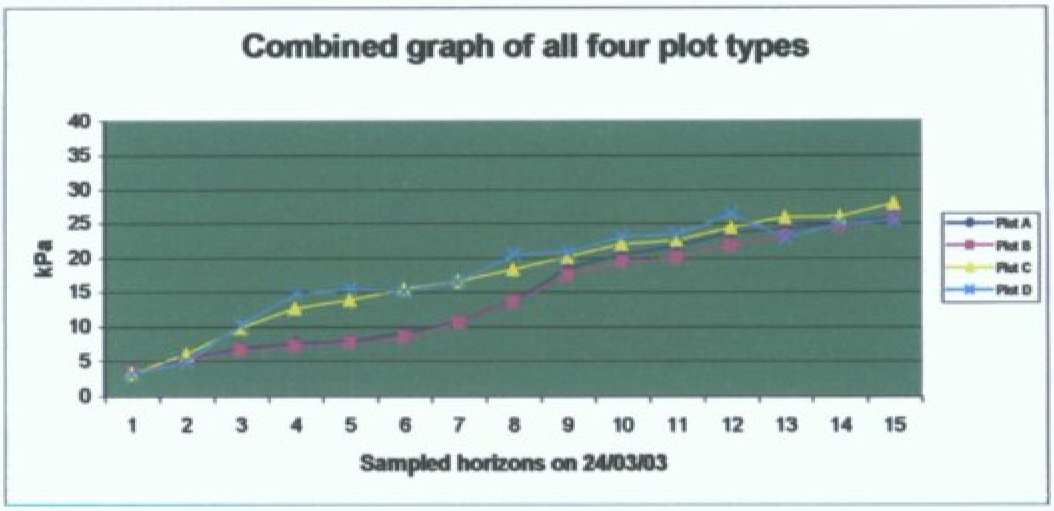
A = Conventional tillage (straw removed)

B = Conventional tillage (straw incorporated)

C = Reduced tillage (straw removed)

D = Reduced tillage (straw incorporated)

Fig.5.8.4. Cone Penetration Resistance determined on 24/03/03 for all treatments.



### *Cone Penetration Resistance Results.*

*Table 5.8.1.*

In figure.5.8.1. cone penetration resistance can be seen to be affected by cultivation method, or more accurately by the degree of soil disturbance caused by cultivation methods. In plots which were treated by conventional tillage, soil resistance to the cone penetrometer remained low to a sample depth of 28cm, after which resistance can be seen to increase to greater than 30 kg of force per cm$^2$. Where soil disturbance was reduced (by the use of the tine cultivator), soil resistance to the cone penetrometer increased higher up in the soil profile, but at the lower sampling depths below 30cm the soils resistance to the cone penetrometer varied little between the cultivation methods.

*Table 5.8.2.*

In figure 5.8.2. the results of the cone penetrometer resistance readings can be seen to be affected by the reduction in the soils moisture content (refer to table 5.8.8.). This impact is greatest in the top 20cm of soil, where soil resistance can be seen to increase for all four treatments at a depth of 7cm, before returning to the same pattern as was obtained in March, this occurred at a depth of approximately 21cm. The reduced cultivation plots both with and without the incorporation of straw were affected to the greatest extent by the loss in soil moisture. The incorporation of straw did not appear to limit the loss of soil water under either cultivation method.

*Table 5.8.3.*

Soil resistance to the cone penetrometer, was affected by the degree of soil disturbance from the tillage processes, and by the soils moisture content. The increase in the moisture content of the soil has decreased the soils resistance to the penetrometer. This can be seen to occur for both cultivation methods, although the pattern of resistance for each cultivation method remained the same.

*Table 5.8.4.*

The pattern of soil resistance to cone penetration continued to occur as in previous results, for each cultivation method in March 2003 i.e. resistance was higher in the upper horizon of soil under reduced tillage, but this difference between treatments levelled out at the lower sample depths in the profile i.e. from 30cm downwards.The required kg of force per $cm^2$ to push the penetrometer into the soil was lower on this sampling date than had been in the previous March (2002). However, soil moisture concentrations were higher in 2003.

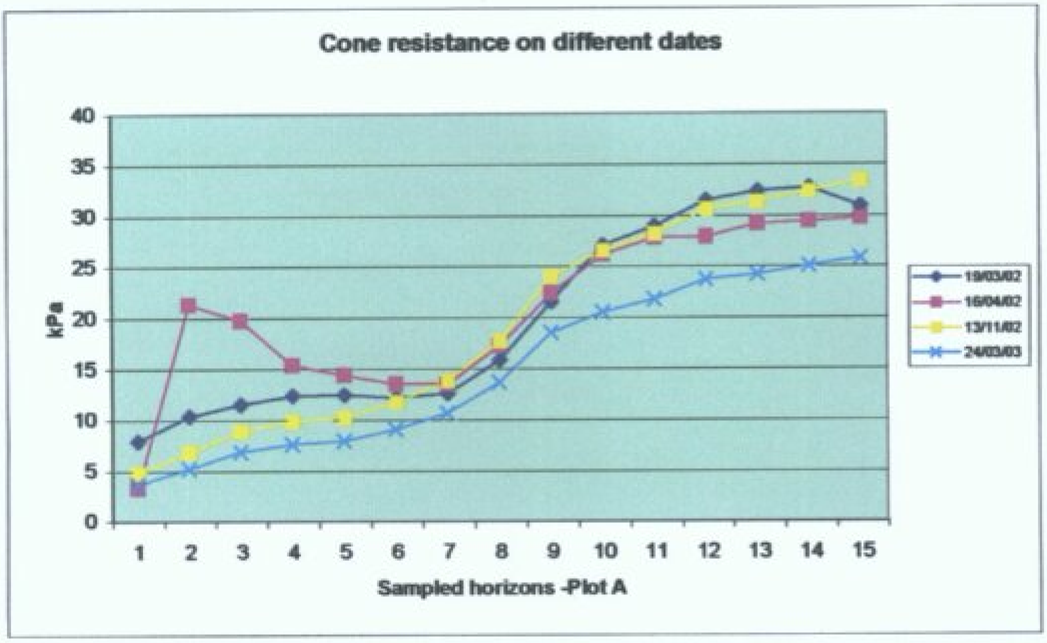
Table. 5.8.5. Effect of soil moisture content on cone resistance (kPa) for the Ploughed treatments (straw removed), when measurements were taken on different dates.

| **Sample Depth (cm)** | **kPa 19/03/02** | **kPa 16/04/02** | **kPa 13/11/02** | **kPa 24/03/03** |
|---|---|---|---|---|
| **3.5** | 8 | 3 | 5 | 4 |
| **7.0** | 10 | 21 | 7 | 5 |
| **10.5** | 12 | 20 | 9 | 7 |
| **14.0** | 12 | 15 | 10 | 8 |
| **17.5** | 12 | 14 | 10 | 8 |
| **21.0** | 12 | 14 | 12 | 9 |
| **24.5** | 13 | 14 | 14 | 11 |
| **28.0** | 16 | 17 | 18 | 14 |
| **31.5** | 22 | 22 | 24 | 19 |
| **34.0** | 27 | 26 | 27 | 21 |
| **37.5** | 29 | 28 | 28 | 22 |
| **41.0** | 31 | 28 | 31 | 24 |
| **44.5** | 32 | 29 | 31 | 24 |
| **48.0** | 33 | 29 | 32 | 25 |
| **51.5** | 31 | 30 | 33 | 26 |

Table 5.8.6. Soil Moisture Contents on the dates sampled.

| Depth cm | 19/03/2002 | 16/04/2002 | 13/11/2002 | 24/03/2003 |
|---|---|---|---|---|
| 0-10 | 20.29 | 16.08 | 21.71 | 18.29 |
| 10-20 | 20.49 | 17.89 | 21.15 | 19.33 |
| 20-30 | 18.53 | 18.03 | 19.84 | 18.05 |

Fig.5.8.5. Effect of soil moisture content on cone resistance (kPa) for the Ploughed treatments (straw removed), when measurements were taken on different dates.



This graph outlines the changing profile of soil resistance in the soil horizon. This analysis was carried out on four different sampling dates, (with the exception of a set of data- 16/04/02), the soils resistance can be seen to increase beyond a sample depth of 28cm. As these soils were subject to inversion and mixing to a depth of approximately 25cm, one would expect that beyond the point of soil disturbance, soil resistance would increase.

The rapid increase in soil resistance in April within the upper soil horizon was possibly due to losses in soil moisture due to evaporation, which caused the soil to crust, increasing its resistance to penetration.

The slight fluctuations in soil resistance observed in the above graph are due to fluctuations in the moisture content of the soil.

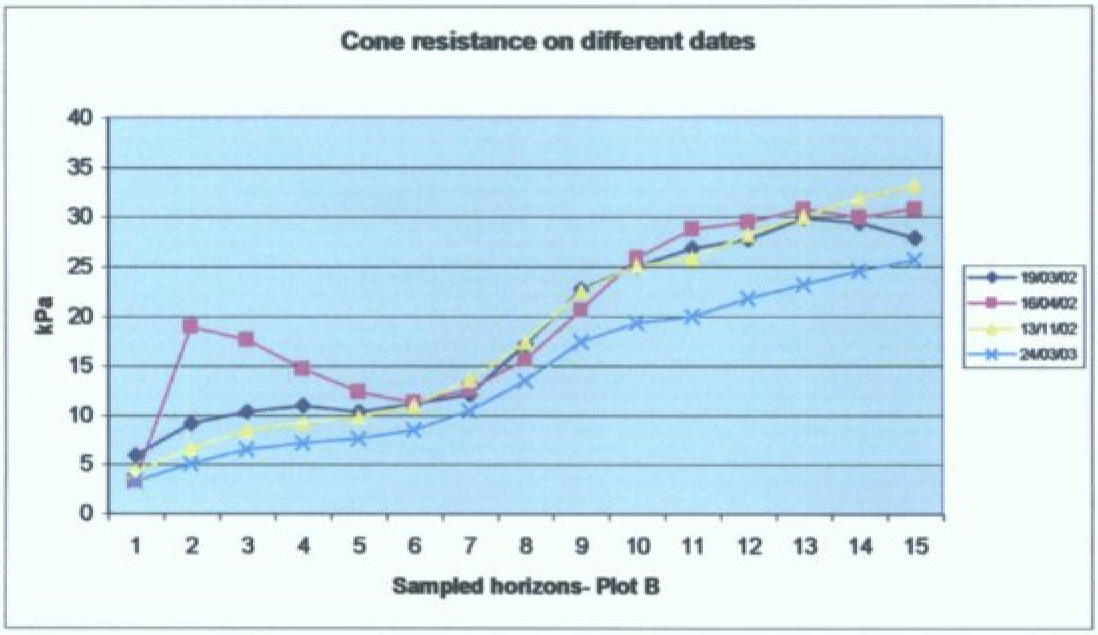
Table.5.8.7. Effect of soil moisture content on cone resistance (kPa) for the Ploughed treatments (straw incorporated), when measurements were taken on different dates.

| Sample Depth (cm) | kPa 19/03/02 | kPa 16/04/02 | kPa 13/11/02 | kPa 24/03/03 |
|---|---|---|---|---|
| **3.5** | 6 | 3 | 4 | 3 |
| **7.0** | 9 | 19 | 7 | 5 |
| **10.5** | 10 | 18 | 8 | 7 |
| **14.0** | 11 | 15 | 9 | 7 |
| **17.5** | 10 | 12 | 10 | 8 |
| **21.0** | 11 | 11 | 11 | 9 |
| **24.5** | 12 | 13 | 14 | 10 |
| **28.0** | 17 | 16 | 17 | 13 |
| **31.5** | 23 | 21 | 23 | 17 |
| **34.0** | 25 | 26 | 25 | 19 |
| **37.5** | 27 | 29 | 26 | 20 |
| **41.0** | 28 | 29 | 28 | 22 |
| **44.5** | 30 | 31 | 30 | 23 |
| **48.0** | 29 | 30 | 32 | 25 |
| **51.5** | 28 | 31 | 33 | 26 |

Table.5.8.8. Soil moisture contents on the dates sampled.

| Depth cm | 19/03/2002 | 16/04/2002 | 13/11/2002 | 24/03/2003 |
|---|---|---|---|---|
| 0-10 | 19.74 | 15.43 | 22.53 | 18.64 |
| 10-20 | 18.83 | 17.37 | 21.58 | 19.69 |
| 20-30 | 17.70 | 16.70 | 16.60 | 17.80 |

Fig.5.8.6. Effect of soil moisture content on cone resistance (kPa) for the Ploughed treatments (straw incorporated), when measurements were taken on different dates.



The soils resistance to the cone penetrometer was not affected by the incorporation of straw under the conventional tillage system. As was evident in the previous set of data the resistance of the soil increased below the sample depth of 28cm, where there was no soil disturbance and the soil was more compacted. Also the soils resistance was greater in the top of the soil profile in April, due to soil drying or crusting at the surface at this time which meant that soil moisture was lower and resistance increased initially. Further down the soil horizon the moisture content was not affected and the soil resistance remained unchanged.

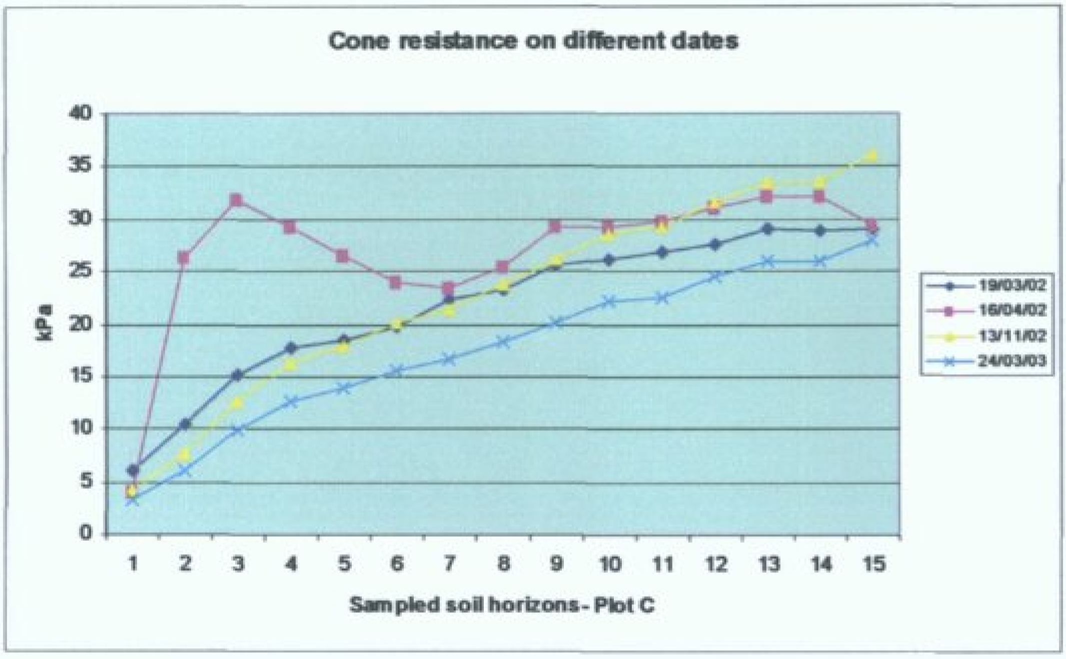
Table.5.8.9. Effect of soil moisture content on cone resistance (kPa) for the Reduced treatments (straw removed), when measurements were taken on different dates.

| **Sample Depth (cm)** | **kPa 19/03/02** | **kPa 16/04/02** | **kPa 13/11/02** | **kPa 24/03/03** |
|---|---|---|---|---|
| **3.5** | 6 | 4 | 4 | 3 |
| **7.0** | 10 | 26 | 8 | 6 |
| **10.5** | 15 | 32 | 13 | 10 |
| **14.0** | 18 | 29 | 16 | 13 |
| **17.5** | 18 | 27 | 18 | 14 |
| **21.0** | 20 | 24 | 20 | 15 |
| **24.5** | 22 | 23 | 21 | 17 |
| **28.0** | 23 | 25 | 24 | 18 |
| **31.5** | 26 | 29 | 26 | 20 |
| **34.0** | 26 | 29 | 29 | 22 |
| **37.5** | 27 | 30 | 29 | 23 |
| **41.0** | 28 | 31 | 32 | 24 |
| **44.5** | 29 | 32 | 33 | 26 |
| **48.0** | 29 | 32 | 34 | 26 |
| **51.5** | 29 | 29 | 36 | 28 |

Table.5.8.10. Soil moisture contents on the dates sampled.

| Depth cm | 19/03/2002 | 16/04/2002 | 13/11/2002 | 24/03/2003 |
|---|---|---|---|---|
| 0-10 | 23.05 | 14.08 | 20.81 | 16.84 |
| 10-20 | 22.23 | 16.21 | 19.62 | 17.57 |
| 20-30 | 20.38 | 15.78 | 17.45 | 16.60 |

Fig.5.8.7. Effect of soil moisture content on cone resistance (kPa) for the Reduced treatments (straw removed). When measurements were taken on different dates.



Soil resistance readings from the cone penetrometer were higher in the upper layers of the soil horizon for the plots treated by reduced cultivation. This result was due to the reduced amount of soil disturbance by this cultivation method. By limiting the degree of soil disturbance to the top 10cm of the soil profile, natural soil compaction occurred at the upper layers of the soil profile. The increase in soil resistance followed a gradual curve.

Although soil resistance was greater at higher levels in the soil profile under reduced cultivation, at the lower sample depths in the soil profile, there was no difference in soil resistance to the cone penetrometer for reduced and conventional tillage.

As had occurred previously in the plots which were conventionally tilled, there was a greater increase in soil resistance during the month of April when compared to the other months sampled. This was due to a loss of soil moisture which increased the soils resistance to the penetrometer.

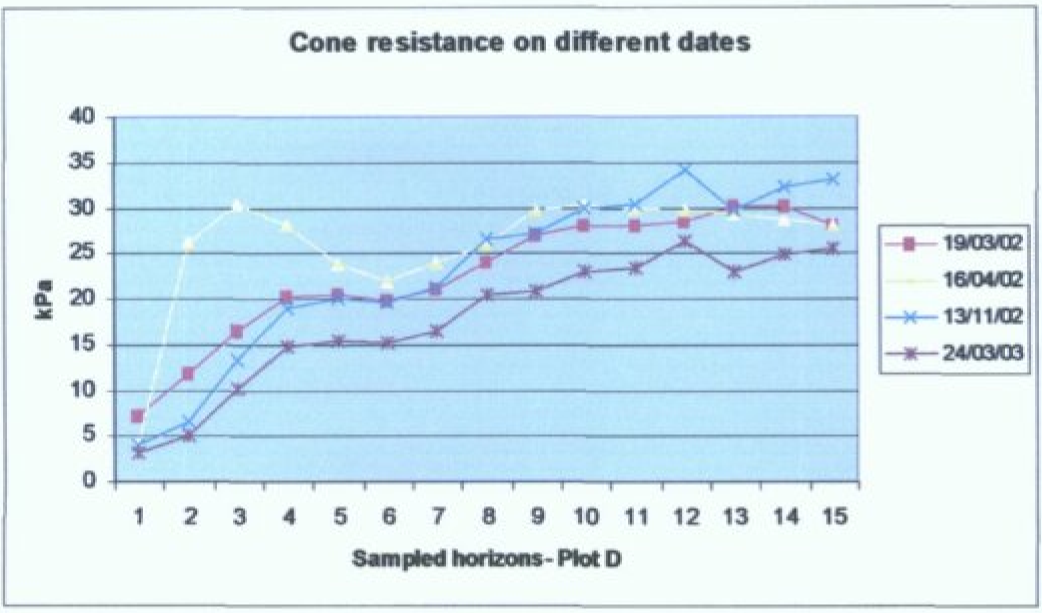
Table.5.8.11. Effect of soil moisture content on cone resistance (kPa) for the Reduced treatments (straw incorporated), when measurements were taken on different dates.

| **Sample Depth (cm)** | **kPa 19/03/02** | **kPa 16/04/02** | **kPa 13/11/02** | **kPa 24/03/03** |
|---|---|---|---|---|
| **3.5** | 7 | 4 | 4 | 3 |
| **7.0** | 12 | 26 | 6 | 5 |
| **10.5** | 17 | 30 | 13 | 10 |
| **14.0** | 20 | 28 | 19 | 15 |
| **17.5** | 20 | 24 | 20 | 15 |
| **21.0** | 20 | 22 | 20 | 15 |
| **24.5** | 21 | 24 | 21 | 16 |
| **28.0** | 24 | 26 | 27 | 21 |
| **31.5** | 27 | 30 | 27 | 21 |
| **34.0** | 28 | 30 | 30 | 23 |
| **37.5** | 28 | 30 | 30 | 23 |
| **41.0** | 28 | 30 | 34 | 26 |
| **44.5** | 30 | 29 | 30 | 23 |
| **48.0** | 30 | 29 | 32 | 25 |
| **51.5** | 28 | 28 | 33 | 25 |

Table.5.8.12. Soil moisture contents on the dates sampled.

| Depth cm | 19/03/2002 | 16/04/2002 | 13/11/2002 | 24/03/2003 |
|---|---|---|---|---|
| 0-10 | 19.44 | 14.89 | 21.48 | 16.96 |
| 10-20 | 18.61 | 17.76 | 19.08 | 18.52 |
| 20-30 | 17.67 | 15.51 | 21.53 | 18.14 |

Fig.5.8.8. Effect of soil moisture content on cone resistance (kPa) for the Reduced treatments (straw incorporated). When measurements were taken on different dates.



The incorporation of straw did not limit the loss of soil moisture during the month of April in the reduced cultivation plots, as soil resistance was seen to increase in the upper horizon of soil during this month. This rapid increase in soil resistance was evident in all four treatments at this time.

As evident in the reduced cultivation plots, which had removed straw, the increase in soil resistance to the cone penetrometer could be seen to gradually increase through the soil profile.

There was no statistically significant differences in soil resistance to cone penetration in the two treatments cultivated by the tine cultivator (with and without straw).

## *5.9. Bulk Density*

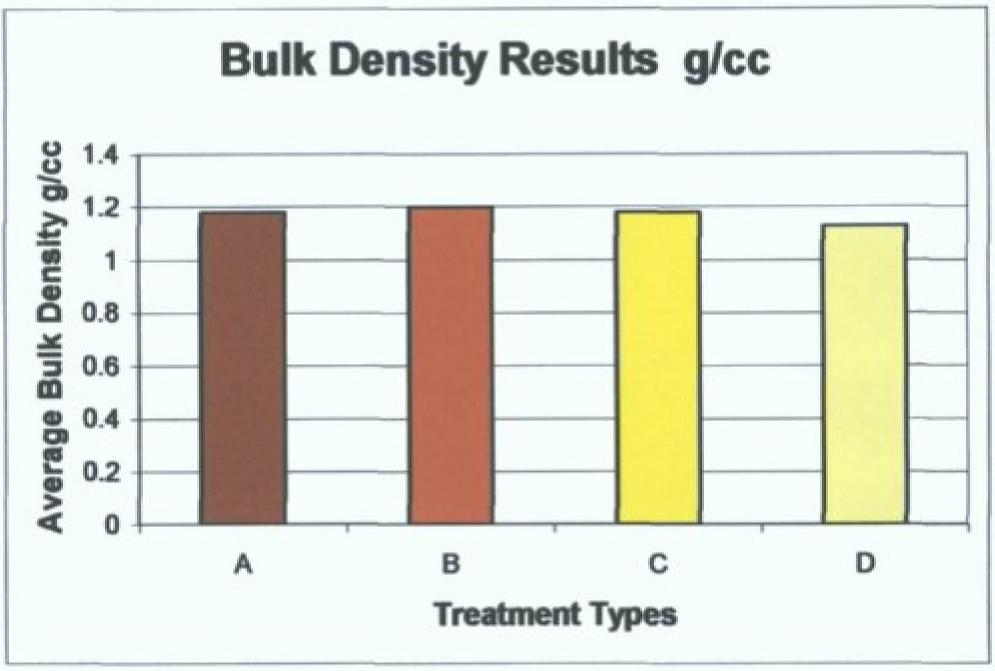
The table below presents the results determined for Bulk Denisty in the four treatments. Samples were collected in a cylinder measuring 5.57 cm X 4.0cm high. The volume of the cylinder was 97.468cc and the density of the soil was 2.65 g/cc. Each result is an average value calculated from 32 samples or cores taken from each treatment type, on the 6th of January 2004.

The results determined for bulk density from the trials, were directly comparable, as the sampling was performed simultaneously, thus eliminating the effect of changing soil moisture. There were no statistically significant differences between bulk density results for the four cultivation methods.

Table 5.9.1. Bulk Density Results for all 4 Cultivation methods on the 6th of January 2004.

| *Treatment Types* | *Wet Bulk Density g/cc* | *Dry Bulk Density g/cc* |
|---|---|---|
| A | 1.46 | 1.18 |
| B | 1.49 | 1.20 |
| C | 1.50 | 1.18 |
| D | 1.46 | 1.13 |

Fig.5.9.1. Bulk Density Results for all 4 Cultivation methods on the 6th of January 2004.



By comparing the average results calculated for bulk density, it was determined that the conventionally tilled treatments contained slightly higher bulk density values than the reduced tillage treatments, these differences are not significant.

Where straw was removed from the cultivations, there were no differences in bulk density results. However, where straw was incorporated into treatments the reduced tillage plots had a lower bulk density value.

## 5.10. Microbiology Results

Isolation procedures for soil microorganisms involve taking microorganisms from their natural conditions and placing them in artifical conditions. This can affect their form, induce dormancy or kill them. All techniques used are selective, including bacterial isolations using plate counts, which account for only about 1 – 50% of the total count.

Tillage and cropping systems have complex effects on the soils physical, chemical and biological environment. The degree of tillage disturbance of the soil, and the resulting location of the crop residues affect soil water content, soil temperature, aeration and the degree of contact between organic materials and mineral soil particles. These changes in the soils physical environment affect the organisms that live within that environment with different soil organisms responding in different ways. Populations, diversity and activity may all be affected by changes in tillage systems.

The following results represent the total numbers of aerobic bacteria determined in the soil samples when incubated at 22°C and 32°C. Each value tabulated is an average figure determined by the enumeration of three samples, and is presented by means of scientific notation, due to the large numbers calculated.
For samples incubated at 32°C the scale of the graphs was increased to incorporate the larger numbers of aerobic bacteria determined during May 2002. At this scale it is difficult to observe numbers of total aerobic bacteria enumerated at other times during the project. Therefore a second graph for each treatment was included, which excludes the results determined for May 2002, and facilitates better observation of periods when lower numbers of total aerobic bacteria occurred.

Table.5.10.1. Total aerobic bacterial numbers for the Conventional tilled treatments with straw removed from September 2001 until March 2003, when incubated at 22°C.

| Sample Depth | Sept 2001 | Oct 2001 | Nov 2001 | Feb 2002 | Apr 2002 | May 2002 | June 2002 | July 2002 | Aug 2002 | Oct 2002 | Nov 2002 | Dec 2002 | Feb 2003 | Mar 2002 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0-10 | 1.37E+7 | 2.05E+6 | 2.05E+6 | 6.78E+7 | 1.09E+8 | 4.27E+2 | 1.66E+6 | 1.12E+6 | 1.07E+7 | 6.61E+6 | 2.03E+06 | 2.36E+06 | 3.67E+06 | 2.35E+06 |
| 10-20 | 2.33E+6 | 1.91E+5 | 2.91E+6 | 6.49E+7 | 2.99E+8 | 1.67E+2 | 1.74E+6 | 1.27E+6 | 7.42E+6 | 9.27E+6 | 2.71E+06 | 2.32E+06 | 6.09E+06 | 1.79E+06 |
| 20-30 | 7.37E+7 | 9.39E+5 | 1.96E+6 | 6.45E+7 | 1.26E+8 | 1.67E+2 | 2.10E+6 | 1.27E+6 | 8.71E+6 | 9.27E+6 | 2.84E+06 | 1.42E+06 | 1.87E+06 | 1.44E+06 |
| Mean | 2.99E+7 | 1.63E+6 | 2.3E+6 | 6.58E+7 | 1.78E+8 | 2.54E+2 | 1.83E+6 | 1.83E+6 | 8.96E+6 | 8.38E+6 | 2.52E+6 | 2.03E+6 | 4.54E+6 | 1.93E+6 |
| Std D | 3.25E+7 | 6.005E+5 | 5.24E+5 | 1.16E+6 | 1.05E+8 | 1.5E+2 | 2.35E+5 | 8.33E+4 | 1.67E+6 | 1.54E+6 | 0.35E+5 | 5.3E+5 | 2.32E+6 | 5.68E+5 |
| Signif | *** | *** | *** | *** | *** | *** | *** | *** | *** | *** | *** | *** | *** | *** |

Significance Key

| | |
|---|---|
| * | P<0.05 |
| ** | P<0.01 |
| *** | P<0.001 |
| NS | No Significant Difference |

Figure.5.10.1. Total aerobic bacterial numbers for the Conventional tilled treatments with straw removed from September 2001 until March 2003, when incubated at 22°C.

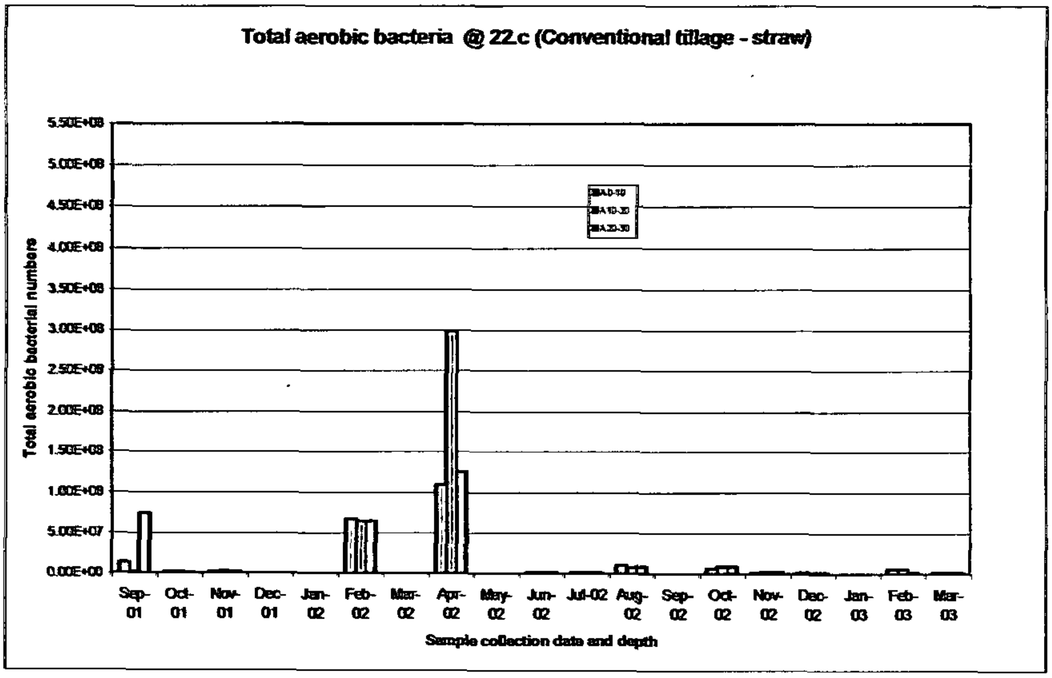


Table.5.10.2. Total aerobic bacterial numbers for the Conventional tilled treatments with straw incorporated from September 2001 until March 2003, when incubated at 22°C.

| Sample Depth | Sept 2001 | Oct 2001 | Nov 2001 | Feb 2002 | Apr 2002 | May 2002 | June 2002 | July 2002 | Aug 2002 | Oct 2002 | Nov 2002 | Dec 2002 | Feb 2002 | Mar 2002 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0-10 | 2.20E+6 | 2.43E+6 | 2.09E+6 | 6.89E+7 | 1.64E+8 | 2.86E+2 | 8.48E+5 | 1.33E+6 | 3.33E+6 | 2.86E+6 | 2.00E+06 | 2.01E+06 | 3.06E+06 | 1.77E+06 |
| 10-20 | 2.52E+6 | 2.10E+6 | 2.59E+6 | 1.81E+8 | 5.14E+8 | 2.52E+2 | 1.24E+6 | 1.55E+6 | 1.23E+7 | 2.48E+6 | 1.79E+06 | 3.54E+06 | 3.46E+06 | 2.009E+06 |
| 20-30 | 1.05E+6 | 1.22E+6 | 1.95E+7 | 2.18E+8 | 4.36E+8 | 2.18E+2 | 1.46E+6 | 1.37E+6 | 2.27E+6 | 1.82E+7 | 4.82E+06 | 2.75E+06 | 2.02E+06 | 1.43E+06 |
| Mean | 1.94E+6 | 1.92E+6 | 8.00E+6 | 1.56E+8 | 3.71E+8 | 2.52E+2 | 1.18E+6 | 1.35E+6 | 5.95E+6 | 7.83E+6 | 2.87E+6 | 2.71E+6 | 2.84E+6 | 1.76E+6 |
| Std D | 7.49E+5 | 6.25E+5 | 9.8E+6 | 7.79E+7 | 1.84E+8 | 3.38E+1 | 3.09E+1 | 1.59E+5 | 5.49E+6 | 8.95E+6 | 1.69E+6 | 7.75E+5 | 7.44E+5 | 3.30E+5 |
| Signif | *** | *** | *** | *** | *** | *** | *** | *** | *** | *** | *** | *** | *** | *** |

Significance Key

*     P<0.05

**    P<0.01

***   P<0.001

NS    No Significant Difference

Figure.5.10.2. Total aerobic bacterial numbers for the Conventional tilled treatments with straw incorporated from September 2001 until March 2003, when incubated at 22°C.

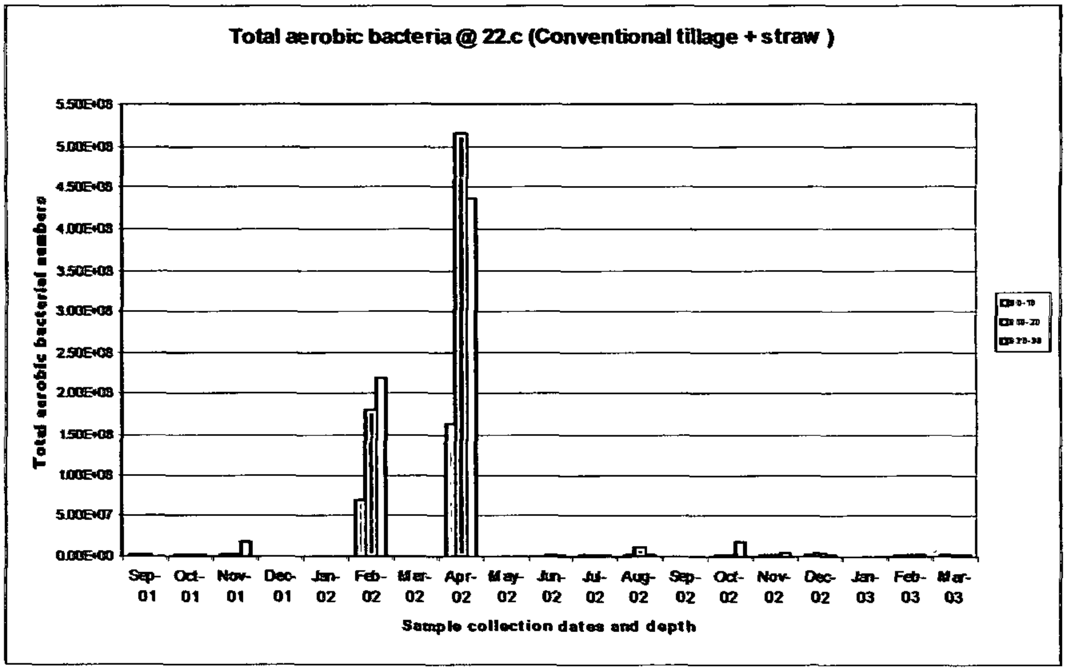


Table.5.10.3. Total aerobic bacterial numbers for the Reduced tillage treatments with straw removed from September 2001 until March 2003, when incubated at 22°C.

| Sample Depth | Sept 2001 | Oct 2001 | Nov 2001 | Feb 2002 | Apr 2002 | May 2002 | June 2002 | July 2002 | Aug 2002 | Oct 2002 | Nov 2002 | Dec 2002 | Feb 2002 | Mar 2002 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0-10 | 2.95E+6 | 1.43E+7 | 3.49E+8 | 6.70E+7 | 1.85E+7 | 2.40E+2 | 1.06E+6 | 1.28E+6 | 7.15E+6 | 2.34E+6 | 4.27E+06 | 2.80E+06 | 2.95E+06 | 2.42E+06 |
| 10-20 | 1.88e+6 | 2.61E+6 | 3.69E+8 | 2.58E+8 | 1.79E+8 | 1.34E+2 | 1.46E+6 | 1.08E+6 | 7.50E+6 | 2.27E+6 | 2.25E+06 | 2.60E+06 | 2.98E+06 | 2.17E+06 |
| 20-30 | 1.09E+8 | 2.13E+6 | 1.45E+7 | 2.16E+8 | 1.48E+8 | 1.87E+2 | 1.21E+6 | 9.33E+5 | 8.87E+6 | 1.43E+6 | 1.48E+06 | 1.73E+06 | 2.45E+06 | 1.51E+06 |
| Mean | 3.78E+7 | 6.36E+6 | 2.44E+8 | 1.60E+8 | 1.15E+8 | 1.87E+2 | 1.21E+6 | 1.10E+6 | 7.81E+5 | 2.01E+6 | 2.67E+6 | 2.38E+6 | 2.80E+6 | 2.03E+6 |
| Std D | 6.13E+7 | 6.86E+6 | 1.99E+6 | 1.35E+8 | 3.52E+7 | 5.31E+1 | 2.02E+5 | 1.63E+5 | 5.10E+5 | 5.05E+5 | 1.44E+5 | 5.67E+5 | 2.68E+5 | 4.71E+5 |
| Signif | *** | *** | *** | *** | *** | *** | *** | *** | *** | *** | *** | *** | *** | *** |

Significance Key

| | |
|---|---|
| * | P<0.05 |
| ** | P<0.01 |
| *** | P<0.001 |
| NS | No Significant Difference |

Figure.5.10.3. Total aerobic bacterial numbers for the Reduced tillage treatments with straw removed from September 2001 until March 2003, when incubated at 22°C.

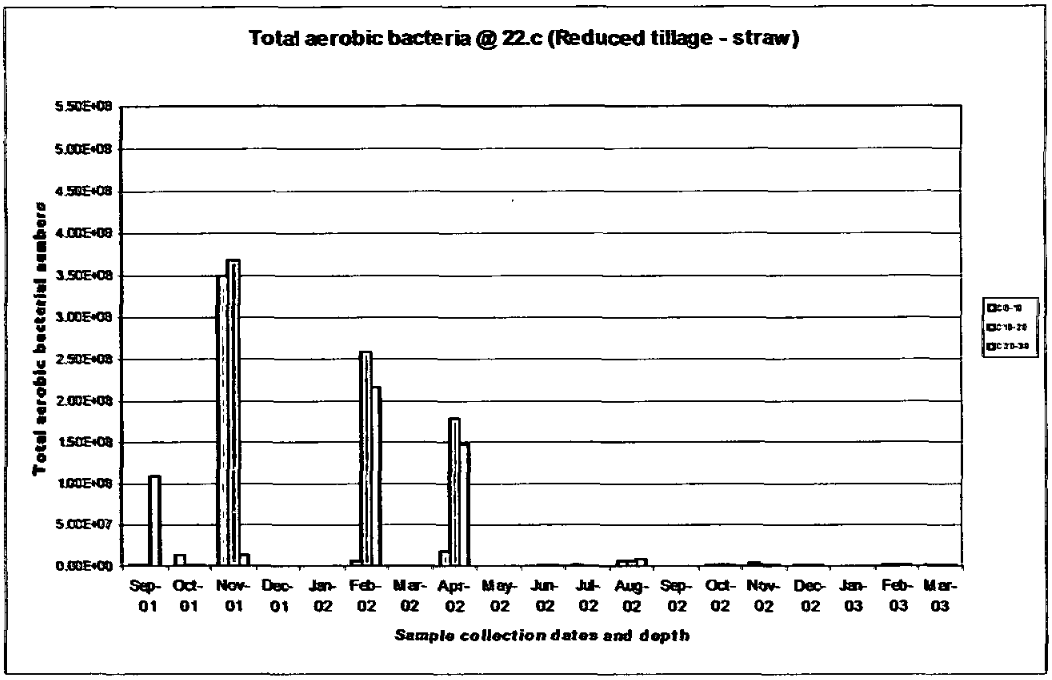
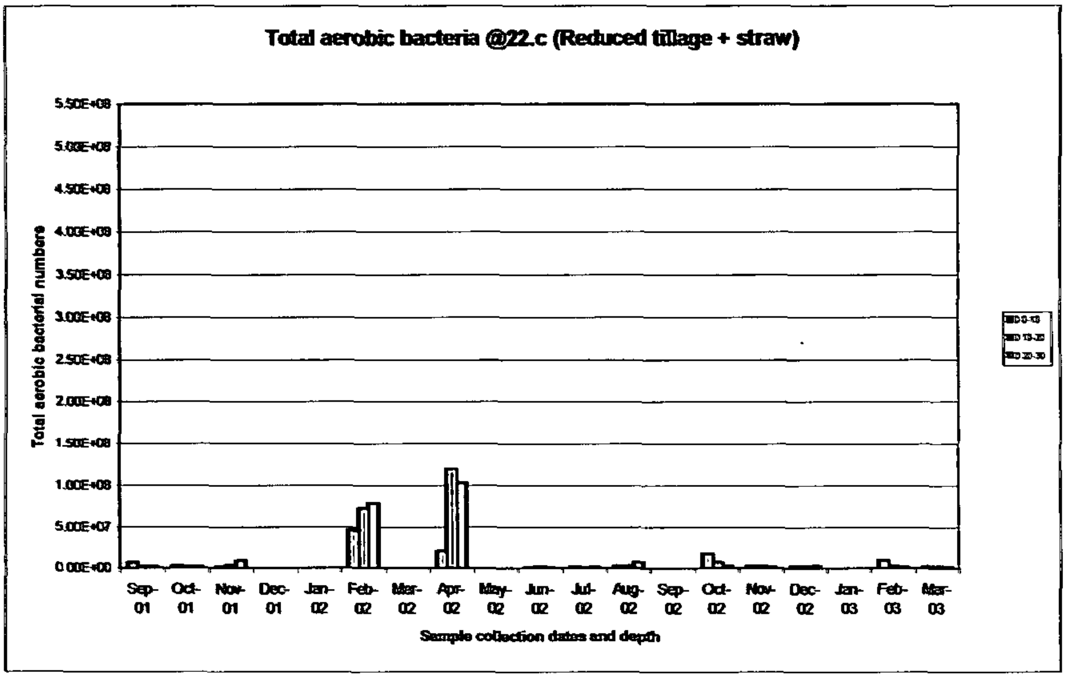


Table 5.10.4. Total aerobic bacterial numbers for the Reduced tillage treatments with straw incorporated from September 2001 until March 2003, when incubated at 22°C.

| Sample Depth | Sept 2001 | Oct 2001 | Nov 2001 | Feb 2002 | Apr 2002 | May 2002 | June 2002 | July 2002 | Aug 2002 | Oct 2002 | Nov 2002 | Dec 2002 | Feb 2002 | Mar 2002 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0-10 | 7.24E+6 | 2.71E+6 | 2.29E+6 | 4.61E+7 | 2.11e+7 | 2.22E+2 | 1.69E+6 | 1.90E+6 | 2.69E+6 | 1.83E+7 | 2.70E+06 | 3.16E+06 | 9.90E+06 | 2.24E+06 |
| 10-20 | 2.01E+6 | 2.39E+6 | 3.38E+6 | 7.21E+7 | 1.15E+8 | 1.74E+2 | 2.23E+6 | 9.82E+5 | 2.56E+6 | 7.66E+6 | 2.76E+06 | 3.10E+06 | 3.17E+06 | 2.04E+06 |
| 20-30 | 2.14E+6 | 2.01E+6 | 9.71E+6 | 7.91E+7 | 1.03E+8 | 1.07E+2 | 9.61E+5 | 1.77E+6 | 8.04E+6 | 2.89E+6 | 1.55E+06 | 2.65E+06 | 1.50E+06 | 1.48E+06 |
| Mean | 3.80E+6 | 2.37E+6 | 5.13E+6 | 6.58E+7 | 3.11E+7 | 1.67E+2 | 1.63E+6 | 1.95E+6 | 4.43E+5 | 9.63E+5 | 2.33E+6 | 2.97E+6 | 4.92E+5 | 1.92E+6 |
| Std D | 2.56E+5 | 3.50E+5 | 4.01E+5 | 1.7E+7 | 5.26E+7 | 5.78E+1 | 6.39E+5 | 4.96E+5 | 3.13E+6 | 7.91E+5 | 6.79E+5 | 2.79E+5 | 4.37E+6 | 3.93E+5 |
| Signif | *** | *** | *** | *** | *** | *** | *** | ** | *** | *** | *** | *** | *** | *** |

Significance Key
* P<0.05
** P<0.01
*** P<0.001
NS No Significant Difference

Figure 5.10.4. Total aerobic bacterial numbers for the Reduced tillage treatments with straw incorporated from September 2001 until March 2003.



### *Total Aerobic Bacterial Numbers when incubated at 22°C for each treatment.*

*Table 5.10.1*

In figure 5.10.1. the numbers of total aerobic bacteria have been graphed for the fourteen month sampling period. On this graph the numbers of total aerobic bacteria remain low during most of the months sampled, and there is no definite pattern of reduction in numbers of bacteria with an increase in sampling depth, as was observed in many other studies (Lynch, 1980).

In February and April, the numbers of aerobic bacteria increased dramatically through the sampled soil horizon. This increase occurred at a time when soil temperatures were rising, which increased microbial activity. During this period fertilisers were also applied to the treatments, which would have increased the quantity of food available to microorganisms.

*Table 5.10.2.*

In general it was determined that the numbers of total aerobic bacteria present in the conventionally tilled treatments with straw incorporated, were greater than those with straw removed.

The numbers of total aerobic bacteria continued to vary significantly between the three sample depths in the soil profile. The greatest concentration was not always determined in the top 10cm of soil. As was previously determined the numbers of total aerobic bacteria often increased through the soil profile. The greatest number of aerobic bacteria occurred in April of 2002, at a sample depth of 10-20cm, and were significantly greater in concentration at all three depths to the conventional tilled treatments which had removed straw, when incubated at 22°C.

*Table 5.10.3.*

The pattern of total aerobic bacterial numbers graphed in figure 5.10.3. for the reduced cultivation treatments with straw removed varied greatly to that of the conventionally tilled treatments. These results yielded a peak of bacterial numbers through February and into April of 2002. As before, the decrease in numbers of total aerobic bacteria through the soil profile was not evident.

*Table 5.10.4.*

The lowest numbers of total aerobic bacteria were determined in the reduced cultivation treatments, which had incorporated straw. This treatment followed the same pattern of bacterial numbers over the sampling period i.e. peaking in February and April, and increasing in numbers down through the soil profile.

Table.5.10.5. Total aerobic bacterial numbers for the Conventional tilled treatments with straw removed from September 2001 until March 2003, when incubated at 32°C.

| Sample Depth | Sept 2001 | Oct 2001 | Nov 2001 | Feb 2002 | Apr 2002 | May 2002 | June 2002 | July 2002 | Aug 2002 | Oct 2002 | Nov 2002 | Dec 2002 | Feb 2002 | Mar 2002 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0-10 | 1.29E+7 | 2.05E+6 | 1.78E+6 | 3.43E+8 | 7.58E+7 | 1.55E+9 | 1.07E+6 | 8.07E+5 | 1.16E+7 | 1.06E+7 | 2.12E+06 | 1.71E+06 | 2.73E+06 | 5.73E+06 |
| 10-20 | 1.29E+6 | 1.91E+6 | 1.68E+6 | 3.51E+8 | 2.77E+8 | 1.80E+9 | 1.27E+6 | 6.94E+5 | 7.78E+6 | 1.15E+7 | 2.19E+06 | 1.45E+06 | 2.39E+06 | 3.75E+06 |
| 20-30 | 1.57E+6 | 9.39E+5 | 1.53E+6 | 9.72E+7 | 2.58E+8 | 1.27E+9 | 1.48E+6 | 9.48E+5 | 8.07E+6 | 1.23E+7 | 1.94E+06 | 1.38E+06 | 1.73E+06 | 2.71E+06 |
| Mean | 5.26E+5 | 1.63E+6 | 1.67E+6 | 3.31E+8 | 2.03E+8 | 6.15E+9 | 1.27e+6 | 3.16E+5 | 9.16E+6 | 1.15E+7 | 2.08E+6 | 1.51E+6 | 2.08E+6 | 4.07E+6 |
| Std D | 6.63E+6 | 6.05E+5 | 1.28E+5 | 2.27E+8 | 1.11E+8 | 8.07E+9 | 1.9E+5 | 1.28E+5 | 2.13E+6 | 8.45E+5 | 1.28E+5 | 1.72E+5 | 5.08E+5 | 1.53E+6 |
| Signif | *** | *** | *** | *** | *** | *** | *** | *** | *** | *** | *** | *** | *** | *** |

Significance Key
- * P<0.05
- ** P<0.01
- *** P<0.001
- NS No Significant Difference

Figure.5.10.5. Total aerobic bacterial numbers for the Conventional tilled treatments with straw removed from September 2001 until March 2003, when incubated at 32°C.

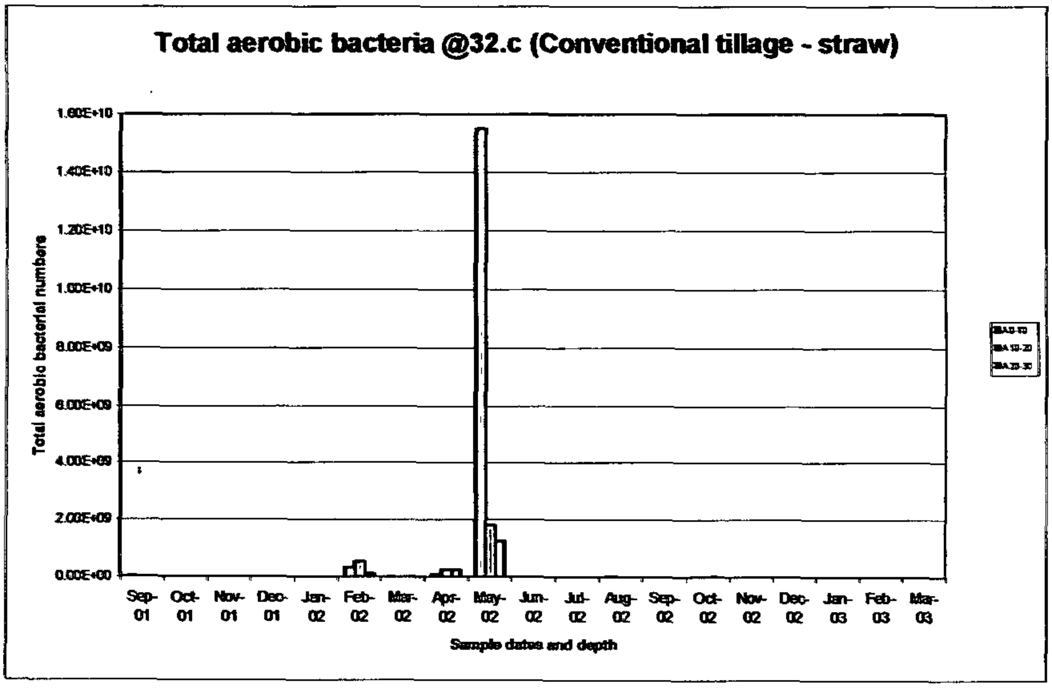


Table.5.10.6. Total aerobic bacterial numbers for the Conventional tilled treatments with straw removed from September 2001 until March 2003 (excluding May), when incubated at 32°C.

| Samp Depth | Sept 2001 | Oct 2001 | Nov 2001 | Feb 2002 | Apr 2002 | June 2002 | July 2002 | Aug 2002 | Oct 2002 | Nov 2002 | Dec 2002 | Feb 2002 | Mar 2002 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0-10 | 1.29E+7 | 2.05E+6 | 1.78E+6 | 3.43E+8 | 7.56E+7 | 1.07E+6 | 8.07E+5 | 1.16E+7 | 1.06E+7 | 2.12E+06 | 1.71E+06 | 2.73E+06 | 5.73E+ |
| 10-20 | 1.25E+6 | 1.91E+6 | 1.68E+6 | 5.51E+8 | 2.77E+8 | 1.27E+6 | 6.94E+5 | 7.78E+6 | 1.15E+7 | 2.19E+06 | 1.45E+06 | 2.39E+06 | 3.79E+ |
| 20-30 | 1.57E+6 | 9.39E+5 | 1.53E+6 | 9.72E+7 | 2.58E+8 | 1.46E+6 | 9.48E+5 | 8.07E+6 | 1.23E+7 | 1.94E+06 | 1.38E+06 | 1.73E+06 | 2.71E+ |

Figure.5.10.6. Total aerobic bacterial numbers for the Conventional tilled treatments with straw removed from September 2001 until March 2003, when incubated at 32°C.

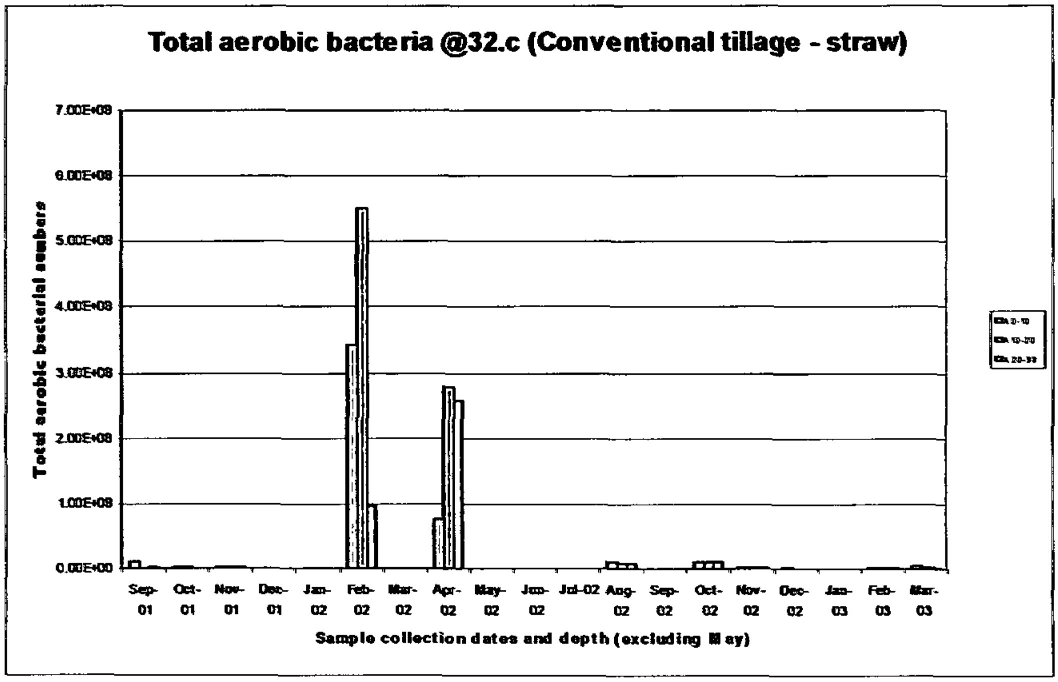


Figure 5.10.6. graphs the same results as figure 5.10.5. with the exclusion of the results for the month of May.

Table.5.10.7. Total aerobic bacterial numbers for the Conventional tilled treatments with straw incorporated from September 2001 until March 2003, when incubated at 32°C.

| Sample Depth | Sept 2001 | Oct 2001 | Nov 2001 | Feb 2002 | Apr 2002 | May 2002 | June 2002 | July 2002 | Aug 2002 | Oct 2002 | Nov 2002 | Dec 2002 | Feb 2002 | Mar 2002 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0-10 | 2.36E+6 | 2.43E+6 | 2.52E+6 | 4.48E+8 | 1.58E+8 | 1.71E+9 | 8.30E+5 | 7.44E+5 | 6.87E+6 | 2.44E+6 | 1.62E+06 | 2.38E+06 | 2.46E+06 | 3.06E+06 |
| 10-20 | 1.17E+6 | 2.10E+6 | 3.58E+6 | 2.76E+7 | 2.08E+8 | 3.22E+9 | 7.04E+5 | 8.94E+5 | 1.61E+7 | 3.16E+6 | 2.15E+06 | 2.36E+06 | 1.84E+06 | 1.16E+06 |
| 20-30 | 1.15E+6 | 1.22E+6 | 2.87E+7 | 1.43E+8 | 1.17E+8 | 2.65E+9 | 1.46E+6 | 1.25E+6 | 1.88E+6 | 3.20E+6 | 1.94E=06 | 1.86E+06 | 1.82E+06 | 1.08E+06 |
| Mean | 1.96E+5 | 1.92E+6 | 1.16E+7 | 2.06E+8 | 1.61E+8 | 2.53E+9 | 9.97E+5 | 9.62E+5 | 8.29E+6 | 2.93E+6 | 1.50E+6 | 2.20E+6 | 2.04E+6 | 1.76E+6 |
| Std D | 6.92E+5 | 6.25E+5 | 1.48E+7 | 2.17E+8 | 4.96E=7 | 7.63E+8 | 4.02E+5 | 2.99E+5 | 7.22E+6 | 4.28E+5 | 2.64E+5 | 2.96E+5 | 3.64E+5 | 1.12E+6 |
| Signif | *** | *** | *** | *** | *** | *** | *** | *** | *** | *** | *** | *** | *** | ** |

Significance Key

| | |
|---|---|
| * | P<0.05 |
| ** | P<0.01 |
| *** | P<0.001 |
| NS | No Significant Difference |

Figure.5.10.7. Total aerobic bacterial numbers for the Conventional tilled treatments with straw incorporated from September 2001 until March 2003, when incubated at 32°C.

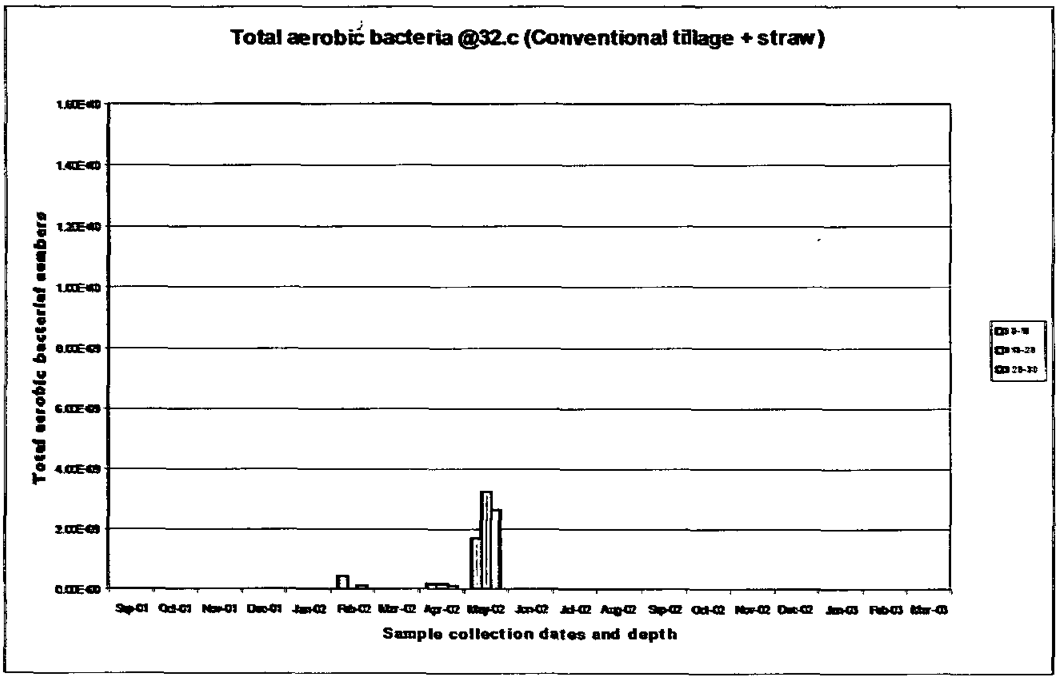


Table.5.10.8. Total aerobic bacterial numbers for the Conventional tilled treatments with straw incorporated from September 2001 until March 2003 (excluding May), when incubated at 32°C.

| Samp Depth | Sept 2001 | Oct 2001 | Nov 2001 | Feb 2002 | Apr 2002 | June 2002 | July 2002 | Aug 2002 | Oct 2002 | Nov 2002 | Dec 2002 | Feb 2002 | Mar 2002 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0-10 | 2.36E+6 | 2.43E+6 | 2.52E+6 | 4.48E+8 | 1.58E+8 | 8.30E+5 | 7.44E+5 | 6.87E+6 | 2.44E+6 | 1.62E+06 | 2.38E+06 | 2.46E+06 | 3.06E+ |
| 10-20 | 1.17E+6 | 2.10E+6 | 3.58E+6 | 2.76E+7 | 2.08E+8 | 7.04E+5 | 8.94E+5 | 1.61E+7 | 3.16E+6 | 2.15E+06 | 2.36E+06 | 1.84E+06 | 1.16E+ |
| 20-30 | 1.15E+6 | 1.22E+6 | 2.87E+7 | 1.43E+8 | 1.17E+8 | 1.46E+6 | 1.25E+6 | 1.88E+6 | 3.20E+6 | 1.94E+06 | 1.86E+06 | 1.82E+06 | 1.05E+ |

Figure.5.10.8. Total aerobic bacterial numbers for the Conventional tilled treatments with straw incorporated from September 2001 until March 2003 (excluding May), when incubated at 32°C.

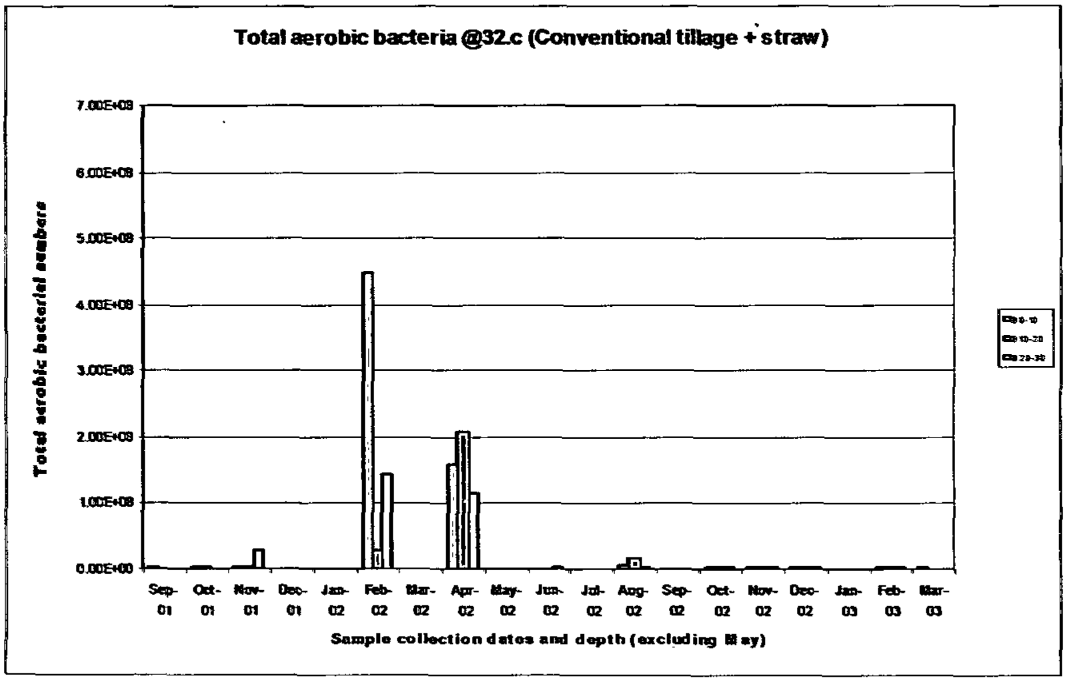


Figure 5.10.8. graphs the same results as figure 5.10.7. with the exclusion of the results for the month of May.

Table.5.10.9. Total aerobic bacterial numbers for the Reduced tillage treatments with straw removed from September 2001 until March 2003, when incubated at 32°C.

| Sample Depth | Sept 2001 | Oct 2001 | Nov 2001 | Feb 2002 | Apr 2002 | May 2002 | June 2002 | July 2002 | Aug 2002 | Oct 2002 | Nov 2002 | Dec 2002 | Feb 2002 | Mar 2002 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0-10 | 7.10E+6 | 1.43E+7 | 3.49E+8 | 8.98E+7 | 1.03E+7 | 2.23E+9 | 7.89E+5 | 6.25E+5 | 9.98E+6 | 2.03E+6 | 2.38E+06 | 2.68E+06 | 3.03E+06 | 1.48E+06 |
| 10-20 | 1.12E+6 | 2.61E+6 | 3.73E+6 | 1.86E+8 | 6.37E+8 | 1.05E+9 | 9.71E+5 | 5.57E+5 | 6.63E+6 | 2.35E+6 | 2.27E+06 | 1.92E+06 | 2.12E+06 | 7.93E+05 |
| 20-30 | 1.12E+7 | 2.14E+6 | 3.78E+6 | 2.39E+7 | 9.21E+7 | 7.45E+7 | 1.08E+6 | 6.46E+5 | 5.18E+6 | 8.58E+5 | 1.68E+06 | 1.01E+06 | 1.99E+06 | 8.76E+05 |
| Mean | 6.47E+6 | 6.35E+6 | 1.19E+8 | 1.00E+8 | 2.46E+8 | 1.12E+9 | 9.46E+5 | 6.09E+5 | 7.26E+6 | 1.75E+6 | 2.11E+6 | 1.87E+6 | 2.38E+6 | 1.05E+6 |
| Std D | 5.07E+6 | 6.86E+6 | 2.00E+8 | 8.04E+7 | 3.41E+8 | 1.06E+9 | 1.46E+5 | 4.67E+4 | 2.46E+6 | 7.87E+5 | 3.76E+5 | 8.31E+5 | 5.67E+5 | 3.72E+5 |
| Signif | *** | *** | *** | *** | *** | *** | *** | *** | *** | *** | *** | *** | *** | *** |

Significance Key

*	P<0.05

**	P<0.01

***	P<0.001

NS	No Significant Difference

Figure.5.10.9. Total aerobic bacterial numbers for the Reduced tillage treatments with straw removed from September 2001 until March 2003, when incubated at 32°C.

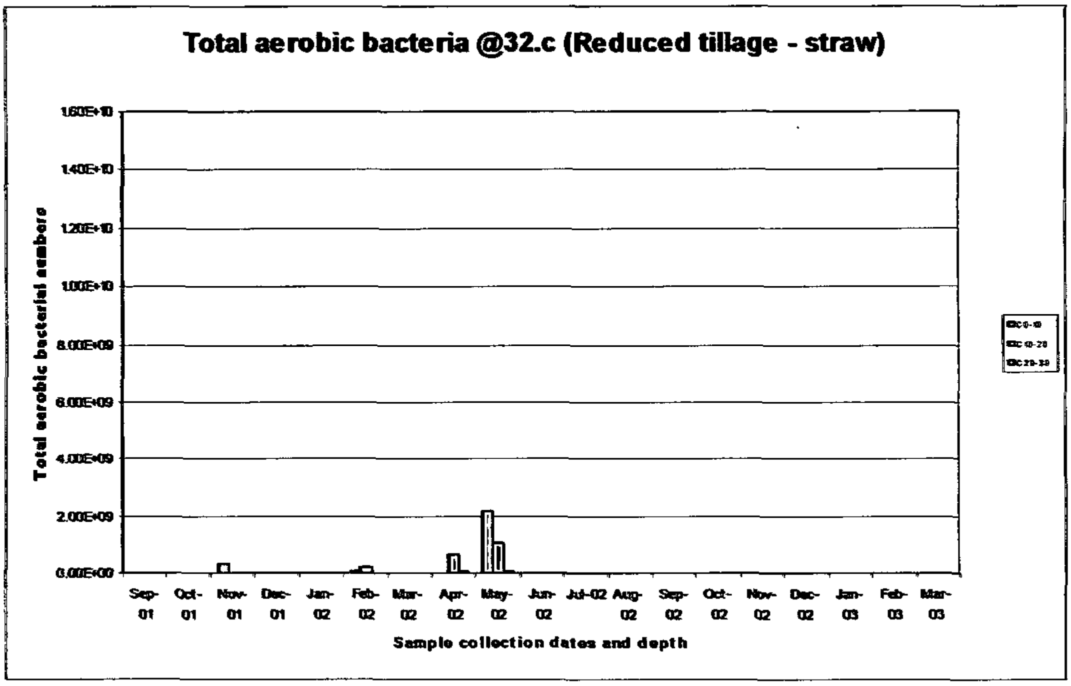


Table.5.10.10. Total aerobic bacterial numbers for the Reduced tillage treatments with straw removed from September 2001 until March 2003 (excluding May), when incubated at 32°C.

| Samp Depth | Sept 2001 | Oct 2001 | Nov 2001 | Feb 2002 | Apr 2002 | June 2002 | July 2002 | Aug 2002 | Oct 2002 | Nov 2002 | Dec 2002 | Feb 2002 | Mar 2002 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0-10 | 7.18E+6 | 1.43E+7 | 3.45E+8 | 8.95E+7 | 1.03E+7 | 7.89E+5 | 6.25E+5 | 9.98E+6 | 2.03E+6 | 2.38E+06 | 2.68E+06 | 3.03E+06 | 1.48E+ |
| 10-20 | 1.12E+6 | 2.61E+6 | 3.73E+6 | 1.86E+8 | 6.37E+8 | 9.71E+5 | 5.57E+5 | 6.63E+6 | 2.35E+6 | 2.27E+06 | 1.92E+06 | 2.12E+06 | 7.93E+ |
| 20-30 | 1.12E+8 | 2.18E+6 | 3.78E+6 | 2.59E+7 | 9.21E+7 | 1.08E+6 | 6.46E+5 | 3.18E+6 | 8.58E+5 | 1.68e+06 | 1.01E+06 | 1.99E+06 | 8.76E+ |

Table.5.10.10. Total aerobic bacterial numbers for the Reduced tillage treatments with straw removed from September 2001 until March 2003 (excluding May), when incubated at 32°C.

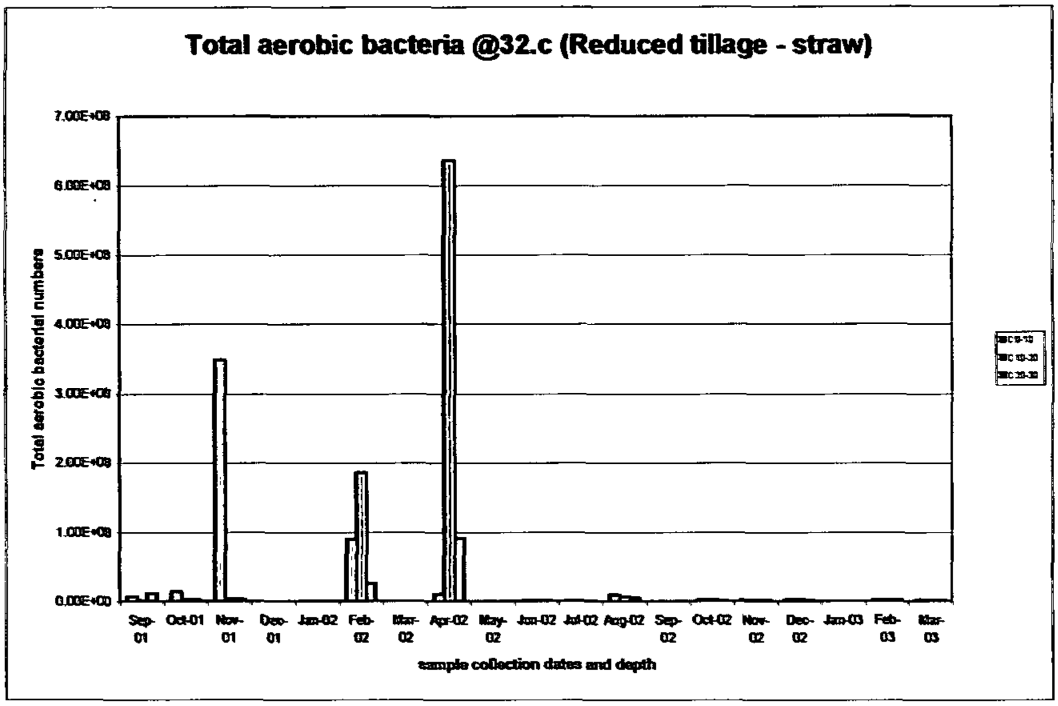


Figure 5.10.10. graphs the same results as figure 5.10.9. with the exclusion of the results for the month of May.

Table. 5.10.11. Total aerobic bacterial numbers for the Reduced tillage treatments, with straw incorporated from September 2001 until March 2003, when incubated at 32°C.

| Sample Depth | Sept 2001 | Oct 2001 | Nov 2001 | Feb 2002 | Apr 2002 | May 2002 | June 2002 | July 2002 | Aug 2002 | Oct 2002 | Nov 2002 | Dec 2002 | Feb 2002 | Mar 2002 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0-10 | 3.69E+6 | 2.71E+6 | 1.73E+6 | 2.06E+6 | 6.50E+7 | 1.55E+6 | 1.01E+6 | 7.00E+5 | 2.50E+6 | 1.95E+6 | 2.28E+06 | 2.27E+06 | 2.92E+06 | 1.49E+06 |
| 10-20 | 1.44E+6 | 2.39E+6 | 2.92E+6 | 3.82E+7 | 5.10E+7 | 1.25E+6 | 1.06E+6 | 1.14E+6 | 2.35E+6 | 2.00E+6 | 1.50E+06 | 1.57E+06 | 2.39E+06 | 1.32E+06 |
| 20-30 | 1.20E+6 | 2.01E+6 | 2.43E+6 | 6.69E+7 | 6.02E+7 | 9.78E+5 | 3.62E+5 | 1.30E+6 | 5.65E+6 | 8.53E+6 | 1.27E+06 | 1.70E+06 | 1.67E+06 | 5.52E+05 |
| Mean | 2.11E+6 | 2.37E+6 | 2.36E+6 | 3.31E+7 | 5.87E+7 | 1.26E+6 | 8.88E+5 | 1.05E+6 | 3.50E+6 | 4.15E+6 | 1.68E+6 | 1.84E+6 | 2.29E+6 | 1.12E+6 |
| Std D | 1.12E+6 | 2.86E+5 | 4.89E+5 | 2.66E+7 | 5.81E+6 | 2.34E+5 | 2.30E+5 | 2.53E+5 | 1.52E+5 | 3.05E+5 | 4.31E+5 | 3.02E+5 | 5.12E+5 | 4.07E+5 |
| Signif | *** | *** | *** | *** | *** | *** | *** | ** | *** | *** | *** | *** | *** | *** |

Significance Key

* P<0.05

** P<0.01

*** P<0.001

NS No Significant Difference

Figure.5.10.11. Total aerobic bacterial numbers for the Reduced tillage treatments with straw incorporated from September 2001 until March 2003, when incubated at 32°C.

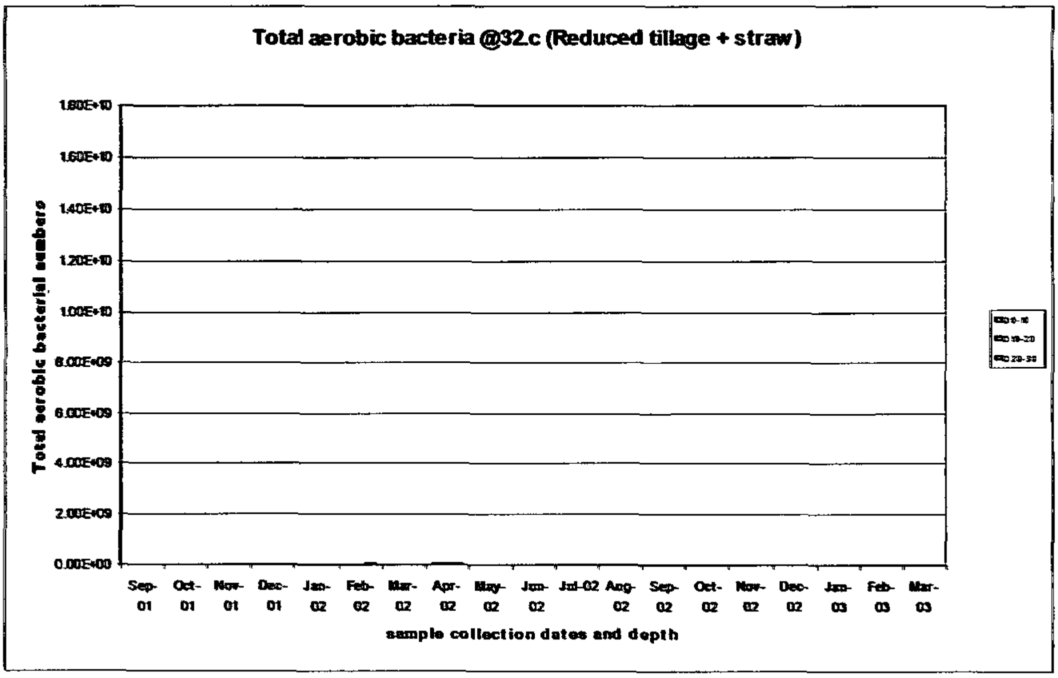


Table .5.10.12. Total aerobic bacterial numbers for the Reduced tillage treatments with straw incorporated from September 2001 until March 2003 (excluding May), when incubated at 32°C.

| Samp Depth | Sept 2001 | Oct 2001 | Nov 2001 | Feb 2002 | Apr 2002 | June 2002 | July 2002 | Aug 2002 | Oct 2002 | Nov 2002 | Dec 2002 | Feb 2002 | Mar 2002 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0-10 | 3.69E+6 | 2.71E+6 | 1.73E+6 | 2.06E+6 | 6.50E+7 | 1.04E+6 | 7.00E+5 | 2.50E+6 | 1.93E+6 | 2.28E+06 | 2.27E+06 | 2.92E+06 | 1.45E+ |
| 10-20 | 1.44E+6 | 2.39E+6 | 2.92E+6 | 3.02E+7 | 5.10E+7 | 1.06E+6 | 1.14E+6 | 2.35E+6 | 2.00E+6 | 1.50E+06 | 1.57E+06 | 2.29E+06 | 1.32E+ |
| 20-30 | 1.20E+6 | 2.01E+6 | 2.43E+6 | 6.69E+7 | 6.02E+7 | 5.62E+5 | 1.30E+6 | 5.65E+6 | 8.53E+6 | 1.27E+06 | 1.70E+06 | 1.67E+06 | 5.52E+ |

Figure .5.10.12. . Total aerobic bacterial numbers for the Reduced tillage treatments with straw incorporated from September 2001 until March 2003 (excluding May), when incubated at 32°C.

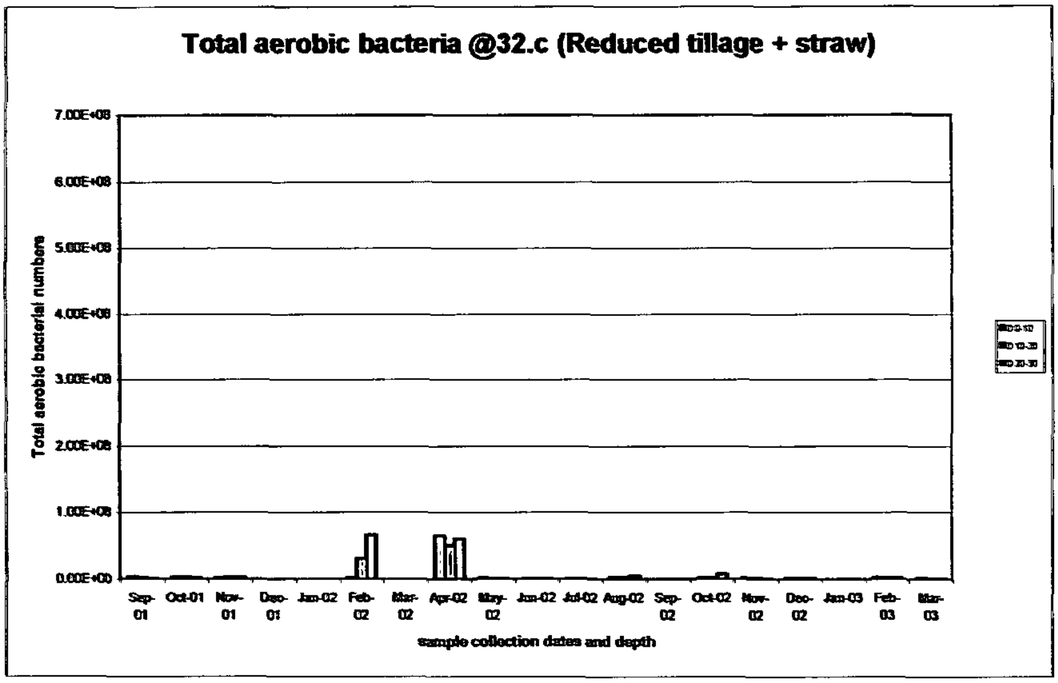


Figure 5.10.12. graphs the same results as figure 5.10.11. with the exclusion of the results for the month of May.

***Total Aerobic Bacterial Numbers when incubated at 32°C for each treatment.***

*Table 5.10.5.*

There was a statistically significant difference in numbers of total aerobic bacteria in May between the three depths sampled in the ploughed treatments with straw removed. The greatest number of bacteria occurring at the 0-10cm depth, and reducing through the profile. This was the only occasion where this occurred, and this treatment contained the largest number of aerobic bacteria of the four treatments sampled.

The increase in numbers of bacteria from February through until May coincided with applications of fertiliser to these treatments, which would have increased microbial activity. From May to June and onwards, there was a dramatic reduction in numbers of total aerobic bacteria throughout the sampled soil horizon.

*Table 5.10.7.*

The conventionally tilled treatments, which had incorporated straw also contained greater numbers of total aerobic bacteria when incubated at 32°C than at the lower incubation temperature of 22°C.

When compared to the conventionally tilled treatments, which had removed straw there were lower numbers of aerobic bacteria present. The high peak in numbers in May, at the 0-10cm sample depth, were not determined in this treatment. Instead numbers increased at the lower depths in the soil profile.

Throughout the fourteen-month sampling period the numbers of total aerobic bacteria were lower in the conventionally tilled treatments with straw than those without straw.

*Table 5.10.9.*

The reduced cultivation treatments contained lower numbers of total aerobic bacteria than the conventionally tilled plots (both with and without the incorporation of straw at 32°C). As with all four treatments at this incubation temperature of 32°C the highest numbers of total aerobic bacteria occurred in February, April and peaked in May. These numbers were all lower than for the conventional treatments.

In this treatment the numbers of total aerobic bacteria were largely concentrated in the top 10cm of soil.

Table 5.10.11.

Of the four treatment types the reduced cultivation treatments, which had incorporated straw contained the least numbers of total aerobic bacteria. The numbers present were all lower than in the previous treatments.

Numbers increased slightly in February and April, but unlike the other treatments they did not peak in May (they reduced). There was also no definite pattern of reduction in numbers through the soil profile.

The reduced cultivation treatments with straw removed continued to show differences of aerobic bacterial numbers, between sample depths.

The numbers of total aerobic bacteria were much greater when incubated at a temperature of 32°C in the conventionally tilled treatments. As was evident when incubated at 22°C the numbers of total aerobic bacteria increased in February and April of 2002, however, they did not peak in numbers until May. This peak in numbers was significantly greater than the peak determined at an incubation temperature of 22°C. The difference in time period of total aerobic bacterial number peaks may be due to the gradual soil warming. Therefore the aerobic bacteria, which grow at the warmer temperatures, peaked at a slower rate i.e. later in the crop season.

# *6.0. DISCUSSION*

## 6.0. Discussion

The Teagasc crops research centre in Carlow implemented a research programme in 2000, which aims to determine the future role of reduced cultivation systems. There are two main areas of study in this programme,

1. Mechanisation and labour, energy input, work rates and labour costs.
2. Agronomic analysis, which includes soil fertility and crop production.

The mechanisation /labour research is showing higher work rates, lower energy inputs and lower estimated machinery costs, for reduced cultivation systems, compared to plough based systems. Results so far have indicated that reduced cultivation techniques can reduce machinery related establishment costs by 30-45%. Labour requirements are also reduced (20-50%) although the peak labour demand may be increased. The effect of the system on crop performance have also indicated promising results, as similar crop yields were determined between the two systems in 2001, and in 2002 the reduced cultivation treatment produced higher crop yields than the conventional system (Forristal and Fortune, 2002).

The aim of this project was to determine the impacts on soils as influenced by conventional and reduced tillage practices. Analysis was carried out on the physical, chemical, and microbiological status of soils under cultivation, to determine if cultivation methods impact on soil properties within the first two years of implementation. These results may help to determine the future role of reduced cultivation systems in arable production.

## *6.1. Organic matter*

Organic matter concentrations were directly compared for conventional and reduced tillage systems, with and without the incorporation of straw at each of the three sample depths in the soil profile. From this analysis, organic matter stratification as affected by tillage treatment was determined.

Distribution differences in organic matter concentration have been reported by Blevins et al., (1997), Carter and Rennie (1982) and Doran (1980) when conventional and reduced tillage were compared for organic matter.

During the autumn and winter months the upper horizons of the sampling profile contained the greatest concentration of organic matter, this was true for both treatments which had straw removed and incorporated under conventional tillage. This corresponded to a period when there is a higher concentration of organic matter in the upper horizon of soil due to decaying vegetation on the soil surface, and when the breakdown of organic matter through mineralisation is at its lowest due to low soil temperatures which limit microbial activity. When the soil temperatures increase during the spring and summer months, the concentration of organic matter in the top 10cm of soil reduces due to organic matter mineralisation and a greater concentration of organic matter is determined at the lower depths in the soil profile (Fig.5.1.1.). In November of 2001 and December 2002, high concentrations of organic matter were determined at the lowest depth sampled in the profile, which would indicate the possibility of organic matter leaching during these periods of heavy rainfall. This was also evident in Figure 5.1.2.

A study by Blevins et al (1997) indicated that higher organic matter levels occur in autumn than in spring, due to the previous crop, which contributes to the maintenance of organic matter by decaying leaves, stems and roots. In spring, most of the incorporated plant residues have decayed, thus levels remain low. To increase organic matter concentrations in the soil, more organic matter must be added to the soil than is removed by decomposition or erosion.

Both the conventional tillage and reduced treatments, which had incorporated straw, did not contain a higher concentration of organic matter than those, which had removed straw (Fig 5.1.2. and Fig 5.1.4.). Where straw is incorporated into the soil, it is expected that over time, the concentration of organic matter would increase, as soil residues have an affect on soil temperature, soil reactions, nutrient distribution and availability, population and activities of soil fauna and therefore on soil organic matter content.

Soil organic matter concentration was seen to follow a gradient in the soil under reduced cultivation, and was clearer in the treatments which had straw incorporated, than those which had straw removed. This reduction in organic matter concentration in the soil profile continued to occur through the summer months when organic matter mineralization was at its greatest. Blevins et al (1984) determined that there is a marked stratification of soil organic matter concentration under reduced tillage, as was determined in this study.

When treatments were contrasted, the reduced tillage treatments contained a higher concentration of organic matter in the top 10cm of soil than the conventional cultivation treatments. This was must obvious in autumn and winter. These differences were not always statistically significant. This result was also obtained in previous studies carried out by Blevins et al (1997) and Doran (1980). Blevins et al (1997) suggested that by reducing the degree of soil disturbance, the concentration of organic matter increases in the top 10cm of soil, as residues are isolated from the rest of the soil profile. Wershaw (1993) concluded that soil organic matter may be retained in reduced tillage due to reduced oxygen availability below the soil surface, which affects decomposition rates and microbial processes.

Carter and Rennie (1982) have suggested that leaving plant material to the uppermost soil layers as with reduced tillage, lowers the local accessibility to soil micro organisms. This may retard the decomposition of the organic material, and the transformation processes may be slowed down additionally as compared to conventional tillage by lower temperatures near the soil surface during rainy seasons or by comparatively low water contents during dry weather. This would suggest that organic matter concentration should be lower in the reduced tillage treatments, through the soil profile. In the present study the concentration of organic matter was greater in the top 10cm of soil under reduced tillage and does not differ significantly in concentration at the two lower depths sampled in the profile when, compared to conventional tillage. It is expected that a higher concentration of organic matter should occur at the lower depths in the soil profile under conventional tillage but this was not determined in the present study. When average values were determined for percentage organic matter present under each of the treatments over the sampling period higher values were determined for reduced cultivation treatments at each of the three sample depths.

The studies carried out by Blevins et al (1977), Carter and Rennie (1982) and Doran (1980) have all been carried out over much longer time frames than this study allowed. The distribution differences in organic matter which have been outlined in these studies that are the greater concentration of organic matter at the lower depths in the soil profile under conventional tillage may only develop over a longer period. However, the increased concentration of organic matter reported in the top 10cm of reduced tillage soils was evident in this study.

It can be concluded that the reduction in soil disturbance and the incorporation of straw in the reduced cultivation treatments increased the concentration of organic matter above that determined in the conventionally tilled plots in the top 10cm of soil.

## *6.2. Nutrient status*

The distribution pattern of macronutrients, micronutrients and their trace elements in topsoil is usually modified by the tillage system (Lavado et al, 1999).

To review the impact of tillage practice on the nutrient status of the soils in this project, analysis was carried out for available phosphorus, exchangeable potassium and nitrate-nitrogen. The concentration of each of these parameters was determined through the soil profile to a depth of 30cm for the four treatments. Organic carbon, organic matter, and pH analysis was also carried out.

To date, the implications of nutrient emissions or losses to the environment have not been a major issue for Irish tillage farmers. This is not surprising considering that tillage accounts for less than 10% of national land use, and generally manure is not a component of nutrient management on these farms. However, legislative changes arising from the implementation of EU Directives, particularly the action programme (AP) required by the Nitrate Directive, will focus more attention on tillage farms as sources of nutrient emissions or loss to the environment.

## *6.3. Nitrate*

This project focused on the nitrate concentration in the soil profile and tracked its availability throughout the sampling period.

The nitrate concentration of the soil was monitored from October 2001 through until March 2003. During this period large fluctuation in the concentration of nitrate occurred. These fluctuations may have been caused by the temperature of the soil and soil moisture and by their influence on biological activity throughout the growing season. When the soil temperature rises in spring and early summer, microbial activity intensifies which enhances decomposition of organic nitrogen and accumulation of nitrogen mineralization. An additional factor may have been the application of Nitrogen fertiliser to the treatments in March, April and June.

The nitrate concentration of soils taken in winter was low due to soil temperature, particularly in the reduced cultivation treatments. The concentration of nitrate varied little in the top two soil horizons sampled and this was true for all four treatments. Therefore the incorporation or removal of straw had no immediate effect on treatments, or on nitrate mobility (Fig.5.2.5.).

Nitrate mobility was observed in November 2001, as the concentration of nitrate in the soil increased (in concentration) through the soil profile, this occurred for all four-treatment types and continued to occur until April of 2002 (Fig.5.2.5.).
In tillage areas this creates an environmental risk as crop demand is low or absent during parts of this period and the mobile nitrate can potentially be lost to groundwater through this leaching .

During this sampling period, the top 10cm of soil appeared to show no statistical differences in nitrate concentration within the different cultivation methods (Table 5.2.1. to 5.3.4.). However, when cultivation methods were compared i.e. reduced versus conventional treatments, there were statistical differences in the concentration of nitrate available. The conventionally tilled treatments contained a greater concentration of nitrate at this depth. Therefore there was greater mobility or movement of nitrates in the reduced cultivation treatments (Fig. 5.2.5.).

At the lower sampling depths of 10-20cm and 20-30cm, there continued to be significant differences (P= <0.001) in nitrate concentration during the winter period between cultivation methods. These differences were not always evident on graphs. The reduced treatments contained the higher concentration of nitrate, in November 2001, but the conventional treatment contained a higher concentration at these depths in October 2001 and 2002, thus indicating mobility of nitrate. This did not continue into spring, as there were no significant differences in concentration of nitrate between any of the four treatments at a depth of 10-20cm in February (Table. 5.2.6.). Follett (2001) has suggested that the leaching potential of nitrogen may be greater under conservation tillage. This is because more undisturbed soil macro pores exist for nitrates and water movement. Increased water flow, into and through the root zone, has been observed under conservation tillage compared to conventional tillage. This higher flow has been attributed to decreased water evaporation because of surface residues and increased numbers of undisturbed channels (e.g. earthworms) continuous to the soil surface. The surface mulch enhances the environment for earthworms and the lack of tillage preserves existing channels for several years.

Bjornberg et al (1996) obtained a greater amount of drain flow of water for reduced tillage in Canada, whereas there was a higher nitrate concentration with the conventional tillage system.

During the months of March, April and June, nitrogen fertilizer was applied to the treatments at rates of 60 Kg/ha and 107 Kg/ha and 28.4 Kg/ha. Nitrogen fertiliser advice is determined by the soil nitrogen supply status. When fertiliser nitrogen is added to the soil, a portion is immobilised, but the minimum rate of the recently immobilised fertiliser nitrogen is greater than that of indigenous organic nitrogen for the same period (Freney and Simpson, 1969).

After the second application of fertiliser in April, the samples collected in May indicated that the reduced cultivation treatments contained statistically higher concentrations of nitrate. There was also a greater occurrence of nitrate movement down through the profile in these treatments when compared to the conventionally tilled treatments. The plots which had straw removed indicated that they had a greater degree of leaching than those which had incorporated straw (Table. 5.2.6. and 5.2.7.).

In June, the concentration of nitrate reduced significantly in all four treatments. This may have been due to utilisation of nitrate by the winter wheat or a reduction in the rate of mineralization of nitrate as the moisture content of the soil was reduced.
Through the months of May and June, leaching was greater in the reduced cultivation treatments, but there was also a greater concentration of nitrate-nitrogen in these treatments (Fig. 5.2.6).

The nitrate concentration of the soil peaked in July and a smaller peak was evident in May, this was determined for all four treatments. Herlighy (1979) measured the mineralization pattern of nitrogen in Irish soils. He determined that the release of nitrogen through mineralization continued throughout the year, with pronounced peaks in May and September

Crop requirements for nutrients are high during the ripening stage of the wheat, this requirement was responsible for the large reduction of nitrate present in the soil during August. In July the reduced cultivation treatments contained the greatest concentration of nitrate. In August, these plots contained the least, therefore they were subjected to the greatest fluctuations and utilisation in nitrate concentration during the ripening process of winter wheat (Fig. 5.2.4.).

Crops were harvested and then re-sown in September each year. After this the concentration of nitrate was greatest in the conventionally tilled treatments, the difference in concentration between the reduced and conventionally tilled treatments was statistically significantly different ($P= <0.001$) and continued to remain so until December, when the concentration of nitrate began to increase in the reduced cultivation treatments. These levels were low however, due to leaching and also because the production of nitrate decreases below 30° C and below 5 ° C very little nitrate is formed (Fig. 5.2.5.).

Thomas and Frye (1984) determined lower mineralization, higher leaching and higher denitrification due to higher surface water content in reduced tillage, tended to lower the available nitrogen, particularly in spring.

In this research it was determined that the rate of mineralization of nitrate in spring was not always statistically significant between the different treatment types, as was identified by Bjornberg et al, (1996).

The concentration of nitrate leached through the profile was slightly higher under reduced cultivation due to greater soil macro pores and water movement. Over time the incorporation of soil residues may immobilize nitrogen and thereby reduce excess nitrate leaching (Christensen, 1986). Some evidence of this was determined in the reduced treatment where leaching was greater in the treatments which had removed straw (Fig. 5.2.3.).

The results of this study indicate that differences occurred in nitrate availability. The conventional treatment contained a higher concentration of nitrate in the top 10 cm of soil. And the reduced treatment containing a higher concentration lower in the soil profile. The reduced tillage system also appears to be subject to greater fluctuations in nitrate concentration, particularly in the summer months. It is expected that over time the reduced tillage, due to the decrease in soil disturbance and the maintenance of soil residues in these practices would provide an environment, which encourages microbial activity and reduces soil and water erosion. The residues would also be expected to immobilize nitrogen and thereby reduce excess nitrate leaching (Madramootoo and Mehdi, 1999).

## *6.4. Available Phosphorus*

Organic phosphorus compounds undergo mineralization and immobilisation processes. The direction and magnitude of phosphorus transformations in conjunction with phosphorus fertilisation history, determine the physical and chemical status of phosphorus in the soil, and in turn, the potential of the soil system to supply phosphorus to plants or to contribute to phosphorus loss to water. A key difference between nitrogen and phosphorus in soil is the fact that phosphorus attaches strongly to the soil matrix and for this reason, phosphorus does not generally leach in large quantities through the soil profile. Phosphorus is generally lost from agricultural systems in runoff either in soluble, colloidal or other forms. However, it has been observed to leach during very heavy rainfall events.

In this study the concentration of available phosphorus was determined to decrease down through the soil profile for each of the four treatments. This was emphasised by the statistical difference (P= <0.001) in phosphorus concentration at each sample depth in the soil horizon, the sample depth of 0-10cm contained the greatest concentration of phosphorus. This distribution was attributed to a number of factors which included, the extraction of phosphorus from subsurface layers by plant roots to the herbage which either decomposes directly returning phosphorus fertilisers, as well as the direct application of fertiliser to the upper soil layers (Table.5.3.1. to 5.3.4.).
Murphy and Culleton (1997) demonstrated that, in Irish grassland soils, the soil phosphorus concentrations tended to decline with increasing depth in the soil profile

The reduction in concentration of available phosphorus through the soil profile was more definite in the reduced cultivation treatments, due to the minimum amount of soil disturbance. There was only one occasion during the sampling programme when phosphorus concentration increased down through the soil profile in all four treatment types. This occurred in November of 2001, after a period of heavy rainfall when phosphorus movement was evident downwards through the soil profile. A greater concentration of phosphorus was observed to leach at this time in the reduced cultivation treatments. This was confirmed by a statistical difference of (P = 0.05) when concentrations were compared at the lower sampling depths (Fig 5.3.5.).

Hansen et al (2000) determined that concentration and loss of water-soluble contaminants from reduced tillage systems are often higher than from conventional tillage systems for rainfall induced runoff and leaching. This may be attributed to an accumulation of nutrients at or near the soil surface due to reduced mixing of applied fertiliser and the leaching of nutrients from crop residues at the soil surface.

After cultivation and replanting of the winter wheat in September 2002, there was uniform distribution of phosphorus through the soil profile in the conventionally tilled treatments, as the soil was mixed and inverted to a depth of 25cm. However, statistical differences were still evident between soil depths during this period (Table.5.3.1. to 5.3.2.).

Tunney (1990) stated that increases in soil phosphorus levels have been observed in many countries. The average soil phosphorus levels in Ireland increased steadily from less than 1mg $P/L^{-1}$ soil in 1950, to about 9 mg $P/L^{-1}$ at present. This information is based on soil samples from Irish farms, which were analysed at Johnstown Castle Laboratories (Tunney, 1990).

This evidence suggests that agricultural phosphorus inputs have increased with time, either as a consequence of increased use of phosphorus by agriculture, associated with agricultural intensification, or, where phosphorus applications have been applied to soils at a constant rate over a number of years, leading to an accumulation. Agriculture as a source of phosphorus inputs to surface waters is receiving increased attention from water resource managers. Although point sources of phosphorus from urban areas and industry have been reduced, the remaining phosphorus inputs from agriculture are often sufficient to maintain eutrophic conditions in the receiving waters (Lennox et al., 1997).

This project has determined that the concentration of available phosphorus in the soil varied over the sampling period. These variations may be due to fluctuations in soil temperature. As the temperature of the soil decreases the rate of phosphorus mineralization also decreases, this occurs during the cooler periods of autumn and winter. Initially the concentration of phosphorus reduced throughout the soil horizons after the planting of the winter wheat crop, as there was a nutrient requirement by the newly planted crop.

Throughout the winter period and into spring when crop requirements for nutrients were low, available phosphorus remained low in the soil and this was evident in both cultivation systems i.e. the conventional and reduced tillage systems where phosphorus availability varied between (0.9 – 2.3 mg P/kg) and the concentration of phosphorus diminished with increasing sampling depth. During this period the concentration of available phosphorus was higher in the plots, which were treated by conventional tillage (P= 0.001) (Fig. 5.3.5.).

There is a general acceptance that only a small proportion of applied fertiliser phosphorus is recovered by growing crops in the year of application and that the unused portion remains in the soil as part of the total soil phosphorus pool. The mobility of phosphorus in soils is low compared with other plant nutrients because of the generally low solubility of phosphate compounds and strong phosphorus binding capacity of soil material. Some studies indicate that movement of fertiliser phosphorus away from the initial reaction site is limited to a few centimetres or so (Khasawneh et al., 1974).

Herlighy (1984) has also noted that a high level of available soil phosphorus showed more yield productivity than an immediate application of fertiliser P, irrespective of the amount applied. The benefit arises because of the restricted mobility of fertiliser P.

There was *no immediate* increase in phosphorus concentration in the soil samples after the first application of fertiliser in March of 2002. From May onwards however, the concentration of available phosphorus increased through the soil profile in all treatments with the highest concentration in the top 10cm of soil. The concentration of available phosphorus continued to increase until it peaked in July. The reduced cultivation treatments appeared to contain a slightly higher concentration of available phosphorus although these differences were not statistically significant (P= 0.259) (Fig.5.3.5.). The differences in the median values among the treatment groups were not great enough to exclude the possibility that the difference was due to random sampling variability.

Although the reduced cultivation treatments contained a slightly higher peak of available phosphorus *in July than* the conventionally tilled treatments, the increase in concentration of phosphorus occurred at a slower rate in soils treated by reduced tillage, this was attributed to slower soil warming in these treatments.

Organic phosphorus compounds undergo mineralization and immobilisation processes similar to nitrogen transformations, and during the summer months mineralization would have increased, as soil temperature increased, and microbial activity increased, thus leading to a greater availability of phosphorus (Tunney, 1990).

Available phosphorus levels declined towards the end of July and beginning of August. This was possibly due to the rapid utilisation of nutrients in the ripening process of the crop as its final stage of development. This was evident for all four treatments (Fig. 5.3.1. to 5.3.4.).

Phosphorus levels in October represent the quantity of phosphorus available for the newly planted winter wheat crop. In the conventionally tilled treatments there was little difference in phosphorus concentration in the top two sampling depths (0-10cm and 10-20cm). This was due to the inversion and mixing process of the ploughing, although, these levels were statistically different from each other (P = <0.001).
The reduced cultivation treatments showed a decrease in available phosphorus concentration through the soil profile.

Within each of the top two sample depths there was no statistically significant differences in phosphorus concentration for all four-treatment types (P = 0.593 and P = 0.075). At the lowest sampling depth of 20-30cm, there were no significant differences in concentration of phosphorus within each cultivation method (i.e. the incorporation and removal of straw). However, when conventional tillage was compared to reduced tillage, the differences in the median values among the treatment groups were greater than would be expected by chance. There was a statistically significant difference of P = <0.001. The conventionally ploughed treatments contain much greater concentrations of phosphorus at this depth of 20-30cm (Fig.5.3.7.).

Through the winter period the available phosphorus continued to decline through the soil profile. This decrease was not observed in the conventionally tilled treatments.

By February of 2003, all four-treatment types decreased in concentration of phosphorus through the soil profile. The concentration of phosphorus increased at all three sample depths during this month and there were statistical differences in concentration between treatments (Fig.5.3.5.).

In addition to the immediate effect of fertiliser phosphorus in the year of application, there was a trend for higher optimum yield with increasing levels of soil phosphorus built up over time (Herlihy and Hegarty, 1994). Yield production in the reduced cultivation treatments can be seen to increase each year that the project has been carried out.

The performance of crops, established with conventional and reduced cultivation systems, has been recorded since 2001. Both cultivation systems were established in very poor conditions in early October 2000. Following the wet autumn and winter there were big differences in crop appearance in the spring, with the reduced cultivation system having much lower and more variable plant populations. However, the wheat crop compensated with extensive tillering and good grain development giving good crop yields at harvest and no significant difference between the establishment systems. The conventionally tilled system produced 10.28 t/ha crop yields in 2001 and the reduced cultivation system produced 10.19 t/ha. For the year 2001 to 2002, the average yields were slightly higher for the reduced cultivation treatments, but this difference was not statistically significant (10.4 t/ha versus 9.75 t/ha for the conventionally tilled treatments) (Forristal and Fortune, 2002).

Hedley et al (1982) demonstrated that by maintaining crop residues on the soil surface and minimising soil disturbance, changes would be produced in the cycling and transformation of nutrients in the soil. Reduced tillage systems are suggested to change the

concentration and distribution of phosphorus in the surface layers of the soil profile. Triplett and Van Doren, (1969) determined that the concentration of phosphorus in reduced tillage soils increases in the 0-5 cm depth and decreases at lower depths when compared to conventionally tilled soils.
These studies were carried out over much greater time periods than this study, some up to nine years. To accurately determine if such changes would occur in this study an extension would be required.

This research shows no statistical differences in the overall concentration of available phosphorus present in the soil under the four different treatments, therefore at the early stages of reduced cultivation there is no immediate impact on phosphorus concentration. All four treatments followed the same pattern of phosphorus availability over time, which may be linked to variations in soil temperature and thus microbial activity. The reduced cultivation treatments appeared to be a little slower than the conventionally tilled treatments in regard to soil warming, especially in the early part of the summer. They also peaked in available phosphorus concentration a month later i.e. in July (Fig.5.3.2. and Fig. 5.3.4.).
The reduction of available phosphorus in the soil profile was also more distinctive in the reduced cultivation treatments throughout the sampling period.

Ohno and Erich (1997) stated that when crop residues were returned to the soil an increase in phosphorus availability might occur, by decreasing the adsorption of phosphorus to mineral surfaces. In the present study it was observed that lower values for available phosphorus were determined for both cultivation systems, which had incorporated straw. These treatments are known to have a slower aeration rate and soil temperature increase, therefore affecting soil reactions and nutrient availability, although these differences were not statistically significant.

It can be concluded that at the early stages of reduced cultivation there are no statistical differences in the concentration of available phosphorus present in the soil profile for the growing crop.
Although over time, previous studies have determined that reduced cultivation yields a higher concentration of phosphorus in the top 5cm of soil and lower levels in the lower horizons when compared to conventional tillage, this was not evident in the first two years of the programme. This suggests that there is no immediate beneficial or detrimental impact on soil phosphorus when cultivation is reduced.

## *6.5. Exchangeable Potassium*

Blevins et al (1977) has shown that reduction in soil cultivation, associated with reduced tillage, can significantly change the distribution of plant available nutrients within the surface soil horizon. Such changes are characterised by concentration gradients in the surface soil for the less mobile plant nutrients such as potassium, under the reduced tillage system.

In this study a concentration gradient for exchangeable potassium was determined under both conventional and reduced tillage systems. Statistical analysis was carried out for exchangeable potassium concentration through the soil profile, for each of the treatments. These showed that there is a significant statistical difference in potassium concentration between all three sample depths, the greatest concentration of potassium being determined in the top 10cm of soil, and decreasing with increasing sample depth. The difference in the mean values through the soil profiles was greater than would be expected by chance. This was true of both cultivation methods with or without the incorporation of straw (Fig.5.4.1. to 5.4.4.).

The concentration of exchangeable potassium was directly compared at each of the three sample depths for each of the four different treatments. Although all treatments followed the same pattern of reduction in exchangeable potassium with depth, there were differences in concentration between cultivation methods. Edwards et al (1992) determined that exchangeable potassium concentration was greater under conventional tillage than under reduced tillage through the soil profile, with the exception of the top 5cm, where the results were reversed.

A greater concentration of exchangeable potassium was determined in the top 10cm of the reduced cultivation treatment, this may be due to the reduction in soil inversion with this cultivation method. Therefore the dispersion of potassium was reduced under this method of cultivation compared with the conventionally tilled treatments where the exchangeable potassium would have been dispersed further down the soil profile. It has been suggested that the processes of cultivation are solely responsible for the movement of exchangeable potassium, as it is not considered a mobile nutrient in the soil profile. However, as was evident in November 2001 for available phosphorus analysis, exchangeable potassium concentration appears to be greatest further down through the soil profile on this sampling occasion. This would suggest the leaching of potassium through the soil, and was only evident on this date (Fig.5.4.3.).

The concentration of exchangeable potassium can be seen to fluctuate throughout the crop season in all four treatments. These fluctuations are created by crop utilisation and the changes in soil temperature, which affect microbial activity and thus rate of potassium mineralization. The application of fertiliser in March did not appear to have an immediate impact on the conventionally tilled treatments, as the concentration of exchangeable potassium reduced from that previously determined in February and remained low through the summer months. This coincided with the period of greatest crop growth. During this time crops often uptake potassium levels far in excess of their nutrient requirements, which is termed ‘luxury consumption’ and therefore reducing the concentration of exchangeable potassium remaining in the soil profile. The concentration can be seen to increase again in February 2003, when crop requirements were low (Fig. 5.4.1. to 5.4.4.).

The incorporation of straw into the conventionally tilled treatments did not reduce the degree of exchangeable potassium fluctuation in the soil profile. Although the concentration of potassium was a little greater in treatments, which had incorporated straw as opposed to those which had removed straw, this difference was not statistically significant. Both treatment types under conventional tillage decreased in concentration of exchangeable potassium down through the soil profile, the greatest concentration occurring in the top 10cm of soil (Table 5.4.1. and 5.4.2.).

The pattern of exchangeable potassium concentration determined throughout the sampling period varied between the reduced and the conventionally tilled treatments (Fig. 5.4.1. to 5.4.4.). The reduced cultivation treatments increased in concentration of potassium after application of fertiliser. No increase was found in the conventionally tilled treatments.
The concentration of exchangeable potassium decreased during the months of May and June, as crop utilisation was high during the ripening stage of the crop and 'luxury consumption' may have occurred. It was also possible that the rate of potassium mineralization was reduced, as the moisture content of the soil was low. Large concentrations of potassium were determined in July and August when crop requirements were met and the wheat no longer utilised large reserves of potassium from the soil.

The concentration of exchangeable potassium is greater during this period in the reduced cultivation treatment than the conventional treatments, with and without the incorporation of straw. Within the reduced treatments those, which had removed straw contained a higher concentration of potassium than those which had incorporated straw. However, these treatments also showed greater fluctuations in concentration of exchangeable potassium over time than the conventionally tilled treatments (Fig. 5.4.3. to 5.4.4.).

On comparison of cultivation methods at a sample depth of 0-10cm, the greatest concentration of exchangeable potassium occurred in the reduced cultivation treatments, as previously determined by Edwards et al (1992) (Fig. 5.4.5.). At the lower sampling depth of 10-20cm, this was reversed and the conventionally tilled treatments contained a higher concentration of exchangeable potassium (Fig.5.4.5.). This was also expected to occur at the lowest sample depth of 20-30cm (Fig.5.4.6.), but on completion of statistical analysis it was determined that any differences in exchangeable potassium concentration at this depth were insignificant and were probably due to random sampling variability.
As potassium is not a very mobile nutrient, differences at this depth of 20-30cm could only be due to cultivation of the soil. As there is no difference in concentration of exchangeable potassium at this depth, cultivation methods evidently did not have a significant impact this far down the soil profile.

In the overlying layer of soil the mixing and inversion of the soil through ploughing has relocated some of the potassium from the top 10cm of soil, therefore uniformly distributing the exchangeable potassium in the top 20cm of soil. Thus there is a greater concentration of exchangeable potassium at a sampling depth of 10-20cm under conventional tillage, but a higher concentration of potassium in the reduced cultivation treatment at the 0-10cm depths, as the soil has not been disturbed beyond this depth.

The incorporation of straw into the reduced cultivation treatment led to a slight reduction in the concentration of exchangeable potassium in these plots (although the differences were not statistically significant). Where reduced tillage was implemented, the utilisation of exchangeable potassium by the growing crop occurred at a faster rate, leaving greater surplus quantities of potassium in July and August than the conventionally tilled treatments. These treatments were however prone to greater fluctuations in exchangeable potassium concentration through the sampling period.

Therefore after the initial two years of implementation of this programme, differences were evident in the availability of exchangeable potassium. The reduced cultivation treatments contained higher concentrations of potassium in the top 10cm of soil, whereas the conventionally tilled treatments had higher concentrations at 10-20cm. These differences did not exist at the lowest sampling depth of 20-30cm, as cultivation methods did not appear to influence at this depth.

There were also seasonal differences in exchangeable potassium concentration, as the reduced cultivation is seen to contain higher concentrations in the summer.

## *6.6. Organic Carbon*

Carbon outputs from soil are primarily from decomposition of soil organic carbon and crop and organic inputs, and from sediment loss where erosion is a factor. The rate of decomposition of a specific organic material is controlled largely by environmental conditions for instance, temperature and moisture (Parr and Papendick, 1978). However, the rate of decomposition can also be altered by the material (for example, surface or buried), which modifies the temperature and moisture variables (Douglas et al, 1980).

Soil disturbed usually reduces the concentration of soil organic carbon, and the subsequent changes in organic carbon chemistry reflect formation of new organic matter. The formation of new stable soil organic carbon depends on factors such as climate, the nature of carbon inputs into the system, and pre-existing soil properties such as texture and clay and mineral type.

In the present study all treatments were inclined to decrease in concentration of organic carbon through the soil profile. The greatest concentration of organic carbon occurring in the top 10cm of soil, throughout the sampling period, and during May 2002 peaked. This has been attributed to increased microbial activity as soil temperatures increased, which caused the mineralsiation of organic matter. Throughout most of the sampling period the concentration of organic carbon did not vary significantly through the soil profile in the conventionally tilled plots, and the increased losses of soil organic carbon, which have been documented by Studdert et al (1997), for conventional tillage are not evident during the duration of this study. Romkens et al (1999) has shown that ploughing disperses soil organic carbon from the 0-20 cm soil depth down to 60-80cm depths. This would indicate that soil organic carbon should increase in concentration down through the soil profile under conventional tillage practices.

All four treatments followed the same general pattern of reduction in organic carbon with increasing sample depth through the majority of the sampling programme. However, exceptions to this did occur in each of the four treatment types over the sampling programme, particularly in the treatments which had incorporated straw under both cultivation methods, in these treatments the conventional tillage system contained higher concentrations of organic carbon at lower depths in the soil profile on four occassions and the reduced tillage system on three. In November of 2001, the concentration of organic carbon can be seen to increase lower in the soil profile, for all four treatments, this was the only month when all four treatments displayed this characteristic, and may indicate the movement of organic carbon through the soil profile as it corresponds to a period of heavy rainfall.

The position and quantity of crop residue as well as nitrogen fertilisation also have variable influences on soil organic carbon storage (Paustian et al, 1997). When more crop residues are on or near the surface, the storage of soil organic carbon has been increased but when incorporated by mouldboard tillage the quantity of crop residue has had little or no influence on soil organic carbon storage (Higgins et al, 1998).

Where straw was incorporated into the conventional tillage treatments in this study, the concentration of organic carbon was reduced, particularly in the top 10cm of soil (Fig.5.5.2.). The previous peak in organic carbon concentration in May was not evident, instead the greatest concentration of organic carbon occurred earlier in the crop season during spring, a rapid increase was determined during the final month sampled of March 2003.

Angers et al (1995) found that corn derived soil organic carbon was evenly distributed with depth in a mouldboard plough treatment. The results obtained over the sampling period in this study indicate that soil organic carbon decreased in concentration down through the soil profile under conventional tillage practice (Fig.5.5.1. to 5.5.2.).

No statistically significant difference occurred in the concentration of organic carbon in the top 10cm for the different cultivation methods throughout the duration of the sampling programme (Fig.5.5.5.). Therefore there were no initial benefits in reduced cultivation to increase organic carbon in the top 10cm of soil. This is in contradiction to the findings of Dick and Durkalski (1987), who determined that the storage of soil organic carbon in shallow soil depths (7.5cm) is usually greater with reduced tillage than in annually tilled systems. Results in two Ohio soils showed that soil organic carbon storage was greater in the reduced tillage systems near the surface, but below 7.5cm, the soil organic carbon storage was equal to or less than in the mould board plough system

Conservation tillage is promoted, in part, for it's beneficial effects on carbon retention that occurs with time. Lal (1976) reported that reduced tillage in conjunction with crop residue improved soil quality and crop yield by increasing infiltration of water into soil profile, and lessening water runoff and soil erosion. Minimum tillage practices are considered as an important component of sustainable farming (Carter, 1994). The system is thought to enhance soil quality. Crop residue mulch has improved soil quality in terms of organic carbon and biotic activity (Karlen et al, 1994).

It has been suggested that the minimal soil disturbance and surface placement of residues with reduced tillage restricts contact of residues with the soil matrix, resulting in extreme moisture and temperature fluctuations in and around residues, thereby limiting decomposition (Douglas et al, 1980). Slower subsurface decomposition rates would lower oxidative losses of organic carbon.

However, in the present study, the results obtained for organic carbon concentration in the reduced cultivation treatments were not statistically greater than the concentration of organic carbon determined for the conventionally tilled treatments, as suggested by Blevins et al, (1984), Havlin et al, (1990) and Franzluebbers et al, (1982). All of these indicated that there was an accumulation of soil organic carbon at the soil surface under reduced tillage, and that this was due to the surface placement of crop residues and a lack of soil disturbance, which kept residues isolated from the rest of the soil profile.

The concentration of organic carbon did not fluctuate greatly throughout the sampling period, although there was a slight reduction in concentration through the summer period. A definite pattern of organic carbon stratification can be seen to occur with depth in these treatments. The incorporation or removal of straw in the reduced cultivation treatments did not greatly effect the concentration of organic carbon available in the soil profile (Fig.5.5.3. and Fig.5.5.4.).

Ghuman et al (2001) noted that organic carbon was significantly increased in the reduced tillage treatment over that of conventional tillage treatments in the surface 20cm but, that there was no noticeable difference in organic carbon concentration between the two reduced cultivation treatments. The results in this study agree with the findings of Ghuman et al (2001), in that they indicate that there was no significant difference in organic carbon concentration between the two reduced cultivation treatments. However, they do not indicate that under reduced cultivation the concentration of organic carbon increases above that determined under conventional tillage.

As no statistical difference was determined in organic carbon concentration over the sampling programme in the top 30cm of soil, it can be concluded that cultivation methods did not greatly impact on the concentration of organic carbon or its distribution in the soil profile.

## *6.7. pH Readings*

pH analysis was carried out as part of this project, to determine if cultivation method affects the values for pH determined in the soil. Any variations in soil pH among cultivation methods would enhance differences in nutrient availability for subsequent crops.

Conventional tillage treatments mix and invert the soil to depths of between 20-25cm. This process homogenises many of the soils characteristics to this depth, including soil pH. In this study it was determined that there were statistical differences in ph between the three sample depths in the soil profile, under conventional tillage. The only exception occurred where straw was removed. The pH of the soil was also seen to increase in value down through the profile (Fig.5.7.1. and Fig.5.7.2.).
The reduced tillage system also yielded results of statistical differences in soil pH between the three depths sampled. The pH often increased in value down through the soil profile (Fig.5.7.3. and Fig.5.7.4.).

The differences in pH values through the soil profile determined from April onwards were due in part to the addition of lime to the treatments (Fig.5.7.1. to 5.7.4.), the purpose of which was to increase the pH of the soil. This increase was most evident at the lower depths in the soil profile. The heavier the texture of a soil and the higher its organic content, the larger must be the application of lime to force a given change in pH.

As with other soil characteristics, the pH of the soil can be seen to fluctuate over the growing season of the crop. The treatments, which had straw removed contained greater pH values and were less prone to fluctuations than those, which had straw incorporated (Fig.5.7.1. and Fig.5.7.3.). These fluctuations are due to changes in hydrogen ion concentrations as soil solutions can suffer from major, as well as minor fluctuations, for instance, the drying of soils, especially above field temperatures, will often cause a noticeable increase in acidity. This may in part be responsible for lower pH readings at the soil surface during the summer months in this study. Also the pH of mineral soils can decline during the summer, especially if under cultivation, as a result of the acids produced by micro organisms. The activities of the roots of higher plants, particularly with regard to acidic exudates, may also be a factor. In winter and spring an increase in pH is often noted, because biotic activities during this time are considerably slower.

When the pH readings for reduced cultivation treatments were compared to the conventionally tilled, there were periods when there were no statistically significant differences in the values for pH determined at each of the three depths sampled in the soil profile (Fig.5.7.5. to 5.7.7). The reduced cultivation system did not yield a higher value for pH within the top 10cm of soil, with or without the incorporation of straw (Fig.5.7.5.). Blevins et al (1977) has indicated that pH values decrease through the soil profile under reduced cultivation. Whereas, Hargrove et al (1982) determined that tillage had little effect on soil pH. He observed that the pH was slightly higher in the 5-10cm depths under reduced tillage than conventional tillage, but that this was of little significance.

The observation that the surface soil becomes more acidic under conservation tillage than under conventional tillage, has been previously reported (Blevins et al., 1977). Acidification is primarily due to nitrification of surface applied nitrogen fertiliser. Blevins et al (1977) found that surface pH decreased with increasing nitrogen application after 5 years of continuous corn. Surface applied lime has been shown to be effective in neutralising soil acidity under reduced tillage (Moschler et al., 1973) because it creates contrasts directly with the soil layer where most of the acidity is produced. Soil acidity produced deeper in the soil profile, however, cannot be as effectively neutralised under reduced tillage compared to conventional tillage where mixing of the soil and lime occurs.

Of the four treatments studied the greatest fluctuations in pH occurred in the reduced cultivation treatments which had straw removed, and the least degree of fluctuation for pH was determined in the reduced cultivation treatment which had straw incorporated (Fig.5.7.3.).

It has also been suggested by Blevins et al (1977), that soil pH decreased with an increasing rate of nitrogen fertiliser. The application of fertiliser was consistent for all four treatments, therefore any impact of this was imposed on all of the treatments. Another consistent factor affecting all four treatments was the quantity of rainfall, as rainfall increases the pH falls, this occurs as a result of the depletion of basic cations.

## *6.8. Physical Results*

During tillage operations the soil is subject to shearing, compressive and tensile stresses. A pure shear stress causes a change in shape without a change in soil volume. Pure compression results in volume change without change in shape. In practice shear and compression usually occurs together in soils. Tensile stresses cause tensile failures, which open up fissures and cracks; this decreases the bulk density of the soil but causes little alteration to the soil between the failure zones. The stresses that tillage imposes result in deformation of the soil and failure.

The characteristics and properties of the soil macro pore system may cause different infiltration behaviour under different tillage practices. A greater pore continuity and connectivity in soils under conservation tillage has been attributed to higher activity of bioturbative soil animals, such as earthworms. Tillage always influences soil structure and its results in soil strength decrease. But different tillage operations have varying effects on soil mechanical properties. Soil after conventional tillage operations has a relatively loose structure within the depth of tillage implement range.

The structure of the soil in the ploughed layer of a cultivated field is influenced by external factors, both man made and natural. These factors can cause compaction, fragmentation or even displacement of the soil (Boizard et al, 1994).

### *6.8.1. Shear Vane*

A shear vane tester estimates soil strength and mechanical characteristics. The torque required to deform the soil is defined as the 'torque index'. The applied torque provides only an approximation of shear resistance. When the soil shears, the force on the torsion device is released and the pointer registers the maximum deflection to which the spring was subjected.

The compression of shear strength values from trials with different cultivation methods were possible for each sampling period, as the sampling of soil strength was performed simultaneously, thus eliminating the effect of changing soil moisture. As soil moisture content changes between the three occasions soil strength was determined it was not possible to compare results directly over time.

The shear strength of the soil under each of the four treatments was determined on three occasions between 2002 and 2003. The first of these occurred on the 19th of March. From this analysis it was evident that tillage practices influenced the shear strength of the soil. As the reduced cultivation treatment contained significantly ($P=<0.001$) higher values for shear strength than the conventional tillage method, this was seen through the soil profile to a depth of 12cm (Fig.5.7.1.). This increase in shear strength may be due to the reduction in soil inversion, with this treatment type. The shear strength of the soil increases deeper into the soil profile for all of the four treatments.

A second set of shear strength results were obtained in April of 2002. These were determined when soil conditions were considered to be more favourable than previously in March. At this time soil moisture content was reduced through the soil profile. This reduction in soil moisture content from March to April affected the soil shear strength to a depth of 12cm. By reducing the moisture content of the soil the shear strength can be seen to increase (Table.5.8.12). This increase was evident in all four of the treatments, and the previous statistical differences that were evident between the two treatments were not prevalent. The reduced cultivation treatments remained higher in shear strength values, but the differences were not statistically significant. Therefore any differences may have been due to random sampling variability. Differences only occurred between the 4 and 12 cm depths sampled in the reduced cultivation treatments. The conventionally tilled treatments contained the same shear strength at both depths this was due to the inversion of the soil beyond 12 cm in this treatment (Table.5.7.2.).

A final set of shear vane results were determined in March of 2003. At this time the moisture content of the soil was high, which impacts the shear strength of the soil, as when moisture content increases the shear strength of the soil decreases. This was evident when values for shear strength were compared to the previous sampling occasion of April 2002 (Table 5.8.12).

However, the shear strength of the soil remained higher in the treatments, which were cultivated by reduced cultivation. This was the only sampling occasion, which yielded higher values for shear strength at the 4 cm depth, than at 12 cm, and was only evident in the conventionally tilled treatments. This can indicate the occurrence of soil crusting (Table 5.7.3.).

### *6.8.2. Penetration Resistance*

Soil compaction can be measured with penetrometers. Since compaction is an increase in the density of soil, it is easily measured by determining the force needed to push the penetrometer through it. Generally speaking, the more dense the soil, the harder it is to push a probe through it.

Cone penetrometer readings were recorded in conjunction with shear vane analysis. The results determined indicate that cone penetration resistance is affected by cultivation method, or more accurately by the degree of disturbance to the soil. This was determined, as the cone penetration resistance remained low in the conventionally tilled treatments to a sample depth of approximately 28cm, after which the resistance was seen to increase to greater than 30 kg of force per $cm^2$. Where soil disturbance was reduced by use of the tine cultivator, soil resistance to the cone penetrometer increased higher up in the soil profile but at the lower sampling depths below 40cm, required less kg or force per $cm^2$ to push the penetrometer through the profile than the conventionally tilled treatments. However these differences were not statistically significant (Fig.5.8.1.).

Repeated cone penetrometer analysis was carried out in April when conditions were considered more favourable. As with the shear vane results the reduction in moisture content of the soil altered the results obtained for cone penetrometer resistance. This alteration was greater in the top 20cm of soil, where soil resistance can be seen to increase in all four treatments from 7cm down the soil profile before returning to the same pattern of resistance as previously determined in March at a depth of approximately 21cm (Fig.5.8.2.).

The reduced cultivation treatments both with and without the incorporation of straw were affected to the greatest extent by the reduction in soil moisture content, this was in conjunction with the minimal soil disturbance occurring.

After crop cultivation in autumn of 2002, a further set of cone penetrometer readings were determined. These readings recorded the least resistance to the cone penetrometer of the sets obtained. This was due to the recent cultivation processes, which the soils were subjected to; there were also increased moisture content values determined when compared to the previous analysis. This increase in soil moisture was also responsible for a reduction in the soil resistance to the cone penetrometer. This was evident for all four treatments at this time, although the pattern of soil resistance to the cone penetrometer remained similar to previous results (Fig.5.8.3.).

A final set of readings for soil resistance to the cone penetrometer, were determined in March of 2003. These results followed the same pattern of soil resistance to the cone penetrometer as was previously outlined, where resistance was higher in the upper horizon of soil under reduced tillage but this difference was negligible at lower sample depths in the profile for the two cultivation methods (Fig.5.8.4.).

Materchera and Mloza-Barola (1979) showed that penetration resistance was significantly higher for reduced tillage systems when compared to conventional tillage. Bowen (1976) indicated that there were negative correlations between penetrating resistance and crop growth. In contradiction to this Miller and Sirois (1986) noted that soil compaction does not seem to affect the nutrient content of the soil to a significant extent but that microbial immobilisation might be slowed down due to the poor aeration.

It was concluded in this study that a reduction in the degree of soil disturbance under reduced cultivation ensures that the soil resistance to the cone penetrometer is greater in the upper horizons of the soil when compared to conventional tillage, that is, resistance increases below the depth of cultivation. However this difference does not exist at the lower levels in the soil profile, beyond the depth of cultivation in both treatments penetration resistance stabilises.

Therefore cultivation method along with moisture content directly affects the pattern of penetrometer resistance in the soil.

### *6.8.3. Bulk Density*

Bulk density is a soil physical parameter used extensively to quantify soil compaction. It is defined as, the mass of dry soil per unit volume of solid, liquid and gaseous phase by Froehlich and McNabb (1984).

One set of bulk density results were determined for this study. These were sampled on the 6th of January 2004 (28 months into the project). The results determined for bulk density from the trials, with different cultivation methods were directly comparable, as the sampling was performed simultaneously, thus eliminating the effect of changing soil moisture.

By comparing the average results calculated for bulk density, it was determined that the conventionally tilled treatments contained slightly higher bulk density values than the reduced tillage treatments (these differences were not statistically significant).
Where straw was removed from the different treatments there was no difference in bulk density results. However, where straw was incorporated into the treatments the reduced tillage plots had a lower bulk density value, indicating that these plots were less prone to compaction, and had higher macro porosity and infiltration rates.

Previous studies have indicated that the bulk density was always higher in the reduced tillage treatment than, in the conventional tillage treatment (Hill and Cruse, 1985). These results were not determined after over two years of implementation of this project, at the Knock beg site.

## *6.9. Microbiology*

This research has focused on the total aerobic bacterial numbers at incubation temperatures of 22°C (for 72 hours) and 32°C (for 48 hours). As a large number of micro organisms exist in the soil, a general purpose media was selected i.e. nutrient agar. The objective of this research was to evaluate and review the short-term (0-20 months) effects of reduced tillage and conventional tillage on the microbial biomass pools in soil.

The numbers of total aerobic bacteria determined at an incubation temperature of 32°C were much greater than those determined at 22°C for all four treatment types.
Lower numbers of total aerobic bacteria were determined at both incubation temperatures in the reduced cultivation treatments, both with and without straw. The reduced treatment, which had incorporated straw, contained the lowest numbers of bacteria at both incubation temperatures of all four treatments. These differences were statistically significant through the soil profile. As soils managed with reduced tillage are generally cooler and wetter, this reduction in temperature would impact on microbial activity.

Existing experimental evidence indicates that soil water content is an important factor that influences microbial type and extent of metabolism (Paul and Clark, 1996). The water content of soil exerts its influence through the regulation of oxygen availability, and thus microbial carbon and nitrogen metabolism. Aerobic microbial activity increases with soil water content until a point is reached where water displaces air and restricts the diffusion and availability of oxygen (Linn and Doran, 1994). The water filled pore space denotes the well-known relative soil water content i.e. the ratio of volumetric water content over the total soil porosity.

A general picture of the relation between microbial activity and soil moisture is described by Linn and Doran (1984), which illustrates that the wetter, denser and cooler conditions typically associated with reduced tillage systems result in higher amounts of organic matter and greater microbial activity/biomass, principally in the upper layers of the soil (Blevins et al., 1983). For instance, Doran (1987) found that in seven conservation tillage soils, microbial biomass and potentially mineralisable nitrogen averaged 54 and 37% higher respectively, than those in the surface layer of ploughed soils. Deeper in the soil profiles (7.5 cm to 30cm) differences between tillage treatments were negligible.

In this study these distinctions were not evident in the results obtained at either incubation temperature. The numbers of total aerobic bacteria were greater at the lower depths sampled in the soil profile, this was particularly evident at an incubation temperature of 22°C for all treatment types.

Linn and Doran (1984) stated that in a long-term study of ten years ‘populations of aerobic and anaerobic micro organisms in the surface (0-75mm) of reduced tillage were generally greater than those from conventionally tilled soils’. It was suggested that this was due to differences in bulk densities, volumetric water contents, and water filled pore space. It was possible that during the initial stages of this research these differences were negligible between treatments.

It is possible that the inversion processes of conventional tillage increased the rate of aeration of the soil at lower depths in the soil profile, therefore increasing the numbers and distribution of total aerobic bacteria in the soil at lower depths.
Tillage clearly affects the size, distribution, and topography of pore networks, and thus will indirectly regulate organism

interactions and their access to oxygen as well as substrates and water.

The transport of gases in soil is crucial to the survival and functioning of micro organisms. As the supply of oxygen flowing into microbial habitats decreases below respiratory demand, aerobic activity will decrease and ultimately cease. The structure of the soil may act to speed up or slow down oxygen diffusion to habitat sites. Due to the reduction in soil inversion with reduced tillage the transport of gases in the soil may be limited and the number of aerobic micro organisms may decrease.

Aon et al., (2001) indicated that reduced tillage soils were less aerobic than conventionally tilled ones because of higher water contents and bulk density. This may explain the lower numbers of total aerobic bacteria determined in the reduced cultivation treatments by comparison with the conventionally tilled treatments in the present study, but is in contradiction with other research findings. For instance, research in the US and UK have both yielded more microbial groups under reduced tillage. Wardle (1995) found less soil microbial biomass in conventional tillage than in reduced tillage, although these differences were quite small. The greater microbial biomass in the reduced tillage was suggested to be due in part to cooler, wetter conditions and the reduction in temperature fluctuations and moisture.

In all of the four treatments the lowest numbers of total aerobic bacteria were determined during the winter period when soil temperatures were at their minimum. Therefore microbial activity was limited.

At an incubation temperature of 22°C the conventionally tilled treatments increased in numbers in February and peaked in April and there were higher numbers of total aerobic bacteria in the treatments, which had straw incorporated.

On comparison the reduced cultivation treatments, which had straw removed, peaked in total aerobic bacterial numbers in Nov 2001, although high numbers were also determined in February and April. The treatments which had straw incorporated, followed the same pattern of availability as the conventionally tilled treatments i.e. increasing in numbers in February and peaking in April. Both treatments increased in numbers of total aerobic bacteria down through the soil profile. This population distribution pattern was not expected as generally the available energy substrates and inorganic nutrients are present in their greatest quantities near the soil surface, therefore concentrating aerobic bacteria in the top few centimetres of soil, particularly in the reduced cultivation treatments. The process of mixing and inversion in the conventionally tilled treatments may have distributed the substrates further down the soil profile, making conditions suitable for aerobic bacteria deeper in the profile.

When treatments were compared, the greatest numbers of total aerobic bacteria after incubation at 22°C was determined for the conventionally tilled treatments, which had incorporated straw. However, when samples were incubated at 32°C, the conventionally tilled treatments, which had removed straw, contained greater numbers of total aerobic bacteria. This suggests that the incorporation of straw may have hindered soil warming, as the incorporation of straw is known to limit soil temperature fluctuations.

In general all four treatments contained higher numbers of total aerobic bacteria when incubated at a temperature of 32°C than at 22°C. There were statistically significant differences in numbers between the two cultivation methods, the conventionally tilled treatment containing much higher numbers than the reduced cultivation treatment. The reduced cultivation treatments, which had incorporated straw, contained the least numbers of aerobic bacteria of the four treatment types.

When reviewing the numbers of total aerobic bacteria, which were evident over the sampling period, differences between incubation temperatures occurred. At an incubation temperature of 32°C, the greatest numbers of aerobic bacteria occurred in May, and this was a month after the greatest numbers of aerobic bacteria had been determined at the 22°C incubation temperature. The gradual increase in soil temperature during this period may have led to this distinction.

The numbers of total aerobic bacteria could be seen to increase from February onwards into the summer. This was evident for three of the four treatments, the one exception being the reduced tillage treatment, which had incorporated straw, this reached a peak in bacteria numbers in April.

The greater concentration of aerobic bacteria present in the conventionally tilled treatments did, not have an impact on nutrient availability, during the course of this programme. However, if large distinctions continued to occur between the two cultivation methods in microbial numbers, nutrient availability and physical parameters would be affected.

# 7.0. CONCLUSION

## *7.0. Conclusion*

Reduced tillage has been promoted in part for its beneficial effects on soil properties. Studies by Radecki (1986), Dick (1983), Blevins et al, (1985) and Hansen et al (2000) have all indicated the improvement of soil characteristics under reduced tillage.
Hedley et al (1982) demonstrated that by maintaining crop residues on the soil surface and minimising soil disturbance, changes would be produced in the cycling and transformation of nutrients in the soil, increasing their concentration in the top 10 cm.

In this study, the only parameter which adhered to this these findings, was exchangeable potassium, the concentration of which was determined to increase in the top 10cm of soil in the reduced cultivation treatment. Above that determined for the conventional tillage treatments. As potassium is not a mobile nutrient its movement is dependent on tillage practice in the soil profile, and therefore reduction of soil disturbance in the reduced cultivation treatments allowed for the accumulation of exchangeable potassium in the top 10cm of the soil profile, whereas in the conventionally tilled treatments it was distributed within the top 20-25cm.
The concentrations of available phosphorus, nitrate-nitrogen, organic carbon and organic matter, were all greatest in the conventionally tilled treatments, particularly in the top 10 cm of soil. The incorporation or removal of straw did not alter these results.

The reduced cultivation treatments were also subject to a greater degree of leaching in the soil profile, particularly nitrate leaching. Where straw was removed leaching was at its greatest. In November of 2001, all four treatments indicated that soil leaching occurred, as concentration of phosphorus, potassium, nitrate, organic carbon and organic matter all increased down through the soil profile. This was the only occasion throughout the sampling programme when this occurred and was due to a heavy rainfall event.

The incorporation of straw in both the conventional and reduced treatments, lowered the concentration of available phosphorus, exchangeable potassium and organic carbon present in the soil profile, throughout the sampling programme. This may be due to a reduction in soil temperatures and therefore microbial activity in these treatments.

In contrast, the concentration of nitrate and organic matter both increased where straw was incorporated into treatments. This increase in organic matter concentration may have been due to reduced oxygen availability below the surface of reduced tillage soils, which affected decomposition rates.

Greater numbers of total aerobic bacteria were also determined in the conventionally tilled treatments. This was possibly due to the greater rates of soil aeration in these treatments. There was also a greater concentration of aerobic bacteria at an incubation temperature of 32°C, than at 22°C, in both treatments.

Physical characteristics were also altered by cultivation methods. The reduction in soil disturbance caused with the tine cultivator, led to both the shear strength and soil resistance to the cone penetrometer increasing in the upper horizons of the soil profile, (when compared to conventional tillage). Therefore, resistance increases below the depth of soil cultivation, as the soil has not been loosened and mixed. This may in time lead to increased soil compaction and thus could impact on nutrient availability in the soil.

To conclude, the beneficial effects of reduced cultivation, which have been suggested in the literature listed, have not been determined in this study.
The conventional tillage method continued to contain higher concentrations of nutrients in the top 10 cm of the soil profile, leaching was less significant, numbers of total aerobic bacteria were greater, and the possibility of soil compaction was reduced.

As this study was carried out over a 2-year duration and in the infancy of the Teagasc programme, the impact on soil conditions by cultivation method may not be immediately obvious. Previous studies have been carried out over much greater time periods, this is necessary if any definite conclusions are to be made on the future role of reduced cultivation in Ireland.

# 8.0. RECOMMENDATIONS FOR FUTURE RESEARCH

## 8.0. Recommendations for Future Research

The findings of this field investigation indicate that more research work is necessary if an understanding of the factors influenced by tillage practice are to be made more complete.

More data is needed on;

The distribution patterns of nutrients in soil, to determine for instance, whether there is an accumulation of nutrients in the top 10 cm of soil over time, as a direct influence of reduced cultivation, as suggested by other studies.

The incorporation and removal of straw in treatments, to determine if the incorporation of straw leads to long term beneficial or negligible effects on the soil profile.

Population diversity within the microbial community, such as anaerobic populations, fungi, nitrifying bacteria etc., as changes in microbial species may change the nutrient cycling dynamics of the soil.

The increased resistance to the cone penetrometer in the upper horizons of the soil under reduced cultivation, to determine if this would lead to soil compaction and thus affect the availability of nutrients in the soil profile.

The movement of water, into soil (infiltration), out of soil (evaporation, drainage) and within a soil profile (hydraulic conductivity). By following water movement, the effect of soil runoff and leaching may be determined.

The temperature regime of the soil, as this influences chemical reactions and biological activity.

In order to determine the applicability of the findings of the field investigation an extension of the study would be required.

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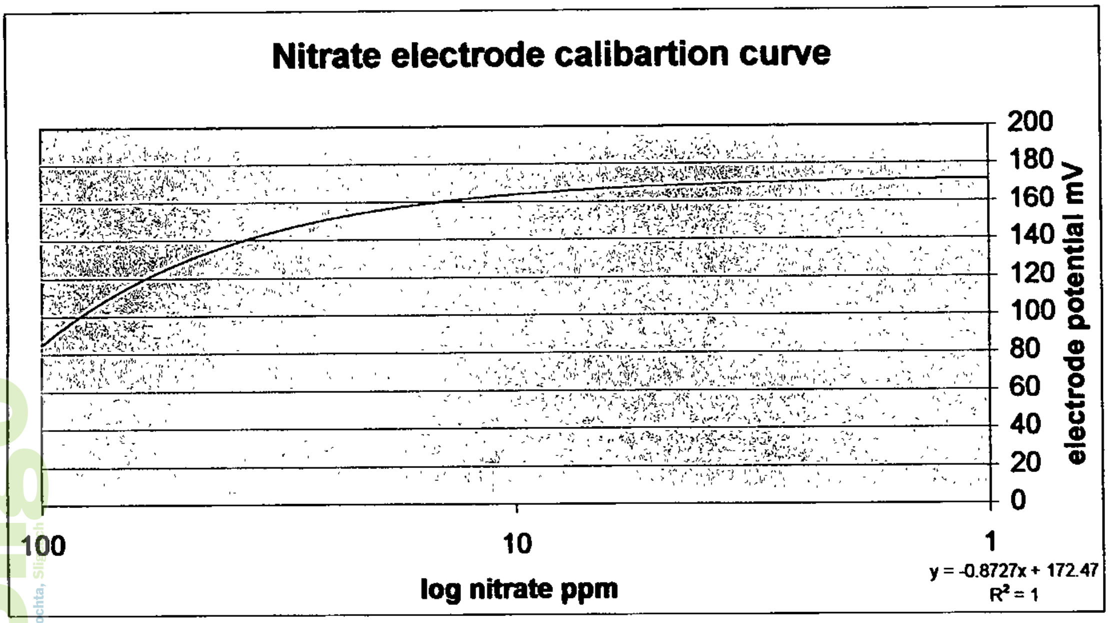
# *APPENDIX A*

## Nitrate Analysis

Sample set no.5- 15/04/02

Electrode preparation

| Aliquot | | Standard mg/l | Mv Reading |
|---|---|---|---|
| 0.1ml of 1000ppm | 0.1ppm | 0.1 | 176.3 |
| 1ml of 1000ppm | 1ppm | 1 | 171.6 |
| 10ml of 1000ppm | 10ppm | 10 | 136.4 |
| 100ml of 1000ppm | 100ppm | 100 | 85.2 |
| | | Slope | 51.2 |



y=mx+c

| | |
|---|---|
| y | Mv |
| m | -0.8727 |
| c | 172.47 |

Sample set no.5 -15/04/2002

Nitrate Analysis

| Sample | Mv Readi | Conc ppm | Dilution | Conc | Ave ppm | Std Devi |
|---|---|---|---|---|---|---|
| A4 0-10 | 159.2 | 15.21 | 60.82 | 61 | | |
| A4 0-10 | 158.4 | 16.12 | 64.49 | 64 | | |
| A4 0-10 | 158.9 | 15.55 | 62.20 | 62 | 62 | 2 |
| | | | | | | |
| A4 10-2 | 170.1 | 2.72 | 10.86 | 11 | | |
| A4 10-2 | 170.1 | 2.72 | 10.86 | 11 | | |
| A4 10-2 | 168.1 | 5.01 | 20.03 | 20 | 14 | 5 |
| | | | | | | |
| A4 20-3 | 164.2 | 9.48 | 37.91 | 38 | | |
| A4 20-3 | 164.3 | 9.36 | 37.45 | 37 | | |
| A4 20-3 | 166.2 | 7.18 | 28.74 | 29 | 35 | 5 |
| SAMPLE 2 | | | | | | |
| A6 0-10 | 134.6 | 43.39 | 173.58 | 174 | | |
| A6 0-10 | 134.6 | 43.39 | 173.58 | 174 | | |
| A6 0-10 | 134.9 | 43.05 | 172.20 | 172 | 173 | 1 |
| | | | | | | |
| A6 10-2 | 166.6 | 6.73 | 26.91 | 27 | | |
| A6 10-2 | 165.1 | 8.45 | 33.78 | 34 | | |
| A6 10-2 | 165.2 | 8.33 | 33.32 | 33 | 31 | 4 |
| | | | | | | |
| A6 20-3 | 170.8 | 1.91 | 7.65 | 8 | | |
| A6 20-3 | 170.3 | 2.49 | 9.95 | 10 | | |
| A6 20-3 | 170.9 | 1.80 | 7.20 | 7 | 8 | 2 |
| SAMPLE 3 | | | | | | |
| B8 0-10 | 91.1 | 93.24 | 372.96 | 373 | | |
| B8 0-10 | 92.3 | 91.86 | 367.46 | 367 | | |
| B8 0-10 | 91.9 | 92.32 | 369.29 | 369 | 370 | 3 |
| | | | | | | |
| B8 10-2 | 158 | 16.58 | 66.32 | 66 | | |
| B8 10-2 | 158.1 | 16.47 | 65.86 | 66 | | |
| B8 10-2 | 157.6 | 17.04 | 68.16 | 68 | 67 | 1 |
| | | | | | | |
| B8 20-3 | 158.8 | 15.66 | 62.66 | 63 | | |
| B8 20-3 | 159.3 | 15.09 | 60.36 | 60 | | |
| B8 20-3 | 159.6 | 14.75 | 58.99 | 59 | 61 | 2 |
| SAMPLE 4 | | | | | | |
| B9 0-10 | 143.4 | 33.31 | 133.24 | 133 | | |
| B9 0-10 | 146 | 30.33 | 121.32 | 121 | | |
| B9 0-10 | 145.2 | 31.25 | 124.99 | 125 | 126 | 6 |
| | | | | | | |
| B9 10-2 | 162.8 | 11.08 | 44.32 | 44 | | |
| B9 10-2 | 162.9 | 10.97 | 43.86 | 44 | | |
| B9 10-2 | 161.3 | 12.80 | 51.20 | 51 | 46 | 4 |
| | | | | | | |
| B9 20-3 | 165.8 | 7.64 | 30.57 | 30 | | |
| B9 20-3 | 166.1 | 7.30 | 29.20 | 29 | | |
| B9 20-3 | 166.2 | 7.18 | 28.74 | 29 | 29 | 1 |

Sample set no.5 - 15/04/2002

Nitrate Analysis

SAMPLE 5

| | | | | | | |
|---|---|---|---|---|---|---|
| C3 0-10 | 119.8 | 60.35 | 241.41 | 241 | | |
| C3 0-10 | 120.1 | 60.01 | 240.04 | 240 | | |
| C3 0-10 | 120.3 | 59.78 | 239.12 | 239 | 240 | 1 |
| C3 10-2 | 153.1 | 22.20 | 88.78 | 89 | | |
| C3 10-2 | 153.6 | 21.62 | 86.49 | 86 | | |
| C3 10-2 | 153.2 | 22.08 | 88.32 | 88 | 88 | 2 |
| C3 20-3 | 154.2 | 20.94 | 83.74 | 84 | | |
| C3 20-3 | 154.1 | 21.05 | 84.20 | 84 | | |
| C3 20-3 | 154.9 | 20.13 | 80.53 | 81 | 83 | 2 |

SAMPLE 6

| | | | | | | |
|---|---|---|---|---|---|---|
| C14 0-1 | 143 | 33.77 | 135.08 | 135 | | |
| C14 0-1 | 143.2 | 33.54 | 134.16 | 134 | | |
| C14 0-1 | 143.6 | 33.08 | 132.32 | 132 | 134 | 2 |
| C14 10- | 158.4 | 16.12 | 64.49 | 64 | | |
| C14 10- | 159 | 15.43 | 61.74 | 62 | | |
| C14 10- | 158.7 | 15.78 | 63.11 | 63 | 63 | 1 |
| C14 20- | 159.7 | 14.63 | 58.53 | 59 | | |
| C14 20- | 159.9 | 14.40 | 57.61 | 58 | | |
| C14 20- | 159.1 | 15.32 | 61.28 | 61 | 59 | 2 |

SAMPLE 7

| | | | | | | |
|---|---|---|---|---|---|---|
| D1 0-10 | 104 | 78.46 | 313.83 | 314 | | |
| D1 0-10 | 104.2 | 78.23 | 312.91 | 313 | | |
| D1 0-10 | 104.2 | 78.23 | 312.91 | 313 | 313 | 1 |
| D1 10-2 | 155.7 | 19.22 | 76.86 | 77 | | |
| D1 10-2 | 156 | 18.87 | 75.49 | 75 | | |
| D1 10-2 | 156.2 | 18.64 | 74.57 | 75 | 76 | 1 |
| D1 20-3 | 161.7 | 12.34 | 49.36 | 49 | | |
| D1 20-3 | 161.1 | 13.03 | 52.11 | 52 | | |
| D1 20-3 | 162 | 12.00 | 47.99 | 48 | 50 | 2 |

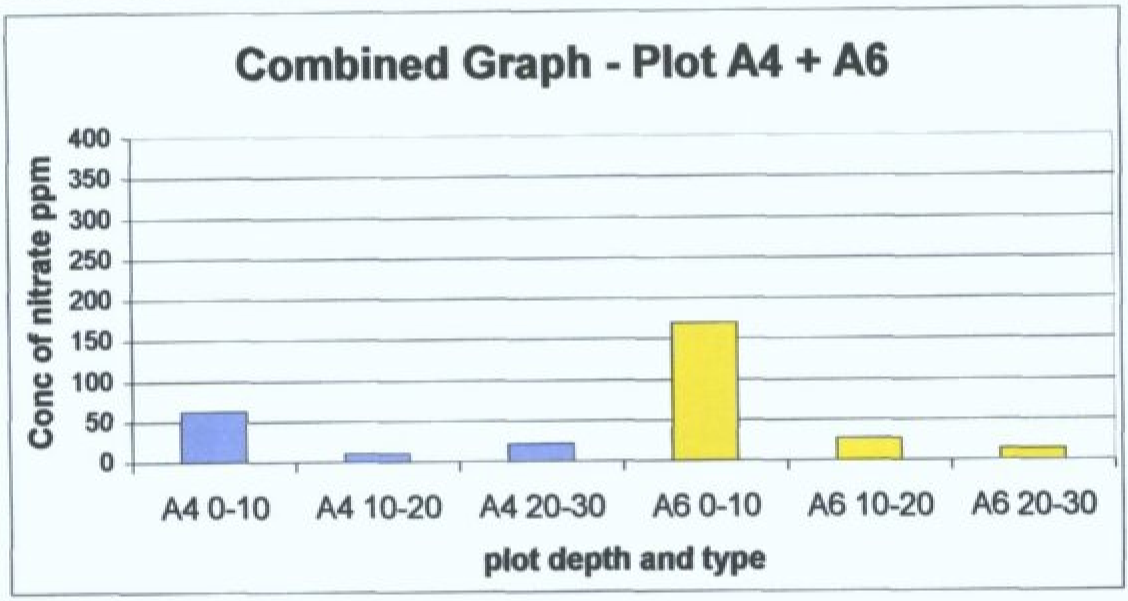
SAMPLE 8

| | | | | | | |
|---|---|---|---|---|---|---|
| D16 0-1 | 135.2 | 42.71 | 170.83 | 171 | | |
| D16 0-1 | 136 | 41.79 | 167.16 | 167 | | |
| D16 0-1 | 135.6 | 42.25 | 168.99 | 169 | 169 | 2 |
| D16 10- | 151.5 | 24.03 | 96.12 | 96 | | |
| D16 10- | 152 | 23.46 | 93.82 | 94 | | |
| D16 10- | 151.1 | 24.49 | 97.95 | 98 | 96 | 2 |
| D16 20- | 162.1 | 11.88 | 47.53 | 48 | | |
| D16 20- | 163 | 10.85 | 43.41 | 43 | | |
| D16 20- | 162.8 | 11.08 | 44.32 | 44 | 45 | 3 |

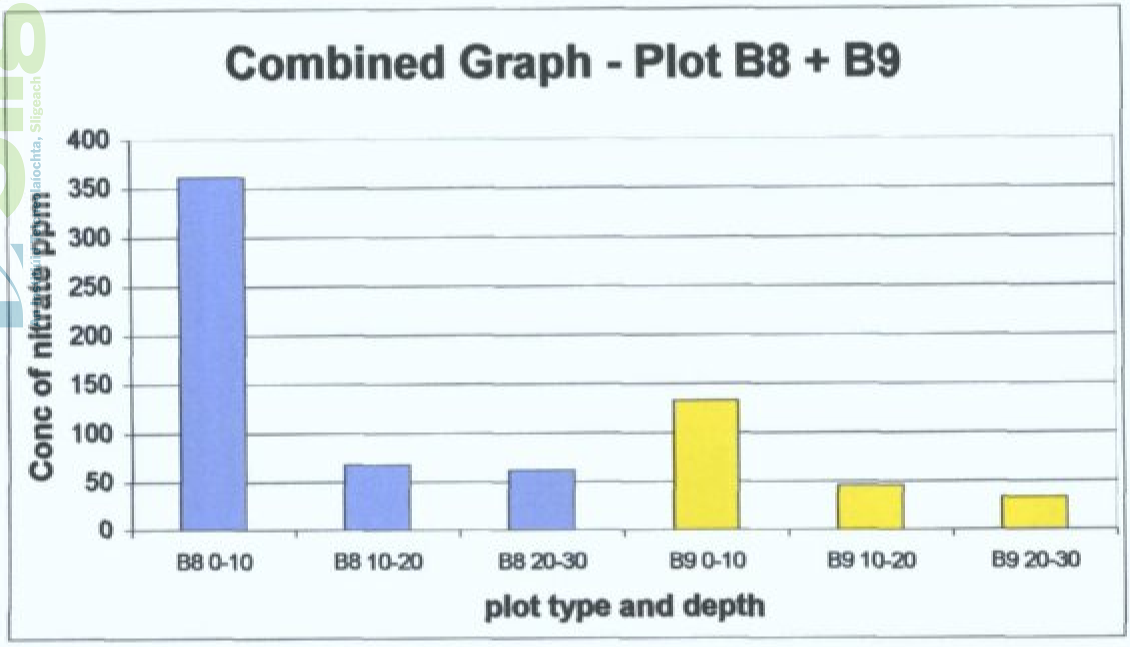
Nitrate Analysis

Sampled 16/04/02

Treatment A = Plough + Power Harrow + Drill ( Straw removed)



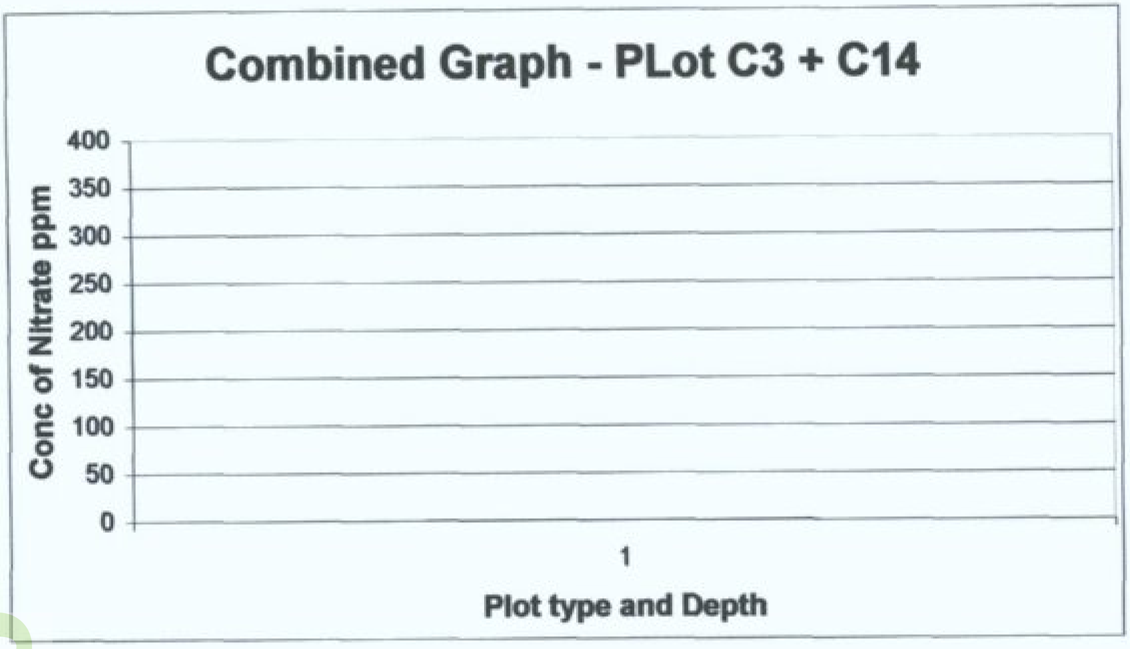
Treatment B = Plough + Power Harrow + Drill ( Straw incorporated)



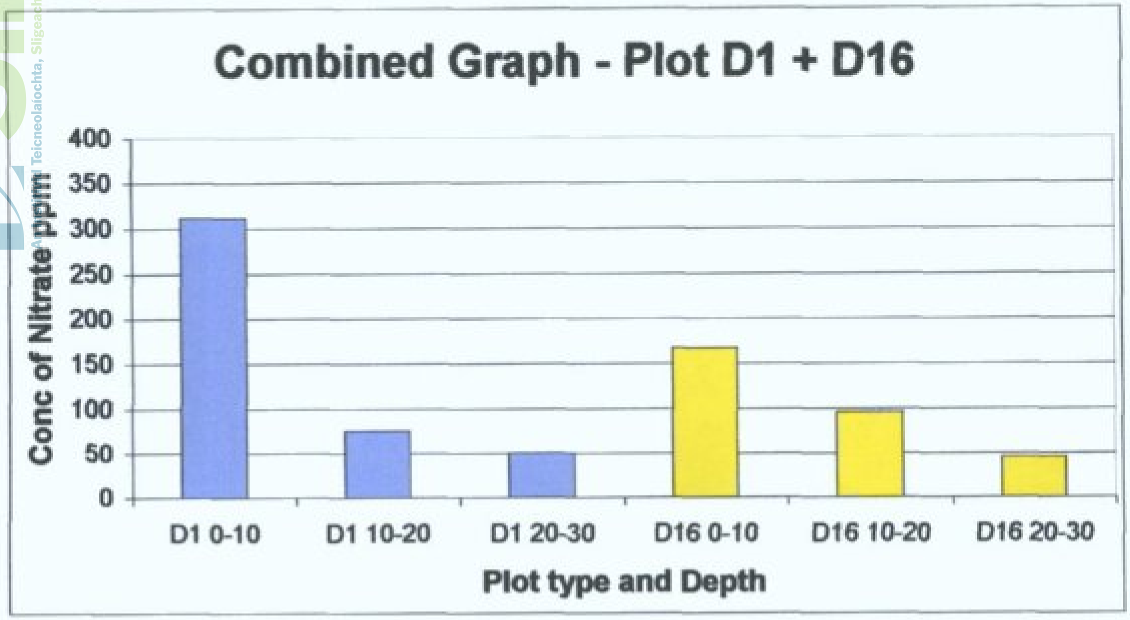
## Nitrate Analysis

Sampled 16/04/02

Treatment C = Tine Cultivator + Press + Drill (Straw removed )



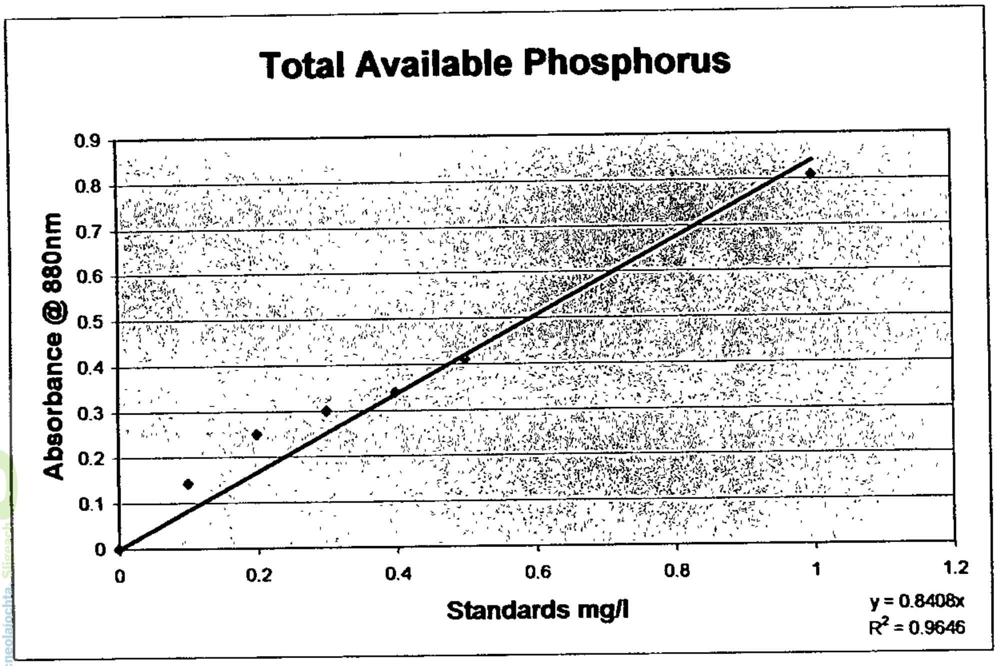
Treatment D = Tine Cultivator + Press + Drill ( Straw incorporated )



Sample set no.5 - 4/15/2002

TOTAL AVAILABLE PHOSPHOURS BY Ag Method.

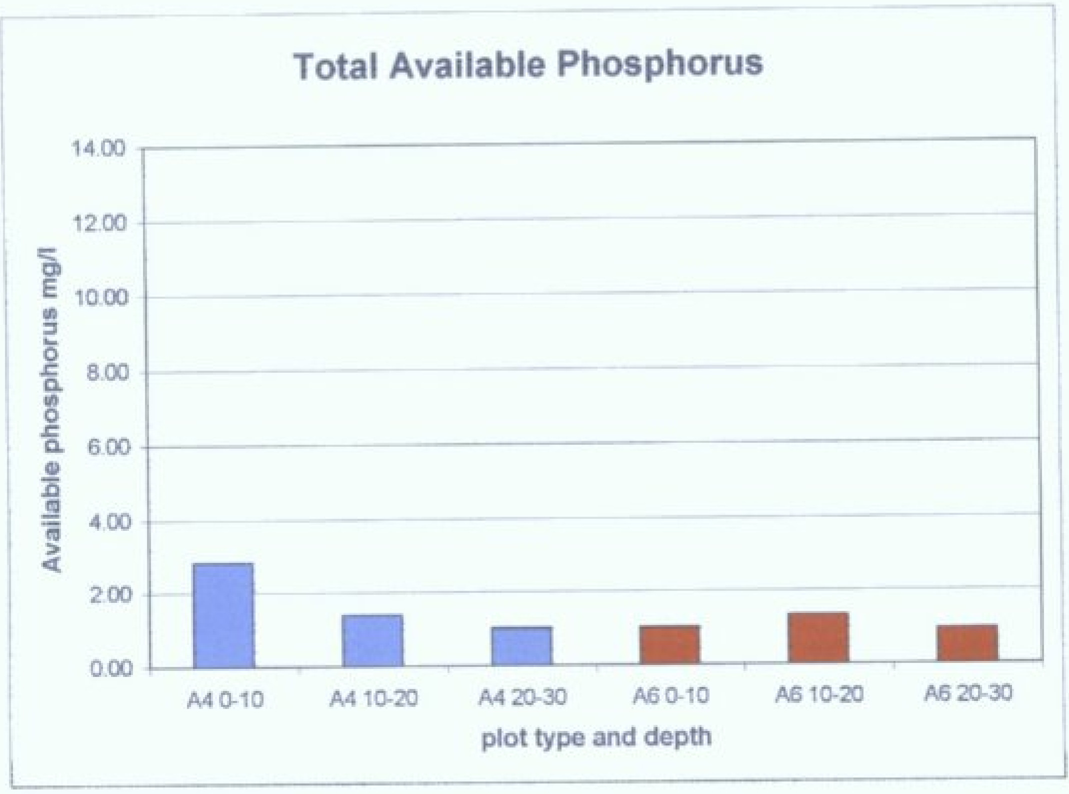
| standard mg/l | abs at 880nm |
|---|---|
| 0 | 0 |
| 0.1 | 0.143 |
| 0.2 | 0.25 |
| 0.3 | 0.3 |
| 0.4 | 0.34 |
| 0.5 | 0.41 |
| 1 | 0.808 |



Sample set no.5 - 15/04/2002

**Plot A = Plough + Harrow + Drill ( straw removed)**

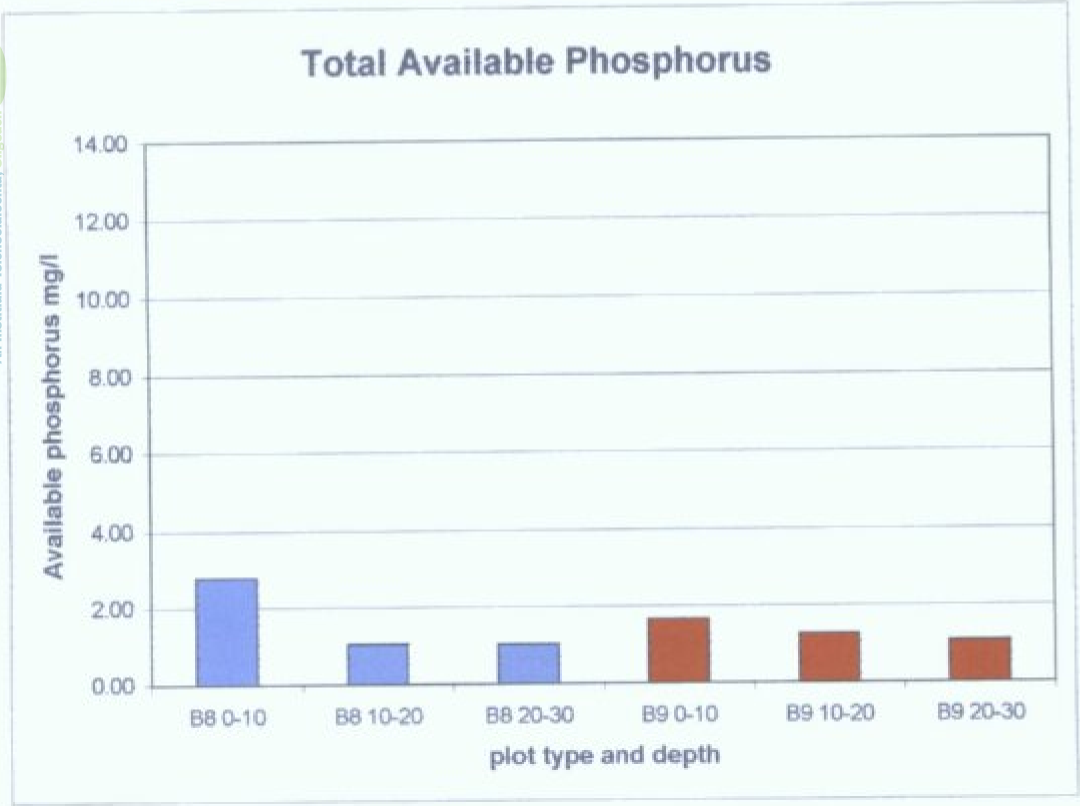
| ID | sample | mg/l | Dilu Factor | Ave mg/l |
|---|---|---|---|---|
| A4 0-10 | 0.465 | 0.553 | 2.77 | |
| A4 0-10 | 0.496 | 0.5899 | 2.95 | |
| A4 0-10 | 0.471 | 0.5602 | 2.80 | 2.84 |
| | | | | |
| A4 10-20 | 0.225 | 0.2676 | 1.34 | |
| A4 10-20 | 0.24 | 0.2854 | 1.43 | |
| A4 10-20 | 0.229 | 0.2724 | 1.36 | 1.38 |
| | | | | |
| A4 20-30 | 0.162 | 0.1927 | 0.96 | |
| A4 20-30 | 0.181 | 0.2153 | 1.08 | |
| A4 20-30 | 0.169 | 0.201 | 1.00 | 1.01 |
| | | | | |
| A6 0-10 | 0.17 | 0.2022 | 1.01 | |
| A6 0-10 | 0.173 | 0.2058 | 1.03 | |
| A6 0-10 | 0.171 | 0.2034 | 1.02 | 1.02 |
| | | | | |
| A6 10-20 | 0.223 | 0.2652 | 1.33 | |
| A6 10-20 | 0.224 | 0.2664 | 1.33 | |
| A6 10-20 | 0.224 | 0.2664 | 1.33 | 1.33 |
| | | | | |
| A6 20-30 | 0.14 | 0.1665 | 0.83 | |
| A6 20-30 | 0.171 | 0.2034 | 1.02 | |
| A6 20-30 | 0.166 | 0.1974 | 0.99 | 0.95 |



Sample set no.5 -15/04/2002

**Plot B = Plough + Harrow + Drill ( straw incorporated)**

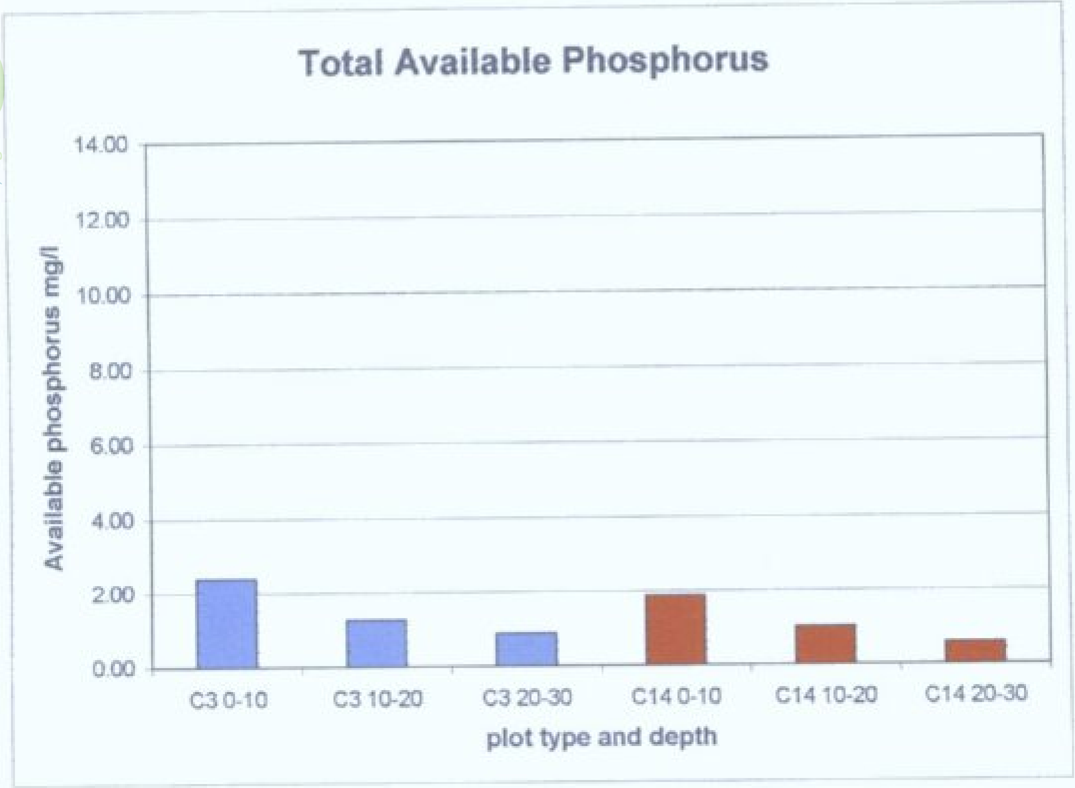
| ID | sample | mg/l | Dilu Factor | Ave mg/l |
|---|---|---|---|---|
| B8 0-10 | 0.495 | 0.5887 | 2.94 | |
| B8 0-10 | 0.496 | 0.5899 | 2.95 | |
| B8 0-10 | 0.416 | 0.4948 | 2.47 | 2.79 |
| B8 10-20 | 0.163 | 0.1939 | 0.97 | |
| B8 10-20 | 0.18 | 0.2141 | 1.07 | |
| B8 10-20 | 0.188 | 0.2236 | 1.12 | 1.05 |
| B8 20-30 | 0.201 | 0.2391 | 1.20 | |
| B8 20-30 | 0.157 | 0.1867 | 0.93 | |
| B8 20-30 | 0.16 | 0.1903 | 0.95 | 1.03 |
| B9 0-10 | 0.295 | 0.3509 | 1.75 | |
| B9 0-10 | 0.291 | 0.3461 | 1.73 | |
| B9 0-10 | 0.255 | 0.3033 | 1.52 | 1.67 |
| B9 10-20 | 0.21 | 0.2498 | 1.25 | |
| B9 10-20 | 0.215 | 0.2557 | 1.28 | |
| B9 10-20 | 0.211 | 0.251 | 1.25 | 1.26 |
| B9 20-30 | 0.188 | 0.2236 | 1.12 | |
| B9 20-30 | 0.177 | 0.2105 | 1.05 | |
| B9 20-30 | 0.18 | 0.2141 | 1.07 | 1.08 |



Sample set no.5 - 15/04/2002

**Plot C = Tine Cultivator + Press + Drill (straw removed)**

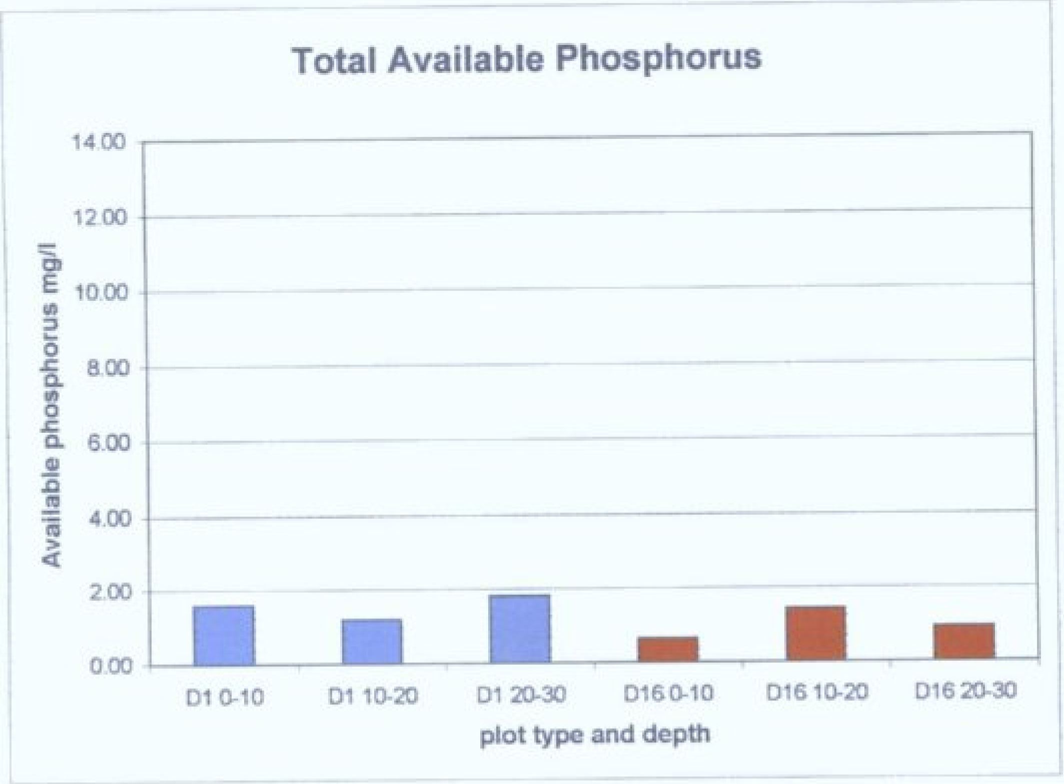
| ID | sample | mg/l | Dilu Factor | Ave mg/l |
|---|---|---|---|---|
| C3 0-10 | 0.404 | 0.4805 | 2.40 | |
| C3 0-10 | 0.395 | 0.4698 | 2.35 | |
| C3 0-10 | 0.401 | 0.4769 | 2.38 | 2.38 |
| | | 0 | | |
| C3 10-20 | 0.214 | 0.2545 | 1.27 | |
| C3 10-20 | 0.209 | 0.2486 | 1.24 | |
| C3 10-20 | 0.21 | 0.2498 | 1.25 | 1.25 |
| | | | | |
| C3 20-30 | 0.151 | 0.1796 | 0.90 | |
| C3 20-30 | 0.145 | 0.1725 | 0.86 | |
| C3 20-30 | 0.144 | 0.1713 | 0.86 | 0.87 |
| | | | | |
| C14 0-10 | 0.32 | 0.3806 | 1.90 | |
| C14 0-10 | 0.312 | 0.3711 | 1.86 | |
| C14 0-10 | 0.316 | 0.3758 | 1.88 | 1.88 |
| | | | | |
| C14 10-20 | 0.16 | 0.1903 | 0.95 | |
| C14 10-20 | 0.178 | 0.2117 | 1.06 | |
| C14 10-20 | 0.174 | 0.2069 | 1.03 | 1.01 |
| | | | | |
| C14 20-30 | 0.095 | 0.113 | 0.56 | |
| C14 20-30 | 0.102 | 0.1213 | 0.61 | |
| C14 20-30 | 0.101 | 0.1201 | 0.60 | 0.59 |



Sample set no.5 - 15/04/2002

**Plot D = Tine Cultivator + Press + Drill ( straw incorporated)**

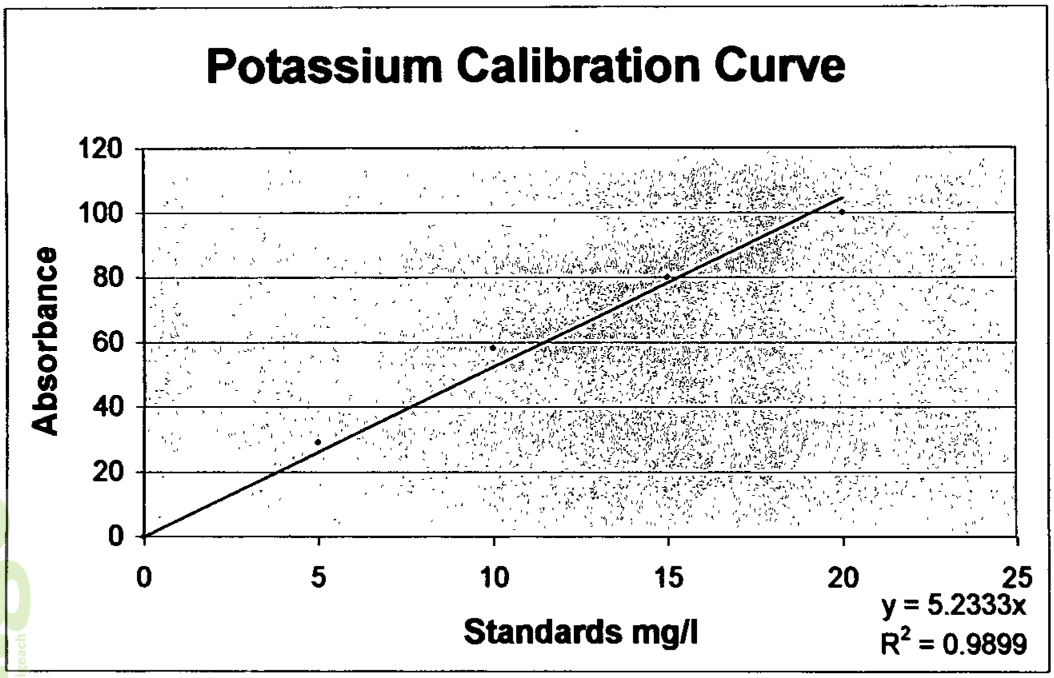
| ID | sample | mg/l | Dilu Factor | Ave mg/l |
|---|---|---|---|---|
| D1 0-10 | 0.264 | 0.314 | 1.57 | |
| D1 0-10 | 0.276 | 0.3283 | 1.64 | |
| D1 0-10 | 0.261 | 0.3104 | 1.55 | 1.59 |
| D1 10-20 | 0.209 | 0.2486 | 1.24 | |
| D1 10-20 | 0.181 | 0.2153 | 1.08 | |
| D1 10-20 | 0.21 | 0.2498 | 1.25 | 1.19 |
| D1 20-30 | 0.306 | 0.3639 | 1.82 | |
| D1 20-30 | 0.305 | 0.3627 | 1.81 | |
| D1 20-30 | 0.301 | 0.358 | 1.79 | 1.81 |
| D16 0-10 | 0.104 | 0.1237 | 0.62 | |
| D16 0-10 | 0.108 | 0.1284 | 0.64 | |
| D16 0-10 | 0.111 | 0.132 | 0.66 | 0.64 |
| D16 10-20 | 0.228 | 0.2712 | 1.36 | |
| D16 10-20 | 0.247 | 0.2938 | 1.47 | |
| D16 10-20 | 0.245 | 0.2914 | 1.46 | 1.43 |
| D16 20-30 | 0.159 | 0.1891 | 0.95 | |
| D16 20-30 | 0.156 | 0.1855 | 0.93 | |
| D16 20-30 | 0.155 | 0.1843 | 0.92 | 0.93 |



Sample set no.5 - 15/04/2002
By flame photometer

**MEASUREMENT OF EXCHANGABLE POTASSIUM**

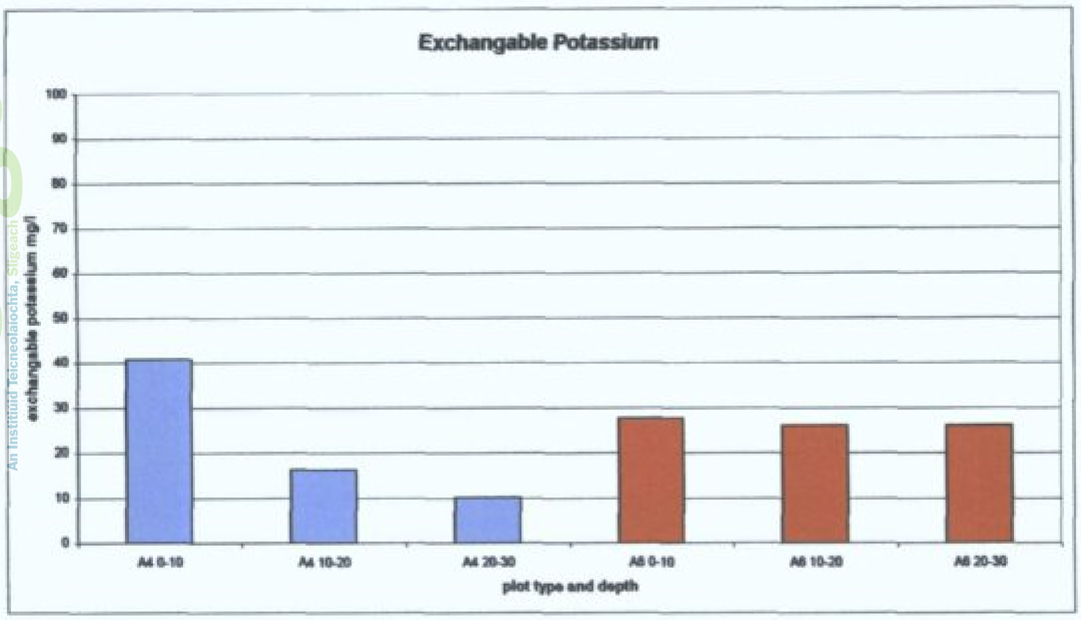
| standard mg/l | Absorbance |
|---|---|
| 0 | 0 |
| 5 | 29 |
| 10 | 58 |
| 15 | 80 |
| 20 | 100 |



Sample set no.5 - 15/04/2002

**Plot A = Plough + Harrow + Drill ( straw removed)**

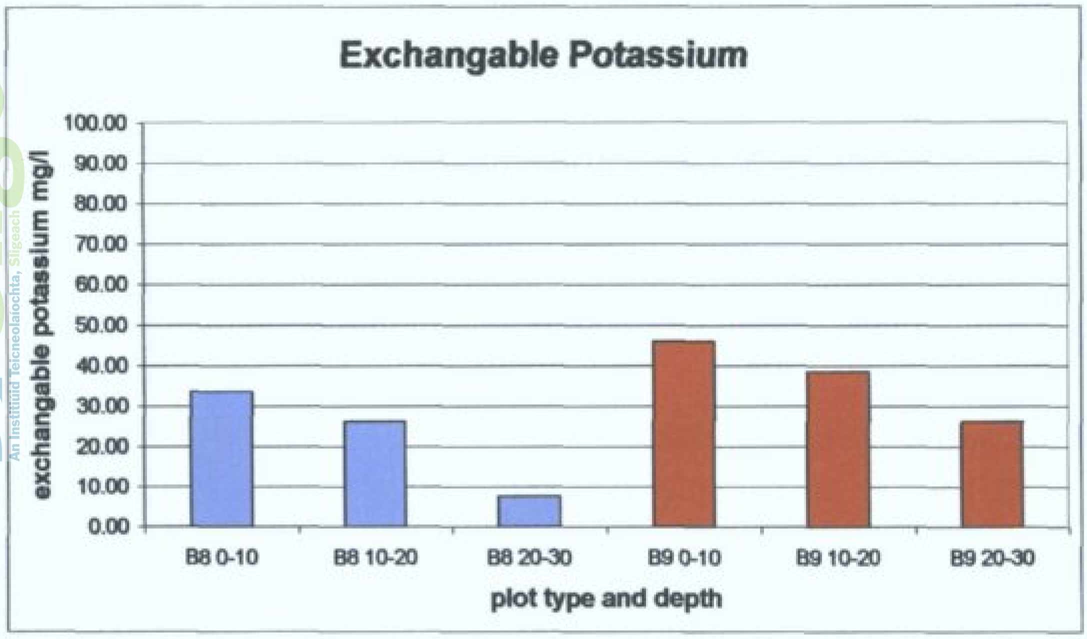
| Samples | Absorbance | mg/l (1/5) | Dilu Factor | Ave mg/l |
|---|---|---|---|---|
| A4 0-10 | 43 | 8.22 | 41.08 | |
| A4 0-10 | 43 | 8.22 | 41.08 | |
| A4 0-10 | 42 | 8.03 | 40.13 | 41 |
| | | | | |
| A4 10-20 | 17 | 3.25 | 16.24 | |
| A4 10-20 | 18 | 3.44 | 17.20 | |
| A4 10-20 | 16 | 3.06 | 15.29 | 16 |
| | | | | |
| A4 20-30 | 10 | 1.91 | 9.55 | |
| A4 20-30 | 11 | 2.10 | 10.51 | |
| A4 20-30 | 11 | 2.10 | 10.51 | 10 |
| | | | | |
| A6 0-10 | 30 | 5.73 | 28.66 | |
| A6 0-10 | 28 | 5.35 | 26.75 | |
| A6 0-10 | 29 | 5.54 | 27.71 | 28 |
| | | | | |
| A6 10-20 | 28 | 5.35 | 26.75 | |
| A6 10-20 | 28 | 5.35 | 26.75 | |
| A6 10-20 | 26 | 4.97 | 24.84 | 26 |
| | | | | |
| A6 20-30 | 8 | 1.53 | 7.64 | |
| A6 20-30 | 10 | 1.91 | 9.55 | |
| A6 20-30 | 6 | 1.15 | 5.73 | 26 |



Sample set no.5 - 15/04/2002

**Plot B = Plough + Harrow + Drill ( straw incorporated)**

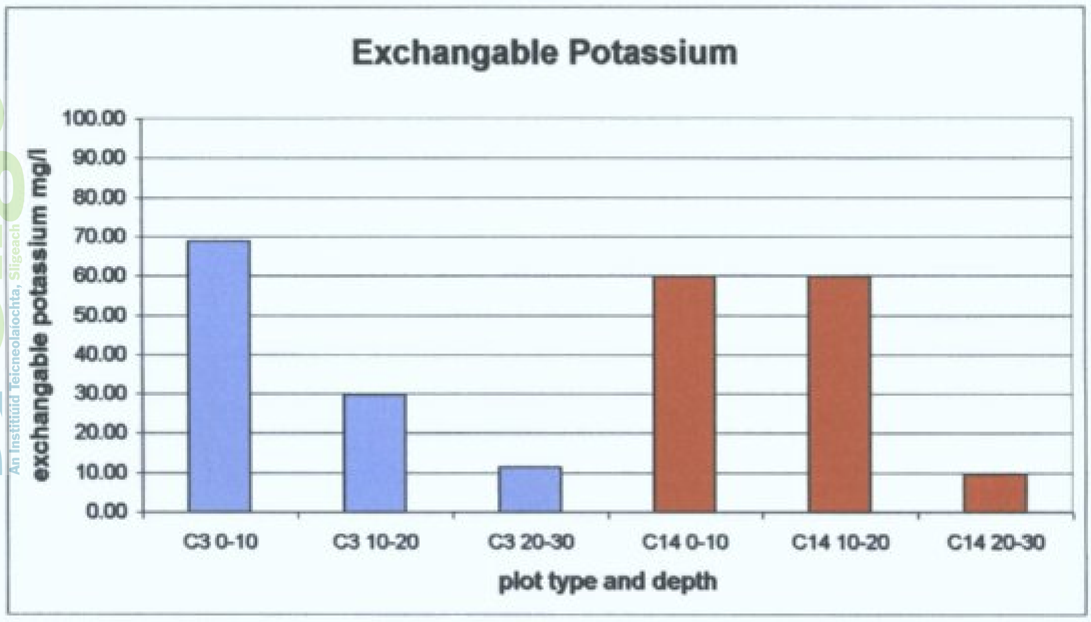
| ID | Absorbance | mg/l | Dilu Factor | Ave mg/l |
|---|---|---|---|---|
| B8 0-10 | 35 | 6.69 | 33.44 | |
| B8 0-10 | 33 | 6.31 | 31.53 | |
| B8 0-10 | 37 | 7.07 | 35.35 | 33.44 |
| | | | | |
| B8 10-20 | 28 | 5.35 | 26.75 | |
| B8 10-20 | 28 | 5.35 | 26.75 | |
| B8 10-20 | 26 | 4.97 | 24.84 | 26.11 |
| | | | | |
| B8 20-30 | 8 | 1.53 | 7.64 | |
| B8 20-30 | 10 | 1.91 | 9.55 | |
| B8 20-30 | 6 | 1.15 | 5.73 | 7.64 |
| | | | | |
| B9 0-10 | 45 | 8.60 | 42.99 | |
| B9 0-10 | 49 | 9.36 | 46.82 | |
| B9 0-10 | 50 | 9.55 | 47.77 | 45.86 |
| | | | | |
| B9 10-20 | 40 | 7.64 | 38.22 | |
| B9 10-20 | 40 | 7.64 | 38.22 | |
| B9 10-20 | 41 | 7.83 | 39.17 | 38.54 |
| | | | | |
| B9 20-30 | 27 | 5.16 | 25.80 | |
| B9 20-30 | 25 | 4.78 | 23.89 | |
| B9 20-30 | 30 | 5.73 | 28.66 | 26.11 |



Sample set no.5 - 15/04/2002

**Plot C = Tine Cultivator + Press + Drill (straw removed)**

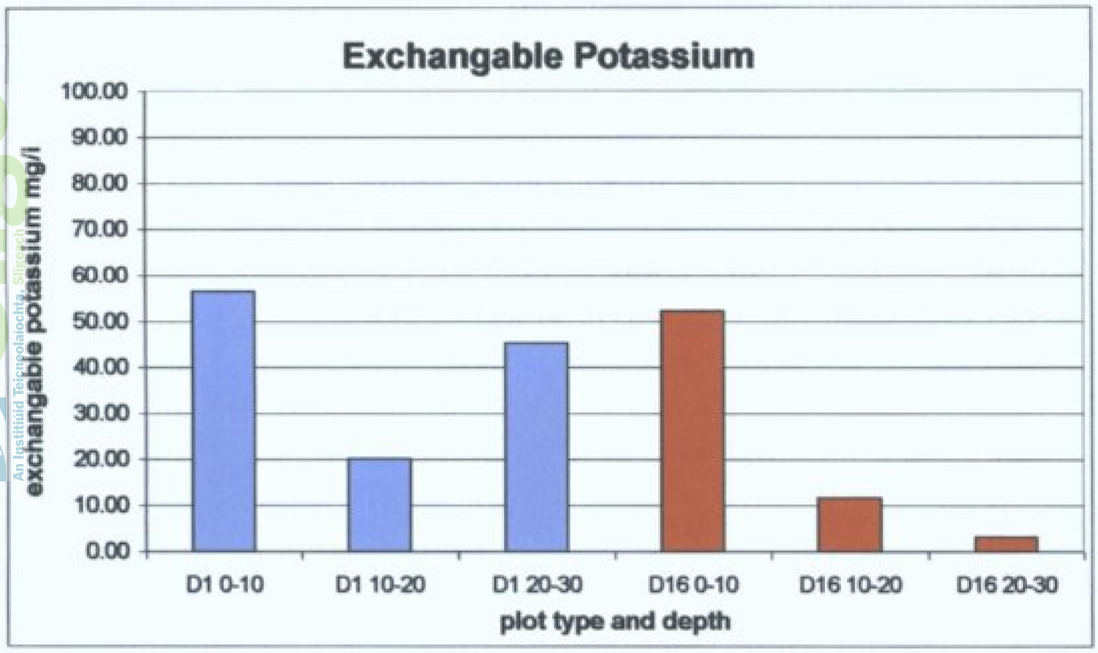
| ID | Absorbance | mg/l | Dilu Factor | Ave mg/l |
|---|---|---|---|---|
| C3 0-10 | 70 | 13.38 | 66.88 | |
| C3 0-10 | 75 | 14.33 | 71.66 | |
| C3 0-10 | 71 | 13.57 | 67.83 | 68.79 |
| C3 10-20 | 33 | 6.31 | 31.53 | |
| C3 10-20 | 29 | 5.54 | 27.71 | |
| C3 10-20 | 31 | 5.92 | 29.62 | 29.62 |
| C3 20-30 | 10 | 1.91 | 9.55 | |
| C3 20-30 | 11 | 2.10 | 10.51 | |
| C3 20-30 | 15 | 2.87 | 14.33 | 11.47 |
| C14 0-10 | 68 | 12.99 | 64.97 | |
| C14 0-10 | 60 | 11.47 | 57.33 | |
| C14 0-10 | 60 | 11.47 | 57.33 | 59.87 |
| C14 10-20 | 15 | 2.87 | 14.33 | |
| C14 10-20 | 14 | 2.68 | 13.38 | |
| C14 10-20 | 12 | 2.29 | 11.47 | 59.87 |
| C14 20-30 | 13 | 2.48 | 12.42 | |
| C14 20-30 | 9 | 1.72 | 8.60 | |
| C14 20-30 | 8 | 1.53 | 7.64 | 9.55 |



Sample set no.5 - 15/04/2002

**Plot D = Tine Cultivator + Press + Drill ( straw incorporated)**

| ID | Absorbance | mg/l | Dilu Factor | Ave mg/l |
|---|---|---|---|---|
| D1 0-10 | 55 | 10.51 | 52.55 | |
| D1 0-10 | 60 | 11.47 | 57.33 | |
| D1 0-10 | 62 | 11.85 | 59.24 | 56.37 |
| | | | | |
| D1 10-20 | 25 | 4.78 | 23.89 | |
| D1 10-20 | 20 | 3.82 | 19.11 | |
| D1 10-20 | 18 | 3.44 | 17.20 | 20.06 |
| | | | | |
| D1 20-30 | 46 | 8.79 | 43.95 | |
| D1 20-30 | 47 | 8.98 | 44.90 | |
| D1 20-30 | 49 | 9.36 | 46.82 | 45.22 |
| | | | | |
| D16 0-10 | 55 | 10.51 | 52.55 | |
| D16 0-10 | 55 | 10.51 | 52.55 | |
| D16 0-10 | 54 | 10.32 | 51.59 | 52.23 |
| | | | | |
| D16 10-20 | 12 | 2.29 | 11.47 | |
| D16 10-20 | 14 | 2.68 | 13.38 | |
| D16 10-20 | 11 | 2.10 | 10.51 | 11.78 |
| | | | | |
| D16 20-30 | 3 | 0.57 | 2.87 | |
| D16 20-30 | 3 | 0.57 | 2.87 | |
| D16 20-30 | 4 | 0.76 | 3.82 | 3.18 |



**Organic Carbon Content**

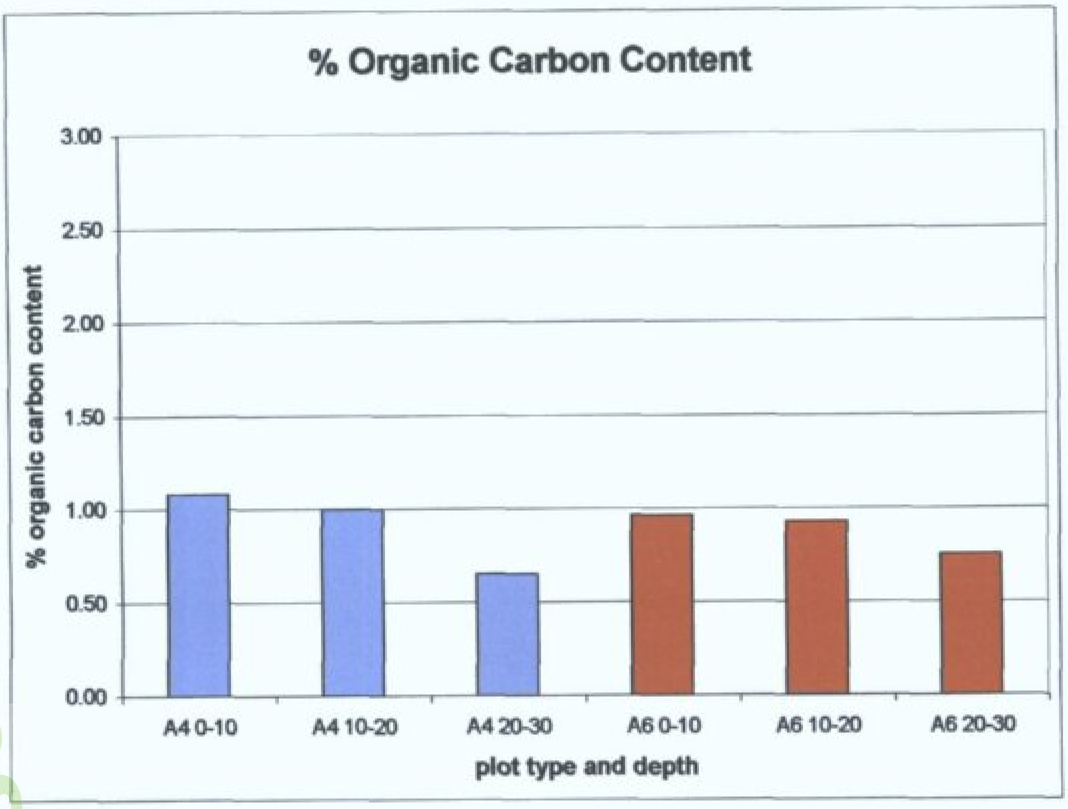
Sample set no. 5- 15/04/02

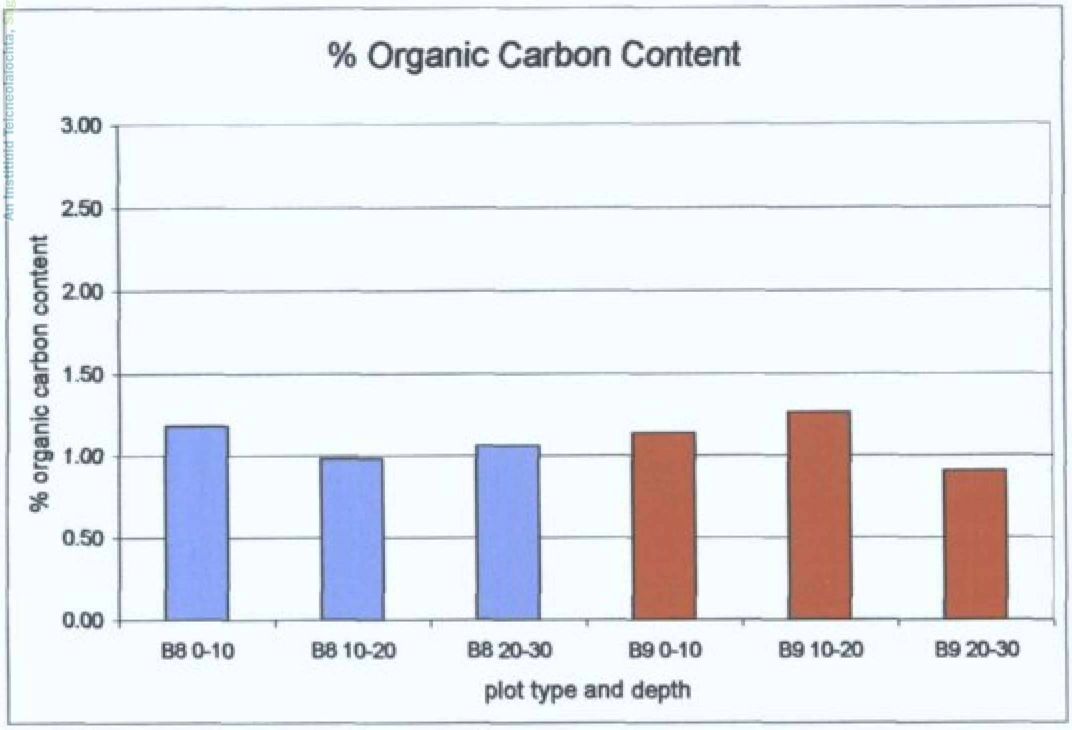
| Sample I.D | Titer vol | | | | | Sample weight | %org carbon | Ave % org Carb |
|---|---|---|---|---|---|---|---|---|
| A4 0-10 | 47.1 | 9.4 | 1.1 | 0 | 0.324 | 0.2987 | 1.08 | |
| A4 0-10 | 47.2 | 9.4 | 1.1 | 0 | 0.318 | 0.2936 | 1.08 | |
| A4 0-10 | 47.2 | 9.4 | 1.1 | 0 | 0.318 | 0.2951 | 1.08 | 1.08 |
| A4 10-20 | 48.3 | 9.7 | 0.8 | 0 | 0.252 | 0.2955 | 0.85 | |
| A4 10-20 | 47 | 9.4 | 1.1 | 0 | 0.33 | 0.2964 | 1.11 | |
| A4 10-20 | 47.4 | 9.5 | 1 | 0 | 0.306 | 0.2997 | 1.02 | 1.00 |
| A4 20-30 | 49.3 | 9.9 | 0.6 | 0 | 0.192 | 0.2969 | 0.65 | |
| A4 20-30 | 49.4 | 9.9 | 0.6 | 0 | 0.186 | 0.2958 | 0.63 | |
| A4 20-30 | 49.2 | 9.8 | 0.7 | 0 | 0.198 | 0.2938 | 0.67 | 0.65 |
| A6 0-10 | 48.7 | 9.7 | 0.8 | 0 | 0.228 | 0.2984 | 0.76 | |
| A6 0-10 | 47.4 | 9.5 | 1 | 0 | 0.306 | 0.2961 | 1.03 | |
| A6 0-10 | 47.3 | 9.5 | 1 | 0 | 0.312 | 0.2871 | 1.09 | 0.96 |
| A6 10-20 | 47.6 | 9.5 | 1 | 0 | 0.294 | 0.2933 | 1.00 | |
| A6 10-20 | 48.3 | 9.7 | 0.8 | 0 | 0.252 | 0.2915 | 0.86 | |
| A6 10-20 | 48 | 9.6 | 0.9 | 0 | 0.27 | 0.2948 | 0.92 | 0.93 |
| A6 20-30 | 49.3 | 9.9 | 0.6 | 0 | 0.192 | 0.2946 | 0.65 | |
| A6 20-30 | 48.8 | 9.8 | 0.7 | 0 | 0.222 | 0.2918 | 0.76 | |
| A6 20-30 | 48.3 | 9.7 | 0.8 | 0 | 0.252 | 0.2987 | 0.84 | 0.75 |
| B8 0-10 | 46.3 | 9.3 | 1.2 | 0 | 0.372 | 0.2963 | 1.26 | |
| B8 0-10 | 47 | 9.4 | 1.1 | 0 | 0.33 | 0.2856 | 1.16 | |
| B8 0-10 | 46.9 | 9.4 | 1.1 | 0 | 0.336 | 0.2984 | 1.13 | 1.18 |
| B8 10-20 | 48.4 | 9.7 | 0.8 | 0 | 0.246 | 0.2936 | 0.84 | |
| B8 10-20 | 47.2 | 9.4 | 1.1 | 0 | 0.318 | 0.2945 | 1.08 | |
| B8 10-20 | 47.5 | 9.5 | 1 | 0 | 0.3 | 0.2918 | 1.03 | 0.98 |
| B8 20-30 | 47.3 | 9.5 | 1 | 0 | 0.312 | 0.2958 | 1.05 | |
| B8 20-30 | 47.3 | 9.5 | 1 | 0 | 0.312 | 0.2971 | 1.05 | |
| B8 20-30 | 47.2 | 9.4 | 1.1 | 0 | 0.318 | 0.2966 | 1.07 | 1.06 |
| B9 0-10 | 47.1 | 9.4 | 1.1 | 0 | 0.324 | 0.2948 | 1.10 | |
| B9 0-10 | 46.7 | 9.3 | 1.2 | 0 | 0.348 | 0.293 | 1.19 | |
| B9 0-10 | 46.9 | 9.4 | 1.1 | 0 | 0.336 | 0.2987 | 1.12 | 1.14 |
| B9 10-20 | 46.9 | 9.4 | 1.1 | 0 | 0.336 | 0.2955 | 1.14 | |
| B9 10-20 | 45.8 | 9.2 | 1.3 | 0 | 0.402 | 0.2968 | 1.35 | |
| B9 10-20 | 46 | 9.2 | 1.3 | 0 | 0.39 | 0.2975 | 1.31 | 1.27 |
| B9 20-30 | 47.8 | 9.6 | 0.9 | 0 | 0.282 | 0.2984 | 0.95 | |
| B9 20-30 | 48.2 | 9.6 | 0.9 | 0 | 0.258 | 0.2939 | 0.88 | |
| B9 20-30 | 48 | 9.6 | 0.9 | 0 | 0.27 | 0.3001 | 0.90 | 0.91 |
| C3 0-10 | 45.3 | 9.1 | 1.4 | 0 | 0.432 | 0.2955 | 1.46 | |
| C3 0-10 | 46.2 | 9.2 | 1.3 | 0 | 0.378 | 0.2989 | 1.26 | |
| C3 0-10 | 45.4 | 9.1 | 1.4 | 0 | 0.426 | 0.2977 | 1.43 | 1.39 |
| C3 10-20 | 46.3 | 9.3 | 1.2 | 0 | 0.372 | 0.2966 | 1.25 | |
| C3 10-20 | 46 | 9.2 | 1.3 | 0 | 0.39 | 0.2899 | 1.35 | |
| C3 10-20 | 45.9 | 9.2 | 1.3 | 0 | 0.396 | 0.2941 | 1.35 | 1.32 |

Sample set no. 5- 15/04/02

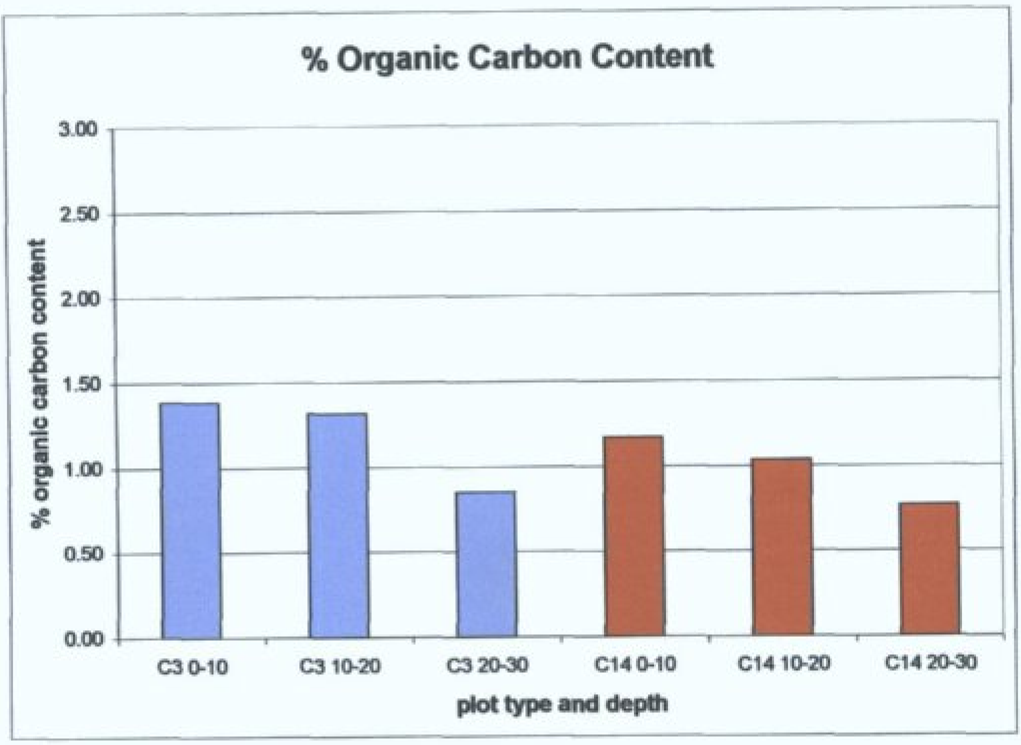
| Sample I.D | Titer vol | | | | | Sample weight | %org carbon | Ave % org Carb |
|---|---|---|---|---|---|---|---|---|
| C3 20-30 | 48.2 | 9.6 | 0.9 | 0 | 0.258 | 0.2993 | 0.86 | |
| C3 20-30 | 48.6 | 9.7 | 0.8 | 0 | 0.234 | 0.2846 | 0.82 | |
| C3 20-30 | 48.2 | 9.6 | 0.9 | 0 | 0.258 | 0.2987 | 0.86 | 0.85 |
| | | | | | | | | |
| C14 0-10 | 46 | 9.2 | 1.3 | 0 | 0.39 | 0.2911 | 1.34 | |
| C14 0-10 | 47.4 | 9.5 | 1 | 0 | 0.306 | 0.2941 | 1.04 | |
| C14 0-10 | 47.1 | 9.4 | 1.1 | 0 | 0.324 | 0.2879 | 1.13 | 1.17 |
| | | | | | | | | |
| C14 10-20 | 47.6 | 9.5 | 1 | 0 | 0.294 | 0.2979 | 0.99 | |
| C14 10-20 | 47.4 | 9.5 | 1 | 0 | 0.306 | 0.2846 | 1.08 | |
| C14 10-20 | 47.4 | 9.5 | 1 | 0 | 0.306 | 0.2936 | 1.04 | 1.03 |
| | | | | | | | | |
| C14 20-30 | 49.2 | 9.8 | 0.7 | 0 | 0.198 | 0.2925 | 0.68 | |
| C14 20-30 | 48.3 | 9.7 | 0.8 | 0 | 0.252 | 0.2987 | 0.84 | |
| C14 20-30 | 48.7 | 9.7 | 0.8 | 0 | 0.228 | 0.2951 | 0.77 | 0.76 |
| | | | | | | | | |
| D1 0-10 | 45.7 | 9.1 | 1.4 | 0 | 0.408 | 0.292 | 1.40 | |
| D1 0-10 | 46.5 | 9.3 | 1.2 | 0 | 0.36 | 0.2915 | 1.23 | |
| D1 0-10 | 46 | 9.2 | 1.3 | 0 | 0.39 | 0.2984 | 1.31 | 1.31 |
| | | | | | | | | |
| D1 10-20 | 46.7 | 9.3 | 1.2 | 0 | 0.348 | 0.2896 | 1.20 | |
| D1 10-20 | 47.1 | 9.4 | 1.1 | 0 | 0.324 | 0.2931 | 1.11 | |
| D1 10-20 | 47 | 9.4 | 1.1 | 0 | 0.33 | 0.2964 | 1.11 | 1.14 |
| | | | | | | | | |
| D1 20-30 | 45.7 | 9.1 | 1.4 | 0 | 0.408 | 0.2978 | 1.37 | |
| D1 20-30 | 47.8 | 9.6 | 0.9 | 0 | 0.282 | 0.2999 | 0.94 | |
| D1 20-30 | 45.4 | 9.1 | 1.4 | 0 | 0.426 | 0.2981 | 1.43 | 1.25 |
| | | | | | | | | |
| D16 0-10 | 48.4 | 9.7 | 0.8 | 0 | 0.246 | 0.2969 | 0.83 | |
| D16 0-10 | 48.6 | 9.7 | 0.8 | 0 | 0.234 | 0.2974 | 0.79 | |
| D16 0-10 | 48.7 | 9.7 | 0.8 | 0 | 0.228 | 0.2983 | 0.76 | 0.79 |
| | | | | | | | | |
| D16 10-20 | 47.6 | 9.5 | 1 | 0 | 0.294 | 0.2879 | 1.02 | |
| D16 10-20 | 45.9 | 9.2 | 1.3 | 0 | 0.396 | 0.2916 | 1.36 | |
| D16 10-20 | 46.1 | 9.2 | 1.3 | 0 | 0.384 | 0.2944 | 1.30 | 1.23 |
| | | | | | | | | |
| D16 20-30 | 49.2 | 9.8 | 0.7 | 0 | 0.198 | 0.2965 | 0.67 | |
| D16 20-30 | 48.1 | 9.6 | 0.9 | 0 | 0.264 | 0.3002 | 0.88 | |
| D16 20-30 | 48.6 | 9.7 | 0.8 | 0 | 0.234 | 0.2989 | 0.78 | 1.08 |

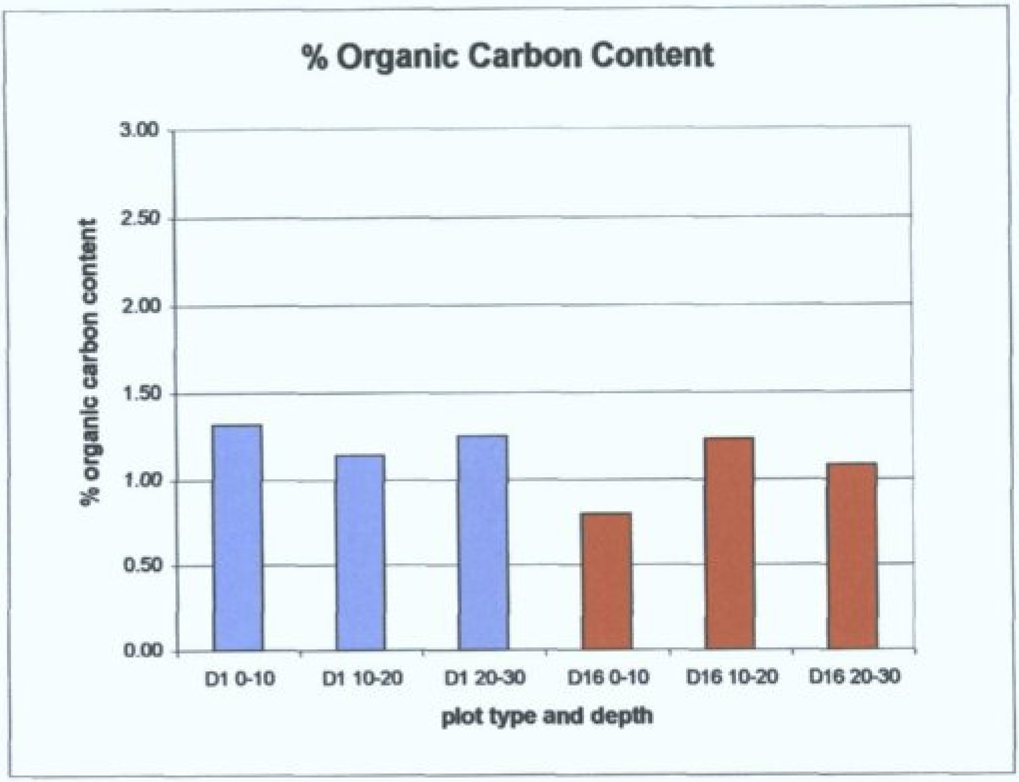
Sample set no. 5- 15/04/02





Sample set no. 5- 15/04/02





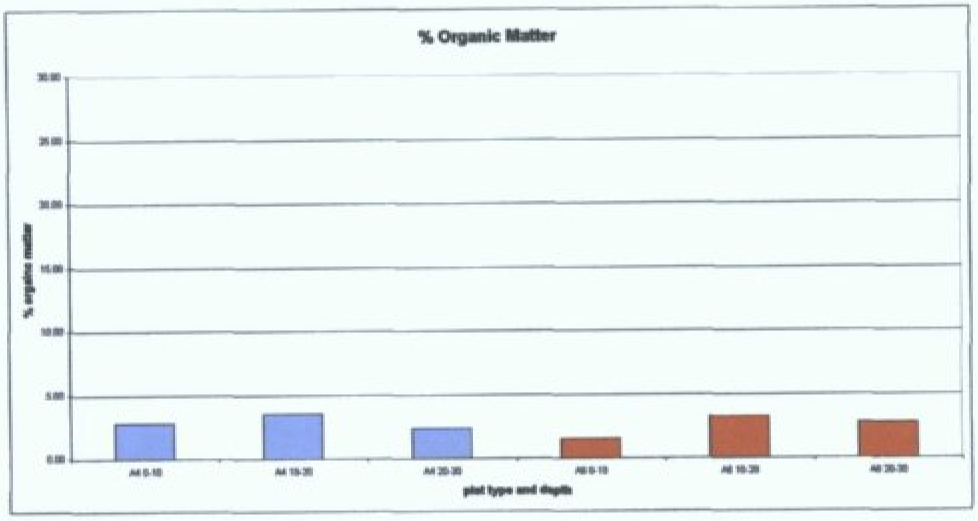
## ORGANIC MATTER ANALYSIS

Sample set no 5 - 15/04/2002

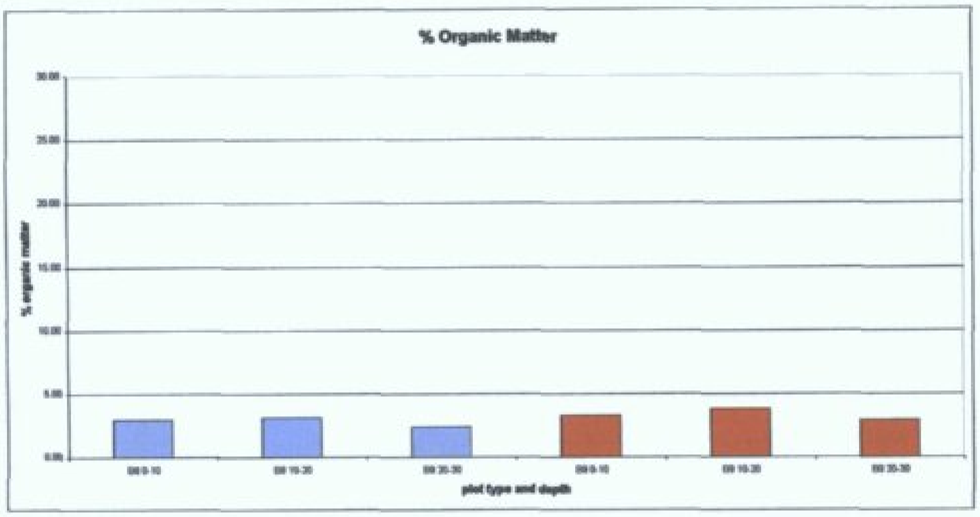
| Samp I.D. | crucible I.D. | Cru & Samp | C&S after fur | After furnace | Orig wt samp B | A-B/orig wt | (*100)%Organic Matter |
|---|---|---|---|---|---|---|---|
| A4 0-10 | 604 | 42.35 | 42 071 | 0.279 | 9.9364 | 0.02807858 | 2.81 |
| A4 10-20 | 31 | 39.9168 | 39.5615 | 0.3553 | 10.0988 | 0.035182398 | 3.52 |
| A4 20-30 | 66 | 37.9601 | 37.7117 | 0.2484 | 10.4327 | 0.023809752 | 2.38 |
| A6 0-10 | 54 | 40.777 | 40.6024 | 0.1746 | 11.4135 | 0.015297674 | 1 53 |
| A6 10-20 | 741 | 34.529 | 34.1926 | 0 3364 | 10.3613 | 0.032466968 | 3 25 |
| A6 20-30 | 18 | 44.6601 | 44.2788 | 0.3813 | 13.792 | 0.027646462 | 2.76 |
| B8 0-10 | 30 | 35 9186 | 35 5932 | 0.3254 | 10.9549 | 0.029703603 | 2.97 |
| B8 10-20 | 3 | 44.2679 | 43.8975 | 0.3704 | 11.7763 | 0.031453003 | 3.15 |
| B8 20-30 | 71 | 45.8337 | 45.5583 | 0 2754 | 11.3449 | 0.024275225 | 2.43 |
| B9 0-10 | 83 | 50 4582 | 50.1327 | 0.3255 | 9.9302 | 0 032778796 | 3.28 |
| B9 10-20 | f13 | 46.1442 | 45.7138 | 0.4304 | 11.318 | 0.03802792 | 3.80 |
| B9 20-30 | 23 | 34 3644 | 34.069 | 0.2954 | 10 0642 | 0 029351563 | 2.94 |
| C3 0-10 | 102 | 37.7636 | 37.2688 | 0 4948 | 12.598 | 0.039276076 | 3.93 |
| C3 10-20 | f1 | 38.7365 | 38.3156 | 0.4209 | 11.1808 | 0.037644891 | 3.76 |
| C3 20-30 | 80 | 36.4973 | 36.0759 | 0.4214 | 13.1965 | 0.031932709 | 3.19 |
| C14 0-10 | 2 | 45.316 | 44.8689 | 0.4471 | 12.7865 | 0.034966566 | 3.50 |
| C14 10-20 | 99 | 46.7956 | 46.3699 | 0.4257 | 14.6729 | 0.02901267 | 2.90 |
| C14 20-30 | 49 | 42.4938 | 42.2519 | 0.2419 | 10.6473 | 0.022719375 | 2.27 |
| D1 0-10 | 6 | 44.1629 | 43.7963 | 0.3666 | 10.3585 | 0.035391225 | 3.54 |
| D1 10-20 | 141 | 44 8302 | 44 4124 | 0.4178 | 12.2992 | 0 033969689 | 3 40 |
| D1 20-30 | 504 | 49 3962 | 49 0054 | 0.3908 | 13.9572 | 0 027999885 | 2.80 |
| D16 0-10 | 35 | 46.5886 | 46.1967 | 0.3919 | 11.4294 | 0.034288764 | 3.43 |
| D16 10-20 | 13 | 32.7154 | 32.3408 | 0.3746 | 10.1434 | 0.036930418 | 3.69 |
| D16 20-30 | 11 | 41.3295 | 41.051 | 0.2785 | 10 6851 | 0.026064333 | 2.61 |

Sample set no 5- 15/04/2002

Plot A = Plough + Harrow + Drill ( straw removed)

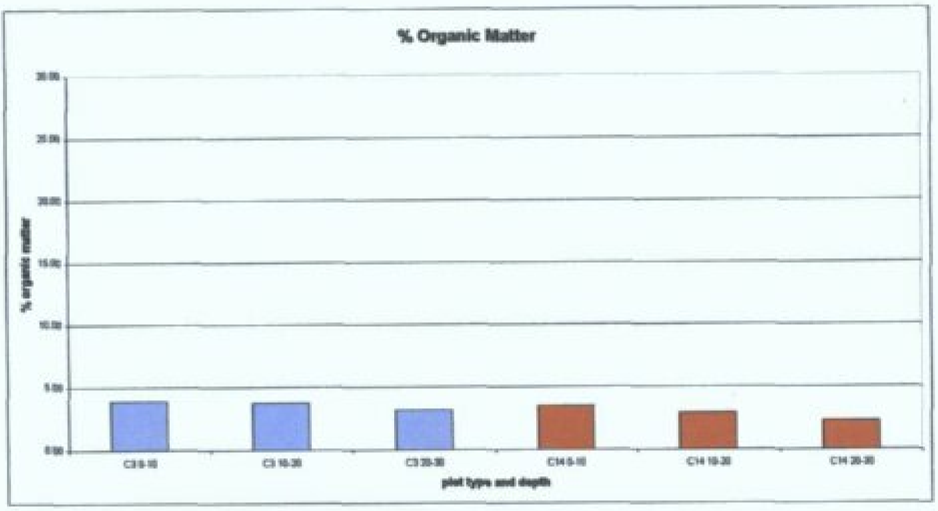


Plot B = Plough + Harrow + Drill ( straw incorporated)

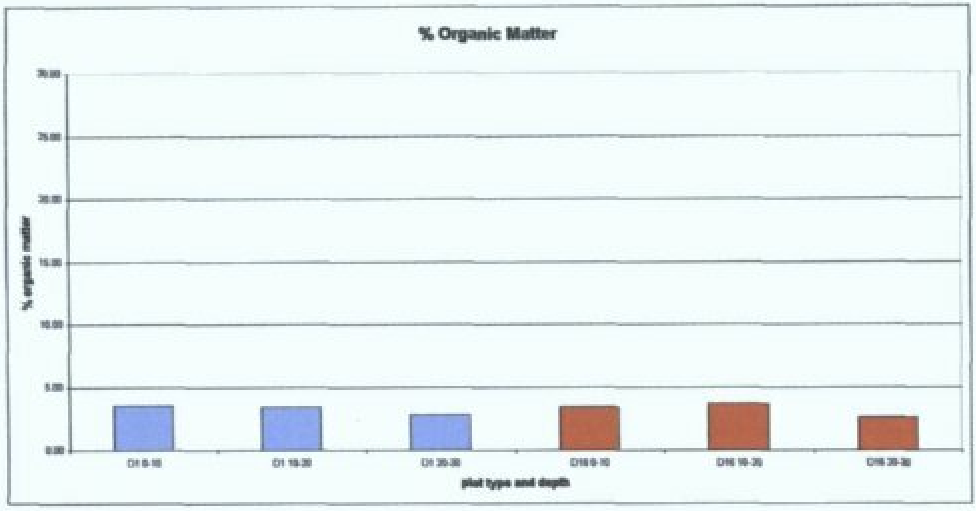


Sample set no.5 - 15/04/2002

Plot C = Tine Cultivator + Press + Drill (straw removed)



Plot D = Tine Cultivator + Press + Drill ( straw incorporated)

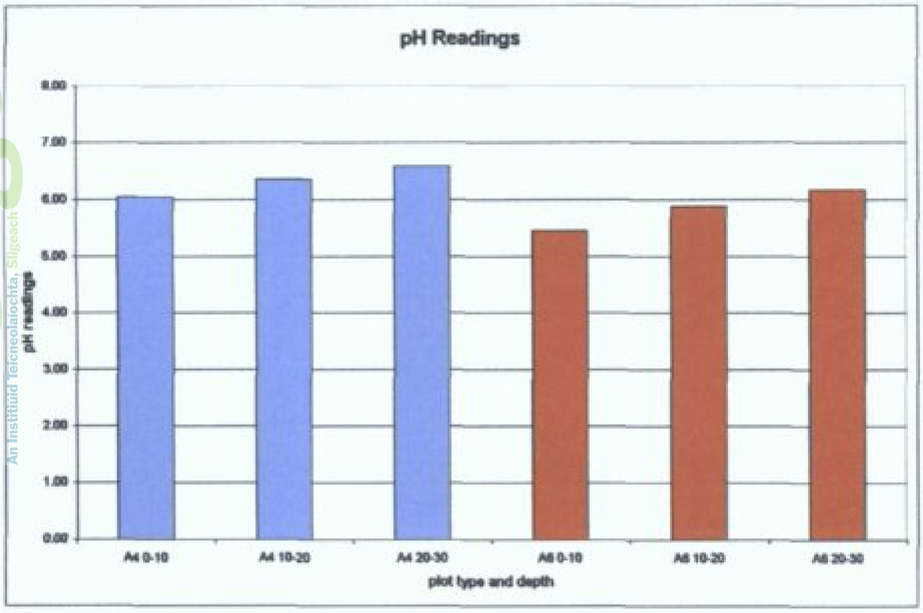


## p H Analysis

Sample set no.5 - 15/04/2002

**Plot A = Plough + Harrow + Drill ( straw removed)**

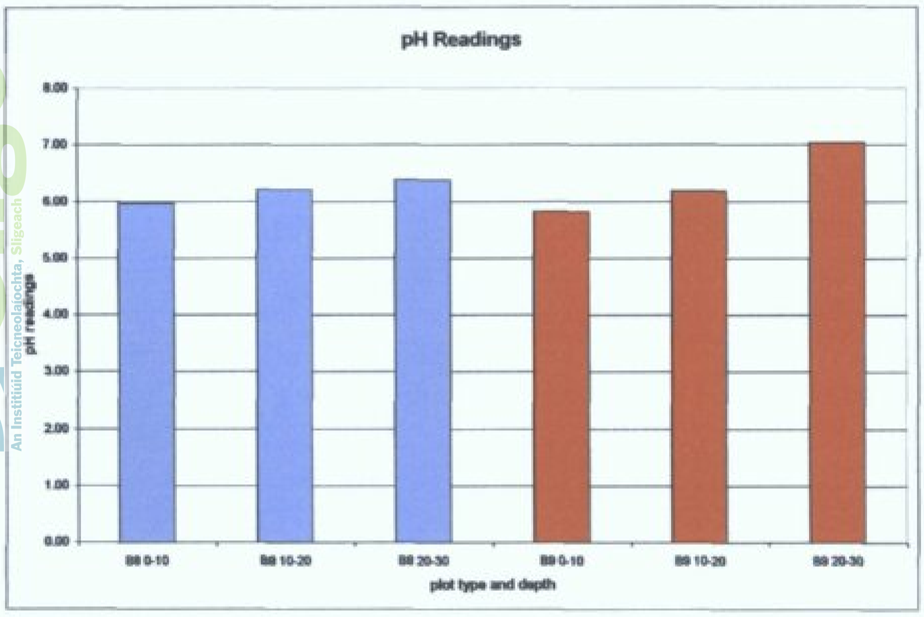
| Sample I.D. | pH readings | Ave pH |
|---|---|---|
| A4 0-10 | 6.2 | |
| A4 0-10 | 5.92 | |
| A4 0-10 | 6.01 | 6.04 |
| A4 10-20 | 6.47 | |
| A4 10-20 | 6.29 | |
| A4 10-20 | 6.31 | 6.36 |
| A4 20-30 | 6.62 | |
| A4 20-30 | 6.56 | |
| A4 20-30 | 6.59 | 6.59 |
| A6 0-10 | 5.49 | |
| A6 0-10 | 5.49 | |
| A6 0-10 | 5.41 | 5.46 |
| A6 10-20 | 5.87 | |
| A6 10-20 | 5.89 | |
| A6 10-20 | 5.89 | 5.88 |
| A6 20-30 | 6.15 | |
| A6 20-30 | 6.19 | |
| A6 20-30 | 6.17 | 6.17 |



Sample set no.5 -15/04/2002

**Plot B = Plough + Harrow + Drill ( straw incorporated)**

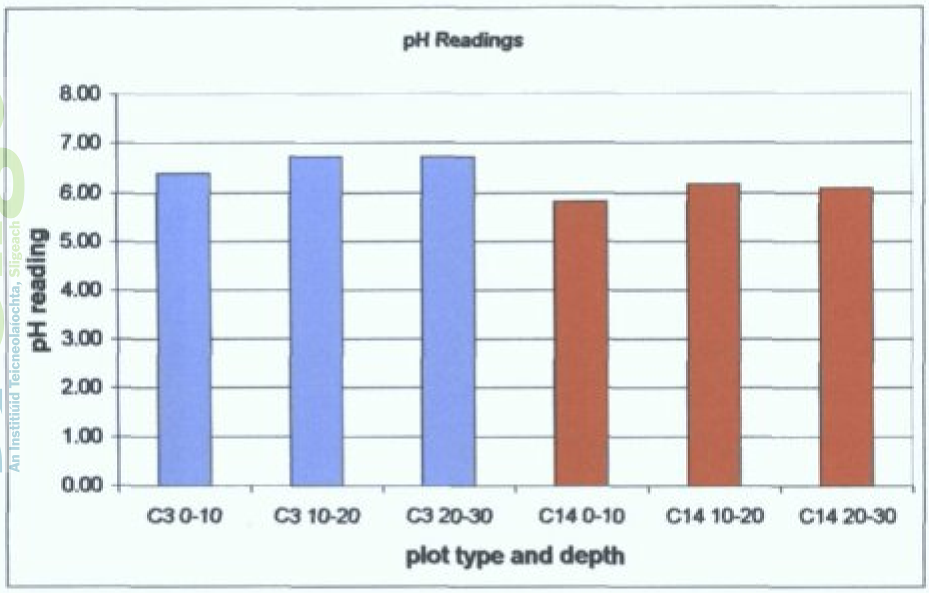
| Sample I.D. | pH readings | Ave pH |
|---|---|---|
| B8 0-10 | 6.02 | |
| B8 0-10 | 5.92 | |
| B8 0-10 | 5.96 | 5.97 |
| | | |
| B8 10-20 | 6.32 | |
| B8 10-20 | 6.13 | |
| B8 10-20 | 6.2 | 6.22 |
| | | |
| B8 20-30 | 6.33 | |
| B8 20-30 | 6.42 | |
| B8 20-30 | 6.4 | 6.38 |
| | | |
| B9 0-10 | 5.8 | |
| B9 0-10 | 5.85 | |
| B9 0-10 | 5.82 | 5.82 |
| | | |
| B9 10-20 | 6.21 | |
| B9 10-20 | 6.17 | |
| B9 10-20 | 6.2 | 6.19 |
| | | |
| B9 20-30 | 6.97 | |
| B9 20-30 | 7.08 | |
| B9 20-30 | 7.05 | 7.03 |



Sample set no.5 - 15/04/2002

**Plot C = Tine Cultivator + Press + Drill (straw removed)**

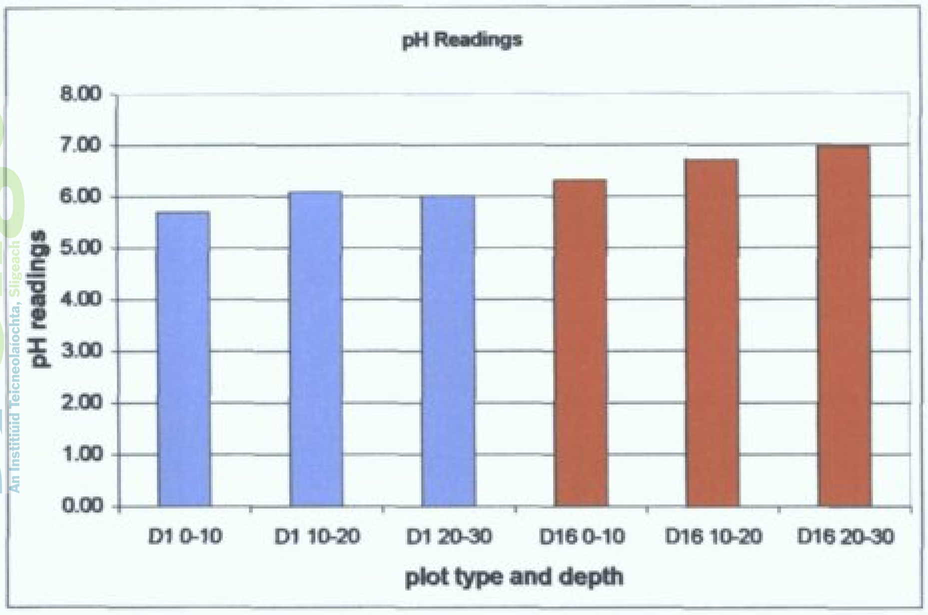
| Sample I.D. | pH readings | Ave pH |
|---|---|---|
| C3 0-10 | 6.36 | |
| C3 0-10 | 6.41 | |
| C3 0-10 | 6.4 | 6.39 |
| | | |
| C3 10-20 | 6.63 | |
| C3 10-20 | 6.81 | |
| C3 10-20 | 6.73 | 6.72 |
| | | |
| C3 20-30 | 6.71 | |
| C3 20-30 | 6.74 | |
| C3 20-30 | 6.74 | 6.73 |
| | | |
| C14 0-10 | 5.89 | |
| C14 0-10 | 5.78 | |
| C14 0-10 | 5.81 | 5.83 |
| | | |
| C14 10-20 | 6.07 | |
| C14 10-20 | 6.25 | |
| C14 10-20 | 6.21 | 6.18 |
| | | |
| C14 20-30 | 6.1 | |
| C14 20-30 | 6.1 | |
| C14 20-30 | 6.1 | 6.10 |



Sample set no.5 - 15/04/2002

**Plot D = Tine Cultivator + Press + Drill ( straw incorporated)**

| Sample I.D. | pH readings | Ave pH |
|---|---|---|
| D1 0-10 | 5.59 | |
| D1 0-10 | 5.8 | |
| D1 0-10 | 5.71 | 5.70 |
| D1 10-20 | 6.07 | |
| D1 10-20 | 6.11 | |
| D1 10-20 | 6.1 | 6.09 |
| D1 20-30 | 5.96 | |
| D1 20-30 | 6.07 | |
| D1 20-30 | 6.02 | 6.02 |
| D16 0-10 | 6.36 | |
| D16 0-10 | 6.26 | |
| D16 0-10 | 6.32 | 6.31 |
| D16 10-20 | 6.69 | |
| D16 10-20 | 6.74 | |
| D16 10-20 | 6.69 | 6.71 |
| D16 20-30 | 7.02 | |
| D16 20-30 | 6.95 | |
| D16 20-30 | 6.93 | 6.97 |

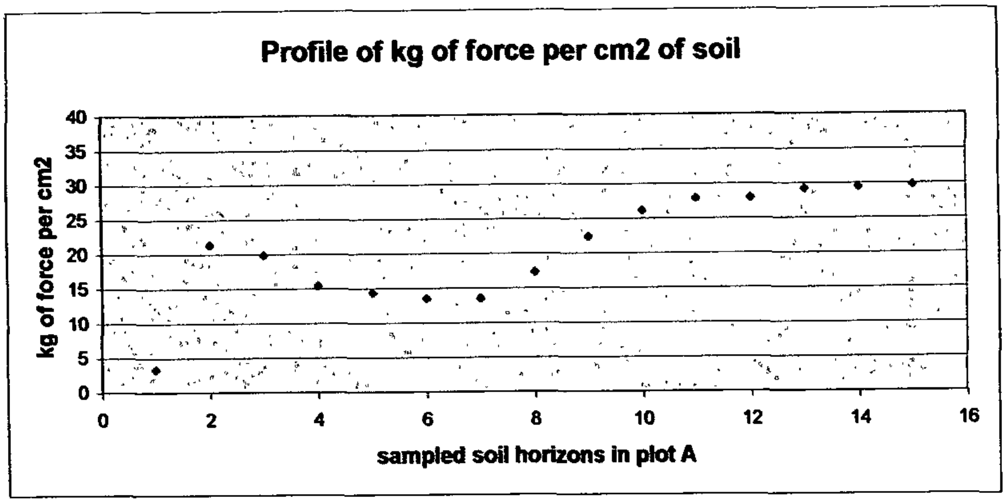


## Average Results from the 4 plots

Grassland Compaction experiment

Date 15/04/02
Site Knockbeg Road
Plot number All 4 A Plots
Treatment Plough + power *harrow* + drill + straw removed

| Depth Level | Mean A4 . A | Mean A4 . B | Mean A6 . A | Mean A6 . B | Mean A11 . A | Mean A11 . B | Mean A13 . A | Mean A13 . B | Mean set results for plot A | Kg Force Cm2 |
|---|---|---|---|---|---|---|---|---|---|---|
| **1** | 5 | 3 | 3 | 3 | 5 | 5 | 5 | 5 | **4** | **3** |
| **2** | 25 | 21 | 24 | 30 | 32 | 34 | 24 | 31 | **28** | **21** |
| **3** | 24 | 21 | 29 | 26 | 25 | 31 | 23 | 26 | **26** | **20** |
| **4** | 19 | 16 | 24 | 21 | 20 | 20 | 20 | 19 | **20** | **15** |
| **5** | 19 | 18 | 18 | 14 | 18 | 18 | 26 | 18 | **19** | **14** |
| **6** | 17 | 16 | 18 | 13 | 15 | 20 | 22 | 19 | **18** | **14** |
| **7** | 15 | 16 | 21 | 12 | 15 | 22 | 22 | 17 | **18** | **14** |
| **8** | 13 | 22 | 19 | 16 | 24 | 31 | 28 | 26 | **22** | **17** |
| **9** | 22 | 34 | 24 | 23 | 26 | 40 | 31 | 32 | **29** | **22** |
| **10** | 30 | 37 | 33 | 30 | 26 | 38 | 41 | 36 | **34** | **26** |
| **11** | 37 | 34 | 41 | 34 | 29 | 37 | 40 | 36 | **36** | **28** |
| **12** | 36 | 33 | 42 | 34 | 32 | 35 | 42 | 35 | **36** | **28** |
| **13** | 40 | 32 | 43 | 33 | 39 | 33 | 42 | 40 | **38** | **29** |
| **14** | 40 | 31 | 43 | 32 | 43 | 35 | 40 | 41 | **38** | **29** |
| **15** | 39 | 26 | 38 | 32 | 53 | 38 | 40 | 42 | **39** | **30** |

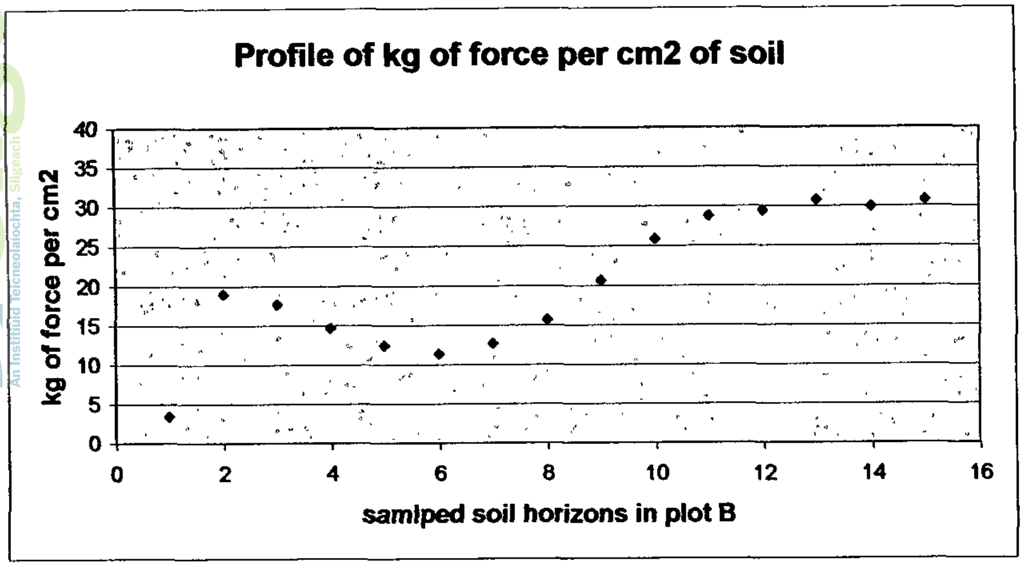


## Average Results from the 4 plots

Grassland Compaction experiment

Date 15/04/02
Site Knockbeg Road
Plot number All 4 B Plots
Treatment Plough + power harrow + drill + straw incorporated

| Depth Level | Mean B2. A | Mean B2. B | Mean B8. A | Mean B8. B | Mean B9. A | Mean B9. B | Mean B15. A | Mean B15. B | Mean set results for plot B | Kg Force Cm2 |
|---|---|---|---|---|---|---|---|---|---|---|
| **1** | 2 | 4 | 2 | 8 | 8 | 3 | 5 | 3 | **4** | **3** |
| **2** | 20 | 28 | 25 | 28 | 27 | 18 | 24 | 26 | **25** | **19** |
| **3** | 19 | 25 | 24 | 24 | 23 | 20 | 23 | 25 | **23** | **18** |
| **4** | 16 | 19 | 18 | 18 | 20 | 21 | 19 | 21 | **19** | **15** |
| **5** | 17 | 13 | 15 | 16 | 16 | 20 | 15 | 16 | **16** | **12** |
| **6** | 15 | 12 | 17 | 16 | 13 | 15 | 13 | 16 | **15** | **11** |
| **7** | 16 | 15 | 18 | 16 | 17 | 15 | 18 | 16 | **16** | **13** |
| **8** | 29 | 18 | 22 | 16 | 19 | 19 | 22 | 17 | **20** | **16** |
| **9** | 31 | 24 | 31 | 30 | 23 | 25 | 29 | 21 | **27** | **21** |
| **10** | 36 | 33 | 39 | 32 | 29 | 33 | 36 | 30 | **34** | **26** |
| **11** | 38 | 41 | 42 | 37 | 39 | 38 | 33 | 30 | **37** | **29** |
| **12** | 36 | 38 | 44 | 39 | 42 | 41 | 37 | 28 | **38** | **29** |
| **13** | 37 | 35 | 44 | 43 | 44 | 48 | 36 | 32 | **40** | **31** |
| **14** | 35 | 30 | 41 | 47 | 44 | 50 | 34 | 29 | **39** | **30** |
| **15** | 35 | 28 | 42 | 49 | 44 | 52 | 36 | 33 | **40** | **31** |

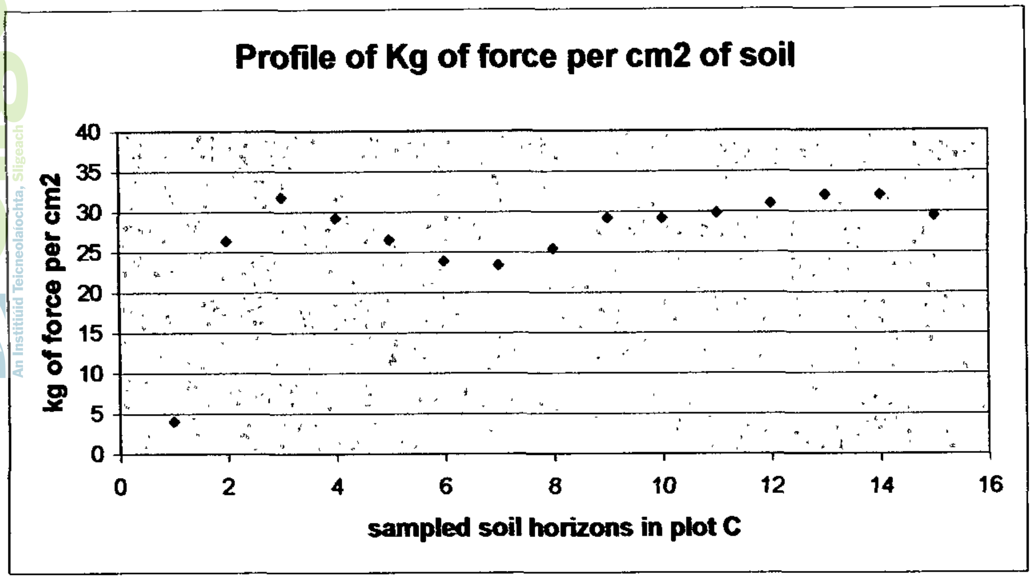


## Average Results from the 4 plots

Grassland Compaction experiment

Date 15/04/02
Site Knockbeg Road
Plot number All 4 C Plots
Treatment Tine cultivator + drill + straw removed

| Depth Level | Mean C3. A | Mean C3. B | Mean C5. A | Mean C5. B | Mean C12. A | Mean C12. B | Mean C14. A | Mean C14. B | Mean set results for plot C | Kg Force Cm2 |
|---|---|---|---|---|---|---|---|---|---|---|
| **1** | 9 | 4 | 5 | 7 | 3 | 4 | 5 | 5 | **5** | **4** |
| **2** | 42 | 30 | 38 | 39 | 30 | 30 | 31 | 33 | **34** | **26** |
| **3** | 46 | 39 | 47 | 40 | 48 | 34 | 41 | 34 | **41** | **32** |
| **4** | 43 | 37 | 38 | 36 | 39 | 37 | 40 | 32 | **38** | **29** |
| **5** | 40 | 34 | 35 | 31 | 42 | 35 | 33 | 25 | **34** | **27** |
| **6** | 36 | 32 | 27 | 30 | 45 | 29 | 29 | 19 | **31** | **24** |
| **7** | 35 | 37 | 25 | 28 | 38 | 31 | 26 | 22 | **30** | **23** |
| **8** | 41 | 40 | 29 | 29 | 38 | 34 | 28 | 24 | **33** | **25** |
| **9** | 51 | 43 | 36 | 33 | 41 | 35 | 31 | 32 | **38** | **29** |
| **10** | 44 | 40 | 38 | 33 | 42 | 39 | 33 | 33 | **38** | **29** |
| **11** | 39 | 41 | 37 | 34 | 43 | 42 | 37 | 36 | **39** | **30** |
| **12** | 37 | 41 | 39 | 39 | 46 | 45 | 37 | 37 | **40** | **31** |
| **13** | 38 | 42 | 39 | 43 | 49 | 44 | 41 | 36 | **42** | **32** |
| **14** | 39 | 43 | 35 | 39 | 53 | 41 | 50 | 32 | **42** | **32** |
| **15** | 36 | 35 | 40 | 36 | 43 | 38 | 46 | 31 | **38** | **29** |

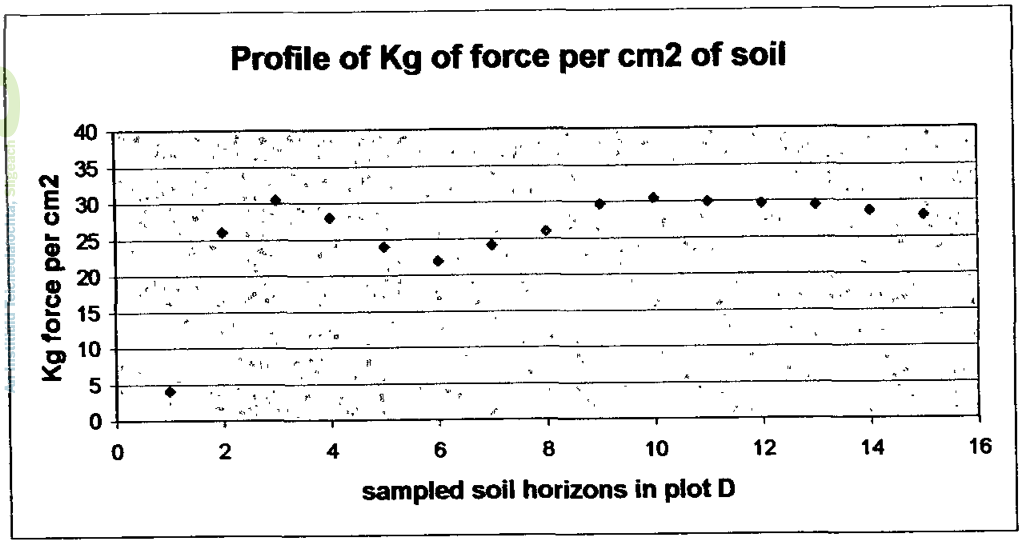

**Profile of Kg of force per cm2 of soil**

## Average Results from the 4 plots

Grassland Compaction experiment

Date 15/04/02
Site Knockbeg Road
Plot number All 4 D Plots
Treatment Tine cultivator + drill + straw incorporated

| Depth Level | Mean D1. A | Mean D1. B | Mean D7. A | Mean D7. B | Mean D10. A | Mean D10. B | Mean D16. A | Mean D16. B | Mean set results for plot D | Kg Force Cm2 |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 4 | 6 | 2 | 3 | 8 | 4 | 7 | 8 | 5 | 4 |
| 2 | 26 | 31 | 21 | 37 | 39 | 42 | 36 | 38 | 34 | 26 |
| 3 | 32 | 29 | 35 | 47 | 42 | 42 | 39 | 49 | 39 | 30 |
| 4 | 31 | 27 | 37 | 43 | 35 | 35 | 38 | 43 | 36 | 28 |
| 5 | 29 | 21 | 39 | 40 | 26 | 31 | 32 | 29 | 31 | 24 |
| 6 | 30 | 21 | 31 | 40 | 25 | 25 | 25 | 30 | 28 | 22 |
| 7 | 25 | 22 | 39 | 36 | 33 | 29 | 26 | 39 | 31 | 24 |
| 8 | 23 | 21 | 42 | 42 | 37 | 31 | 30 | 43 | 34 | 26 |
| 9 | 38 | 27 | 44 | 46 | 41 | 37 | 31 | 43 | 38 | 30 |
| 10 | 33 | 37 | 45 | 50 | 36 | 35 | 39 | 40 | 39 | 30 |
| 11 | 35 | 37 | 44 | 49 | 33 | 34 | 41 | 37 | 39 | 30 |
| 12 | 35 | 35 | 40 | 50 | 33 | 37 | 41 | 36 | 38 | 30 |
| 13 | 34 | 38 | 44 | 47 | 32 | 36 | 39 | 34 | 38 | 29 |
| 14 | 32 | 36 | 36 | 43 | 35 | 39 | 37 | 38 | 37 | 29 |
| 15 | 31 | 29 | 38 | 43 | 37 | 43 | 37 | 31 | 36 | 28 |



Profile of Kg of force per cm2 of soil

Grassland Compaction experiment

Date 15/04/02
Site Knockbeg Road
Plot number A
Treatment Plough + power harrow + drill + straw removed

Shear - Vane Measurements

Vane size 19mm

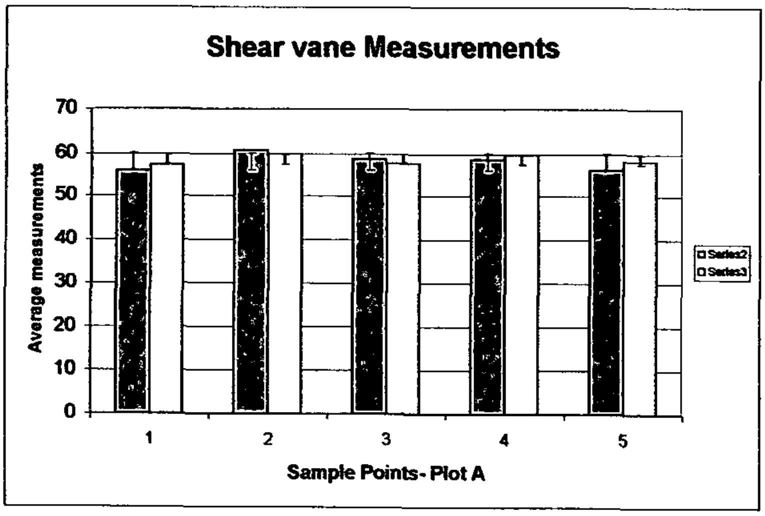
## 4 cm Readings

| | A4 | | A6 | | A11 | | A13 | | |
|---|---|---|---|---|---|---|---|---|---|
| **Points** | **A** | **B** | **A** | **B** | **A** | **B** | **A** | **B** | **Mean** |
| 1 | 56 | 52 | 50 | 56 | 52 | 64 | 68 | 48 | 56 |
| 2 | 55 | 62 | 65 | 48 | 62 | 66 | 67 | 62 | 61 |
| 3 | 56 | 56 | 58 | 48 | 56 | 60 | 74 | 62 | 59 |
| 4 | 62 | 66 | 50 | 50 | 56 | 63 | 64 | 59 | 59 |
| 5 | 62 | 55 | 54 | 48 | 62 | 62 | 48 | 58 | 56 |

## 12 cm Readings

| | A4 | | A6 | | A11 | | A13 | | |
|---|---|---|---|---|---|---|---|---|---|
| **Points** | **A** | **B** | **A** | **B** | **A** | **B** | **A** | **B** | **Mean** |
| 1 | 42 | 70 | 58 | 50 | 63 | 66 | 59 | 50 | 57 |
| 2 | 52 | 68 | 60 | 50 | 66 | 68 | 62 | 54 | 60 |
| 3 | 63 | 64 | 54 | 50 | 55 | 56 | 62 | 58 | 58 |
| 4 | 66 | 68 | 54 | 49 | 62 | 62 | 54 | 63 | 60 |
| 5 | 58 | 60 | 60 | 48 | 60 | 64 | 56 | 60 | 58 |

| | Mean Values | |
|---|---|---|
| **Points** | **4cm Readings** | **12cm Readings** |
| 1 | 56 | 57 |
| 2 | 61 | 60 |
| 3 | 59 | 58 |
| 4 | 59 | 60 |
| 5 | 56 | 58 |
| Average Kp | 58 | 58.6 |



Grassland Compaction experiment

Date 16/04/02
Site Knockbeg Road
Plot number B
Treatment Plough + power harrow + dri traw incorporated

Shear - Vane Measurements

Vane size 19mm

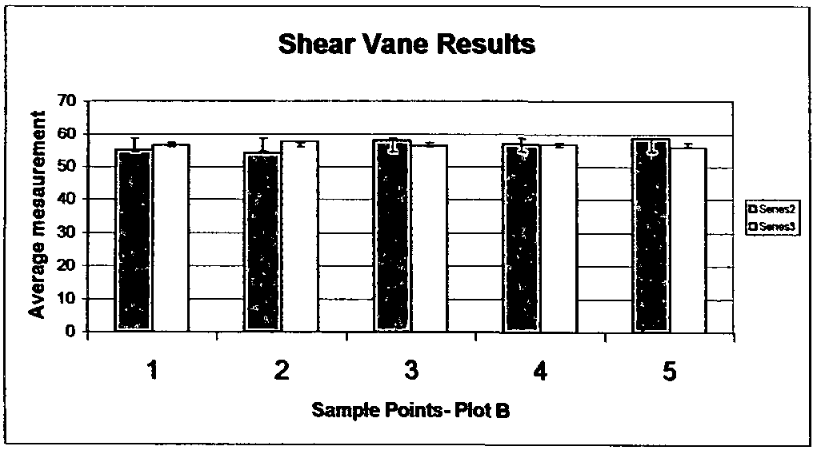
## 4 cm Readings

| | | B2 | | B8 | | B9 | | B15 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Points | | A | B | A | B | A | B | A | B | Mean |
| | 1 | 48 | 42 | 52 | 58 | 64 | 62 | 60 | 54 | 55 |
| | 2 | 48 | 50 | 58 | 57 | 58 | 44 | 62 | 55 | 54 |
| | 3 | 50 | 50 | 62 | 61 | 66 | 62 | 56 | 58 | 58 |
| | 4 | 50 | 50 | 64 | 62 | 66 | 61 | 59 | 44 | 57 |
| | 5 | 60 | 54 | 58 | 64 | 62 | 63 | 57 | 54 | 59 |

## 12 cm Readings

| | | B2 | | B8 | | B9 | | B15 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Points | | A | B | A | B | A | B | A | B | Mean |
| | 1 | 54 | 50 | 60 | 53 | 64 | 52 | 60 | 60 | 57 |
| | 2 | 54 | 54 | 61 | 60 | 59 | 60 | 62 | 52 | 58 |
| | 3 | 58 | 52 | 55 | 66 | 60 | 48 | 56 | 56 | 56 |
| | 4 | 56 | 53 | 56 | 44 | 66 | 63 | 56 | 60 | 57 |
| | 5 | 60 | 56 | 52 | 60 | 59 | 59 | 56 | 44 | 56 |

| | | Mean Values | |
|---|---|---|---|
| Points | | 4cm Readings | 12cm Readings |
| | 1 | 55 | 57 |
| | 2 | 54 | 58 |
| | 3 | 58 | 56 |
| | 4 | 57 | 57 |
| | 5 | 59 | 56 |
| Average Kpa | | 57 | 56.65 |



Grassland Compaction experiment

Date 16-04-02
Site Knockbeg Road
Plot number C
Treatment Plough Tine Cultivator + press + drill (straw removed)

Shear - Vane Measurements

Vane size 19mm

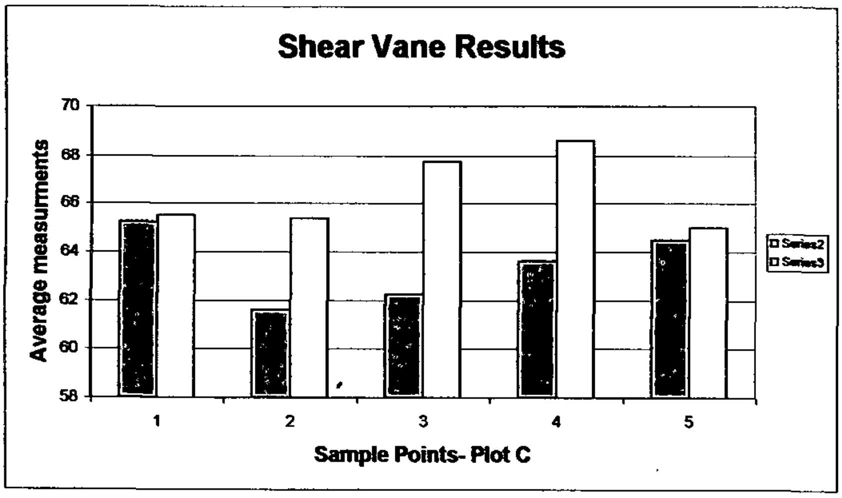
**4 cm Readings**

| | C3 | | C5 | | C12 | | C14 | | |
|---|---|---|---|---|---|---|---|---|---|
| Points | A | B | A | B | A | B | A | B | Mean |
| 1 | 70 | 66 | 69 | 60 | 68 | 62 | 61 | 66 | 65 |
| 2 | 68 | 46 | 72 | 60 | 62 | 68 | 58 | 59 | 62 |
| 3 | 68 | 54 | 60 | 66 | 68 | 68 | 64 | 50 | 62 |
| 4 | 65 | 54 | 76 | 66 | 62 | 68 | 55 | 63 | 64 |
| 5 | 67 | 65 | 60 | 68 | 68 | 65 | 64 | 59 | 65 |

**12 cm Readings**

| | C3 | | C5 | | C12 | | C14 | | |
|---|---|---|---|---|---|---|---|---|---|
| Points | A | B | A | B | A | B | A | B | Mean |
| 1 | 58 | 64 | 72 | 66 | 68 | 70 | 52 | 74 | 66 |
| 2 | 68 | 64 | 72 | 64 | 68 | 68 | 59 | 60 | 65 |
| 3 | 69 | 68 | 78 | 68 | 64 | 62 | 65 | 68 | 68 |
| 4 | 72 | 70 | 70 | 65 | 74 | 64 | 68 | 66 | 69 |
| 5 | 64 | 71 | 64 | 64 | 68 | 68 | 56 | 65 | 65 |

| | Mean Values | |
|---|---|---|
| Points | 4cm Readings | 12cm Readings |
| 1 | 65 | 66 |
| 2 | 62 | 65 |
| 3 | 62 | 68 |
| 4 | 64 | 69 |
| 5 | 65 | 65 |
| Average Kpa | 63 | 66.45 |



## Grassland Compaction Assesment

**Date** 16/04/02
**Site** Knockbeg Road
**Plot number** D1
**Treatment** Tine Cultivator + press + drill (straw incorporated)

**Shear - Vane Measurements**

**Vane size** 19mm

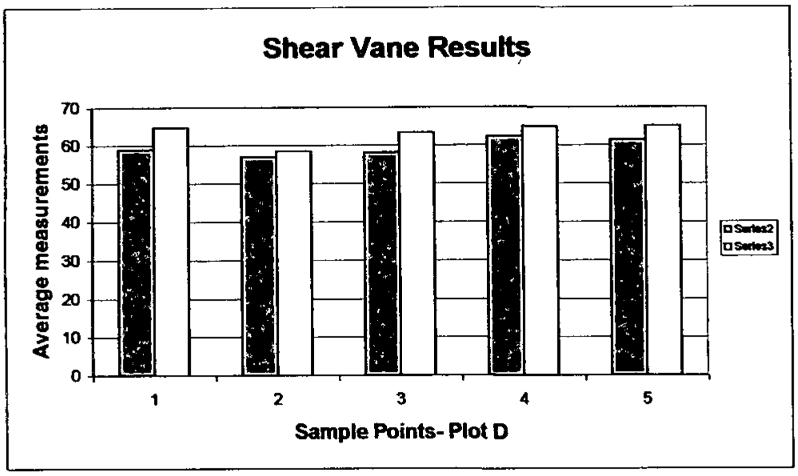
### 4 cm Readings

|  | D1 |  | D7 |  | D10 |  | D16 |  |  |
|---|---|---|---|---|---|---|---|---|---|
| **Points** | **A** | **B** | **A** | **B** | **A** | **B** | **A** | **B** | **Mean** |
| 1 | 68 | 62 | 64 | 53 | 58 | 54 | 52 | 60 | 59 |
| 2 | 72 | 60 | 54 | 50 | 50 | 56 | 58 | 55 | 57 |
| 3 | 60 | 62 | 55 | 62 | 54 | 62 | 50 | 60 | 58 |
| 4 | 62 | 68 | 70 | 65 | 56 | 66 | 54 | 56 | 62 |
| 5 | 70 | 62 | 65 | 60 | 56 | 66 | 56 | 56 | 61 |

### 12 cm Readings

|  | D1 |  | D7 |  | D10 |  | D16 |  |  |
|---|---|---|---|---|---|---|---|---|---|
| **Points** | **A** | **B** | **A** | **B** | **A** | **B** | **A** | **B** | **Mean** |
| 1 | 74 | 64 | 64 | 68 | 54 | 59 | 64 | 70 | 65 |
| 2 | 70 | 58 | 56 | 56 | 57 | 58 | 56 | 56 | 58 |
| 3 | 68 | 66 | 68 | 68 | 60 | 60 | 54 | 62 | 63 |
| 4 | 64 | 72 | 74 | 66 | 60 | 66 | 54 | 62 | 65 |
| 5 | 74 | 66 | 70 | 64 | 54 | 70 | 58 | 64 | 65 |

|  | Mean Values |  |
|---|---|---|
| **Points** | **4cm Readings** | **12cm Readings** |
| 1 | 59 | 65 |
| 2 | 57 | 58 |
| 3 | 58 | 63 |
| 4 | 62 | 65 |
| 5 | 61 | 65 |
| **Average Kpa** | 59 | 63 |



***REDUCED CULTIVATION EXPERIMENT 2003-04***

***WINTER WHEAT - KNOCKBEG***

***SOIL BULK DENSITY ( CORES )***

***SAMPLED 6 / 01 / 04***

Cylinder dimensions Diam.-5.57cm X 4.0 cm high
Volume of Cylinder = 97 468 cc
Soil Density = 2.65 g/cc

| Block | Plot | Treatment | Transect | Wet weight ( g ) | Dry weight ( g ) | Weight of Water ( g ) | Moisture content ( % ) | Wet Bulk Density ( g / cc ) | Dry Bulk Density ( g / cc ) | Total Porosity ( % ) | Air-filled Porosity ( % ) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | D | A | 151 | 117.2 | 33.8 | 28.84 | 1.55 | 1.20 | 54.62 | 19.95 |
| 1 | 1 | D | A | 146.1 | 110 7 | 35.4 | 31.98 | 1.50 | 1.14 | 57.14 | 20 82 |
| 1 | 1 | D | A | 122.6 | 98 | 24.6 | 25.10 | 1.26 | 1.01 | 62.06 | 36.82 |
| 1 | 1 | D | A | 133.5 | 100.8 | 32.7 | 32.44 | 1 37 | 1.03 | 60.97 | 27.42 |
| 1 | 1 | D | B | 138.2 | 103.1 | 35.1 | 34.04 | 1.42 | 1.06 | 60.08 | 24.07 |
| 1 | 1 | D | B | 170.5 | 135.1 | 35.4 | 26.20 | 1.75 | 1 39 | 47 69 | 11.37 |
| 1 | 1 | D | B | 155.9 | 119 6 | 36.3 | 30 35 | 1.60 | 1.23 | 53.70 | 16.45 |
| 1 | 1 | D | B | 133 | 102 | 31 | 30.39 | 1.36 | 1 05 | 60.51 | 28.70 |
| 1 | 2 | B | A | 141.9 | 113 8 | 28.1 | 24.69 | 1.46 | 1 17 | 55.94 | 27.11 |
| 1 | 2 | B | A | 138 6 | 112.3 | 26.3 | 23.42 | 1.42 | 1.15 | 56.52 | 29.54 |
| 1 | 2 | B | A | 128.1 | 104 9 | 23 2 | 22.12 | 1.31 | 1.08 | 59 39 | 35 58 |
| 1 | 2 | B | A | 152.4 | 120.8 | 31.6 | 26.16 | 1.56 | 1.24 | 53.23 | 20.81 |
| 1 | 2 | B | B | 136.3 | 110.6 | 25.7 | 23.24 | 1.40 | 1.13 | 57.18 | 30.81 |
| 1 | 2 | B | B | 142.5 | 115 4 | 27.1 | 23 48 | 1.46 | 1.18 | 55.32 | 27.52 |
| 1 | 2 | B | B | 137.4 | 108.7 | 28.7 | 26.40 | 1.41 | 1.12 | 57.92 | 28.47 |
| 1 | 2 | B | B | 140.9 | 115.1 | 25 8 | 22.42 | 1.45 | 1.18 | 55.44 | 28 97 |
| 1 | 3 | C | A | 140.7 | 109.2 | 31.5 | 28.85 | 1.44 | 1.12 | 57.72 | 25.40 |
| 1 | 3 | C | A | 142.4 | 112.5 | 29.9 | 26.58 | 1.46 | 1.15 | 56.44 | 25.77 |
| 1 | 3 | C | A | 139.4 | 110.1 | 29.3 | 26.61 | 1.43 | 1.13 | 57.37 | 27.31 |
| 1 | 3 | C | A | 140.3 | 112.4 | 27 9 | 24 82 | 1.44 | 1.15 | 56.48 | 27.86 |
| 1 | 3 | C | B | 140.1 | 111.9 | 28.2 | 25 20 | 1.44 | 1.15 | 56.68 | 27 74 |
| 1 | 3 | C | B | 135.2 | 107.3 | 27 9 | 26.00 | 1.39 | 1.10 | 58.46 | 29 83 |
| 1 | 3 | C | B | 126.3 | 100.7 | 25.6 | 25.42 | 1.30 | 1.03 | 61.01 | 34.75 |
| 1 | 3 | C | B | 130.2 | 103.7 | 26.5 | 25 55 | 1 34 | 1 06 | 59.85 | 32.66 |
| 1 | 4 | A | A | 155 3 | 127.8 | 27.5 | 21.52 | 1.59 | 1.31 | 50.52 | 22.31 |
| 1 | 4 | A | A | 126.9 | 102 | 24.9 | 24.41 | 1.30 | 1.05 | 60.51 | 34.96 |
| 1 | 4 | A | A | 144.6 | 116.1 | 28.5 | 24.55 | 1.48 | 1.19 | 55.05 | 25.81 |
| 1 | 4 | A | A | 132.4 | 107.9 | 24 5 | 22.71 | 1.36 | 1.11 | 58.23 | 33.09 |
| 1 | 4 | A | B | 146.1 | 118.9 | 27.2 | 22.88 | 1.50 | 1.22 | 53.97 | 26.06 |
| 1 | 4 | A | B | 139.9 | 113.3 | 26 6 | 23.48 | 1.44 | 1.16 | 56.13 | 28.84 |
| 1 | 4 | A | B | 141.3 | 113.4 | 27.9 | 24 60 | 1.45 | 1.16 | 56.10 | 27.47 |
| 1 | 4 | A | B | 134.1 | 107.8 | 26.3 | 24.40 | 1.38 | 1.11 | 58.26 | 31.28 |
| 2 | 5 | C | A | 160.2 | 125 | 35.2 | 28.16 | 1.64 | 1.28 | 51.60 | 15.49 |
| 2 | 5 | C | A | 154 | 119.4 | 34.6 | 28.98 | 1.58 | 1.23 | 53.77 | 18.27 |
| 2 | 5 | C | A | 158 4 | 123.1 | 35 3 | 28 68 | 1.63 | 1.26 | 52.34 | 16 12 |
| 2 | 5 | C | A | 142 9 | 113.2 | 29.7 | 26.24 | 1.47 | 1.16 | 56.17 | 25 70 |
| 2 | 5 | C | B | 151.2 | 116.9 | 34.3 | 29.34 | 1.55 | 1.20 | 54.74 | 19 55 |
| 2 | 5 | C | B | 141.4 | 112 | 29.4 | 26 25 | 1.45 | 1.15 | 56.64 | 26.47 |
| 2 | 5 | C | B | 134.4 | 105.9 | 28.5 | 26.91 | 1 38 | 1 09 | 59.00 | 29.76 |
| 2 | 5 | C | B | 148.8 | 118.6 | 30.2 | 25.46 | 1 53 | 1 22 | 54 08 | 23.10 |
| 2 | 6 | A | A | 139.7 | 112 5 | 27.2 | 24.18 | 1 43 | 1 15 | 56.44 | 28.54 |
| 2 | 6 | A | A | 136.4 | 111.4 | 25 | 22.44 | 1.40 | 1.14 | 56.87 | 31.22 |
| 2 | 6 | A | A | 154 | 124 9 | 29.1 | 23.30 | 1.58 | 1.28 | 51.64 | 21.79 |
| 2 | 6 | A | A | 135.4 | 109 7 | 25.7 | 23.43 | 1.39 | 1 13 | 57.53 | 31 16 |
| 2 | 6 | A | B | 145 | 119.2 | 25.8 | 21.64 | 1.49 | 1 22 | 53.85 | 27.38 |
| 2 | 6 | A | B | 134.7 | 110.2 | 24.5 | 22 23 | 1.38 | 1.13 | 57.33 | 32.20 |
| 2 | 6 | A | B | 148.4 | 120 8 | 27.6 | 22.85 | 1 52 | 1.24 | 53.23 | 24 91 |
| 2 | 6 | A | B | 142 5 | 116.8 | 25 7 | 22.00 | 1.46 | 1.20 | 54.78 | 28.41 |
| 2 | 7 | D | A | 145.2 | 107.1 | 38 1 | 35.57 | 1.49 | 1.10 | 58.54 | 19.45 |
| 2 | 7 | D | A | 117.5 | 92.5 | 25 | 27.03 | 1.21 | 0.95 | 64.19 | 38 54 |
| 2 | 7 | D | A | 134 9 | 105.2 | 29.7 | 28 23 | 1.38 | 1.08 | 59.27 | 28.80 |
| 2 | 7 | D | A | 131.7 | 101 | 30.7 | 30.40 | 1 35 | 1.04 | 60.90 | 29.40 |
| 2 | 7 | D | B | 162.8 | 123.5 | 39.3 | 31.82 | 1 67 | 1.27 | 52 19 | 11 86 |
| 2 | 7 | D | B | 161.8 | 126 | 35.8 | 28.41 | 1 66 | 1.29 | 51.22 | 14 49 |
| 2 | 7 | D | B | 143.3 | 112.5 | 30.8 | 27.38 | 1 47 | 1.15 | 56.44 | 24.84 |
| 2 | 7 | D | B | 139.3 | 107 6 | 31.7 | 29.46 | 1.43 | 1.10 | 58.34 | 25 82 |
| 2 | 8 | B | A | 142.6 | 115 | 27.6 | 24.00 | 1.46 | 1 18 | 55.48 | 27.16 |
| 2 | 8 | B | A | 144.3 | 116.9 | 27.4 | 23.44 | 1 48 | 1.20 | 54.74 | 26.63 |
| 2 | 8 | B | A | 142.3 | 115.7 | 26.6 | 22.99 | 1.46 | 1.19 | 55.21 | 27.91 |
| 2 | 8 | B | A | 143.3 | 115.1 | 28.2 | 24.50 | 1 47 | 1.18 | 55.44 | 26.51 |
| 2 | 8 | B | B | 130.3 | 105 2 | 25.1 | 23.86 | 1.34 | 1.08 | 59.27 | 33 52 |
| 2 | 8 | B | B | 130.8 | 106.2 | 24 6 | 23.16 | 1.34 | 1.09 | 58.88 | 33.64 |
| 2 | 8 | B | B | 156.3 | 126 | 30.3 | 24.05 | 1.60 | 1.29 | 51.22 | 20.13 |
| 2 | 8 | B | B | 146.5 | 119.4 | 27 1 | 22 70 | 1.50 | 1.23 | 53 77 | 25.97 |

|  |  |  |  |  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 3 | 9 | B | A | 138.6 | 111.7 | 26.9 | 24.08 | 1.42 | 1.15 | 56.75 | 29.16 |
| 3 | 9 | B | A | 138.8 | 111.1 | 27.7 | 24.93 | 1.42 | 1.14 | 56.99 | 28.57 |
| 3 | 9 | B | A | 150.5 | 121.5 | 29 | 23.87 | 1.54 | 1.25 | 52.96 | 23.21 |
| 3 | 9 | B | A | 160.3 | 129.3 | 31 | 23.98 | 1.64 | 1.33 | 49.94 | 18.13 |
| 3 | 9 | B | B | 134.5 | 109.1 | 25.4 | 23.28 | 1.38 | 1.12 | 57.76 | 31.70 |
| 3 | 9 | B | B | 142.5 | 113.9 | 28.6 | 25.11 | 1.46 | 1.17 | 55.90 | 26.56 |
| 3 | 9 | B | B | 159.7 | 135.2 | 24.5 | 18.12 | 1.64 | 1.39 | 47.66 | 22.52 |
| 3 | 9 | B | B | 143.4 | 115.6 | 27.8 | 24.05 | 1.47 | 1.19 | 55.24 | 26.72 |
| 3 | 10 | D | A | 152.7 | 120.7 | 32 | 26.51 | 1.57 | 1.24 | 53.27 | 20.44 |
| 3 | 10 | D | A | 155.7 | 119 | 36.7 | 30.84 | 1.60 | 1.22 | 53.93 | 16.27 |
| 3 | 10 | D | A | 132.3 | 104.8 | 27.5 | 26.24 | 1.36 | 1.08 | 59.43 | 31.21 |
| 3 | 10 | D | A | 149.1 | 114.7 | 34.4 | 29.99 | 1.53 | 1.18 | 55.59 | 20.30 |
| 3 | 10 | D | B | 152.3 | 117.5 | 34.8 | 29.62 | 1.56 | 1.21 | 54.51 | 18.80 |
| 3 | 10 | D | B | 138.3 | 110.4 | 27.9 | 25.27 | 1.42 | 1.13 | 57.26 | 28.63 |
| 3 | 10 | D | B | 141.6 | 110.7 | 30.9 | 27.91 | 1.45 | 1.14 | 57.14 | 25.44 |
| 3 | 10 | D | B | 131.1 | 102.3 | 28.8 | 28.15 | 1.35 | 1.05 | 60.39 | 30.85 |
| 3 | 11 | A | A | 142.2 | 115.6 | 26.6 | 23.01 | 1.46 | 1.19 | 55.24 | 27.95 |
| 3 | 11 | A | A | 135.1 | 108.5 | 26.6 | 24.52 | 1.39 | 1.11 | 57.99 | 30.70 |
| 3 | 11 | A | A | 130.1 | 105.7 | 24.4 | 23.08 | 1.33 | 1.08 | 59.08 | 34.04 |
| 3 | 11 | A | A | 142.8 | 116 | 26.8 | 23.10 | 1.47 | 1.19 | 55.09 | 27.59 |
| 3 | 11 | A | B | 161.7 | 128.7 | 33 | 25.64 | 1.66 | 1.32 | 50.17 | 16.32 |
| 3 | 11 | A | B | 134.5 | 108.8 | 25.7 | 23.62 | 1.38 | 1.12 | 57.88 | 31.51 |
| 3 | 11 | A | B | 148.8 | 119.5 | 29.3 | 24.52 | 1.53 | 1.23 | 53.73 | 23.67 |
| 3 | 11 | A | B | 157.4 | 127.2 | 30.2 | 23.74 | 1.61 | 1.31 | 50.75 | 19.77 |
| 3 | 12 | C | A | 134.5 | 106.9 | 27.6 | 25.82 | 1.38 | 1.10 | 58.61 | 30.30 |
| 3 | 12 | C | A | 138.6 | 109.4 | 29.2 | 26.69 | 1.42 | 1.12 | 57.64 | 27.69 |
| 3 | 12 | C | A | 146 | 116.4 | 29.6 | 25.43 | 1.50 | 1.19 | 54.93 | 24.57 |
| 3 | 12 | C | A | 146.9 | 116.5 | 30.4 | 26.09 | 1.51 | 1.20 | 54.90 | 23.71 |
| 3 | 12 | C | B | 137.9 | 108.5 | 29.4 | 27.10 | 1.41 | 1.11 | 57.99 | 27.83 |
| 3 | 12 | C | B | 168.1 | 133.7 | 34.4 | 25.73 | 1.72 | 1.37 | 48.24 | 12.94 |
| 3 | 12 | C | B | 152.7 | 120.4 | 32.3 | 26.83 | 1.57 | 1.24 | 53.39 | 20.25 |
| 3 | 12 | C | B | 135.5 | 108.1 | 27.4 | 25.35 | 1.39 | 1.11 | 58.15 | 30.04 |
| 4 | 13 | A | A | 129.4 | 103.6 | 25.8 | 24.90 | 1.33 | 1.06 | 59.89 | 33.42 |
| 4 | 13 | A | A | 147.3 | 118.5 | 28.8 | 24.30 | 1.51 | 1.22 | 54.12 | 24.57 |
| 4 | 13 | A | A | 142.7 | 115.8 | 26.9 | 23.23 | 1.46 | 1.19 | 55.17 | 27.57 |
| 4 | 13 | A | A | 162.5 | 129.4 | 33.1 | 25.58 | 1.67 | 1.33 | 49.90 | 15.94 |
| 4 | 13 | A | B | 134 | 107.7 | 26.3 | 24.42 | 1.37 | 1.10 | 58.30 | 31.32 |
| 4 | 13 | A | B | 138.2 | 111.8 | 26.4 | 23.61 | 1.42 | 1.15 | 56.72 | 29.63 |
| 4 | 13 | A | B | 142.1 | 114.2 | 27.9 | 24.43 | 1.46 | 1.17 | 55.79 | 27.16 |
| 4 | 13 | A | B | 150.8 | 121.1 | 29.7 | 24.53 | 1.55 | 1.24 | 53.11 | 22.64 |
| 4 | 14 | C | A | 157.5 | 125.6 | 31.9 | 25.40 | 1.62 | 1.29 | 51.37 | 18.64 |
| 4 | 14 | C | A | 149.2 | 120 | 29.2 | 24.33 | 1.53 | 1.23 | 53.54 | 23.58 |
| 4 | 14 | C | A | 165 | 128.6 | 36.4 | 28.30 | 1.69 | 1.32 | 50.21 | 12.87 |
| 4 | 14 | C | A | 136.4 | 106.4 | 30 | 28.20 | 1.40 | 1.09 | 58.81 | 28.03 |
| 4 | 14 | C | B | 174.4 | 135.4 | 39 | 28.80 | 1.79 | 1.39 | 47.58 | 7.57 |
| 4 | 14 | C | B | 151.6 | 120.1 | 31.5 | 26.23 | 1.56 | 1.23 | 53.50 | 21.18 |
| 4 | 14 | C | B | 149.6 | 117.5 | 32.1 | 27.32 | 1.53 | 1.21 | 54.51 | 21.57 |
| 4 | 14 | C | B | 144 | 116.5 | 27.5 | 23.61 | 1.48 | 1.20 | 54.90 | 26.68 |
| 4 | 15 | B | A | 150.4 | 122.2 | 28.2 | 23.08 | 1.54 | 1.25 | 52.69 | 23.76 |
| 4 | 15 | B | A | 137.8 | 111.8 | 26 | 23.26 | 1.41 | 1.15 | 56.72 | 30.04 |
| 4 | 15 | B | A | 176.9 | 141 | 35.9 | 25.46 | 1.81 | 1.45 | 45.41 | 8.58 |
| 4 | 15 | B | A | 147.9 | 118.4 | 29.5 | 24.92 | 1.52 | 1.21 | 54.16 | 23.89 |
| 4 | 15 | B | B | 147.8 | 119 | 28.8 | 24.20 | 1.52 | 1.22 | 53.93 | 24.38 |
| 4 | 15 | B | B | 150.3 | 121.2 | 29.1 | 24.01 | 1.54 | 1.24 | 53.08 | 23.22 |
| 4 | 15 | B | B | 164.8 | 131.9 | 32.9 | 24.94 | 1.69 | 1.35 | 48.93 | 15.18 |
| 4 | 15 | B | B | 149.2 | 119.9 | 29.3 | 24.44 | 1.53 | 1.23 | 53.58 | 23.52 |
| 4 | 16 | D | A | 145.3 | 112.2 | 33.1 | 29.50 | 1.49 | 1.15 | 56.56 | 22.60 |
| 4 | 16 | D | A | 153.6 | 116.8 | 36.8 | 31.51 | 1.58 | 1.20 | 54.78 | 17.02 |
| 4 | 16 | D | A | 146.2 | 111 | 35.2 | 31.71 | 1.50 | 1.14 | 57.03 | 20.91 |
| 4 | 16 | D | A | 135 | 102.1 | 32.9 | 32.22 | 1.39 | 1.05 | 60.47 | 26.72 |
| 4 | 16 | D | B | 134.5 | 105.2 | 29.3 | 27.85 | 1.38 | 1.08 | 59.27 | 29.21 |
| 4 | 16 | D | B | 124.7 | 96.5 | 28.2 | 29.22 | 1.28 | 0.99 | 62.64 | 33.71 |
| 4 | 16 | D | B | 128.7 | 102.2 | 26.5 | 25.93 | 1.32 | 1.05 | 60.43 | 33.24 |
| 4 | 16 | D | B | 148.4 | 109.9 | 38.5 | 35.03 | 1.52 | 1.13 | 57.45 | 17.95 |
|  | ***AVERAGES*** |  |  |  |  |  |  |  |  |  |  |
|  |  | ***A*** |  | 142.4 | 115.2 | 27.2 | 23.7 | 1.46 | 1.18 | 55.42 | 27.48 |
|  |  | ***B*** |  | 145.2 | 117.3 | 27.9 | 23.8 | 1.49 | 1.20 | 54.58 | 25.92 |
|  |  | ***C*** |  | 146.1 | 115.4 | 30.7 | 26.6 | 1.50 | 1.18 | 55.33 | 23.85 |
|  |  | ***D*** |  | 142.4 | 109.9 | 32.5 | 29.5 | 1.46 | 1.13 | 57.44 | 24.13 |

## SAMPLES INCUBATED AT 22' C

Sample set no.6 - 16/05/2002

**Moisture Content**

| Sample I.D | % Moisture Content | | |
|---|---|---|---|
| | 0-10cm | 10-20cm | 20-30cm |
| A11 | 15.92 | 16.67 | 13.59 |
| A13 | 17.81 | 15.02 | 15.86 |
| B8 | 17.19 | 17.63 | 17.23 |
| B15 | 17.03 | 17.19 | 15.36 |
| C5 | 15.77 | 17.55 | 16.20 |
| C12 | 17.14 | 16.38 | 15.59 |
| D7 | 16.68 | 18.08 | 16.45 |
| D16 | 18.56 | 16.84 | 15.93 |

**Microbial Weight 0-10cm**

| Sample I.D | Wet Weight | Dry Weight |
|---|---|---|
| A11 | 10.0594 | 8.408 |
| A13 | 10.0611 | 8.21 |
| B8 | 10.0011 | 8.28 |
| B15 | 10.0078 | 8.3 |
| C5 | 10.201 | 8.392 |
| C12 | 10.1003 | 8.269 |
| D7 | 10.0056 | 8.332 |
| D16 | 10.0101 | 8.143 |

**Microbial Weight 10-20cm**

| Sample I.D | Wet Weight | Dry Weight |
|---|---|---|
| A11 | 10.0122 | 8.3522 |
| A13 | 10.0089 | 8.5059 |
| B8 | 10.0055 | 8.2415 |
| B15 | 10.0106 | 8.2906 |
| C5 | 10.014 | 8.257 |
| C12 | 10.0013 | 8.3633 |
| D7 | 10.0001 | 8.1921 |
| D16 | 10.0094 | 8.3244 |

**Microbial Weight 20-30cm**

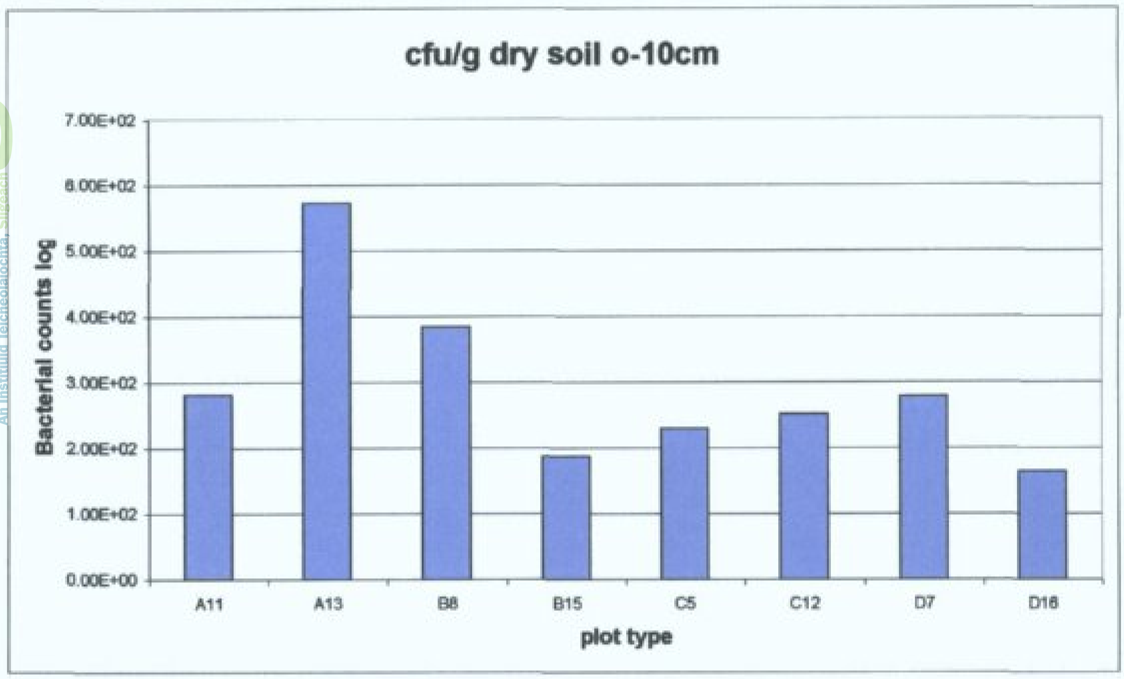
| Sample I.D | Wet Weight | Dry Weight |
|---|---|---|
| A11 | 10.0084 | 8.6484 |
| A13 | 10.0009 | 8.4149 |
| B8 | 10.0061 | 8.2821 |
| B15 | 10.0003 | 8.4643 |
| C5 | 10.0021 | 8.3821 |
| C12 | 10.0014 | 8.4424 |
| D7 | 10.0023 | 8.3573 |
| D16 | 10.0004 | 8.4074 |

Sample set no.6 - 16/05/2002

**Microbial Counts** **At 22.c** **0-10cm** **Sampling depth**

| Sample I.D | Dilution | cfu | cfu | Ave cfu | cfu/original ml(per 1g wet soil) | cfu/g dry soil | Std | std/ml (org) | std/g dry soil |
|---|---|---|---|---|---|---|---|---|---|
| A11 | 0.0001 | 256 | 217 | 236.5 | 2.36E+02 | 2.81E+02 | 2.76E+01 | 2.76E+05 | 3.28E+05 |
| A13 | 0.000001 | 469 | 471 | 470 | 4.70E+02 | 5.72E+02 | 1.41E+00 | 1.41E+06 | 1.72E+06 |
| B8 | 0.000001 | 324 | 312 | 318 | 3.18E+02 | 3.84E+02 | 8.49E+00 | 8.49E+06 | 1.02E+07 |
| B15 | 0.00001 | 170 | 141 | 155.5 | 1.55E+02 | 1.87E+02 | 2.05E+01 | 2.05E+06 | 2.47E+06 |
| C5 | 0.000001 | 186 | 199 | 192.5 | 1.92E+02 | 2.29E+02 | 9.19E+00 | 9.19E+06 | 1.10E+07 |
| C12 | 0.000001 | 202 | 214 | 208 | 2.08E+02 | 2.52E+02 | 8.49E+00 | 8.49E+06 | 1.03E+07 |
| D7 | 0.0001 | 224 | 240 | 232 | 2.32E+02 | 2.78E+02 | 1.13E+01 | 1.13E+05 | 1.36E+05 |
| D16 | 0.0001 | 139 | 129 | 134 | 1.34E+02 | 1.65E+02 | 7.07E+00 | 7.07E+04 | 8.68E+04 |

| Sample I.D | cfu/g dry soil | std | % RSDev |
|---|---|---|---|
| A11 | 2.81E+02 | 2.76E+01 | 10 |
| A13 | 5.72E+02 | 1.41E+00 | 0 |
| B8 | 3.84E+02 | 8.49E+00 | 2 |
| B15 | 1.87E+02 | 2.05E+01 | 11 |
| C5 | 2.29E+02 | 9.19E+00 | 4 |
| C12 | 2.52E+02 | 8.49E+00 | 3 |
| D7 | 2.78E+02 | 1.13E+01 | 4 |
| D16 | 1.65E+02 | 7.07E+00 | 4 |

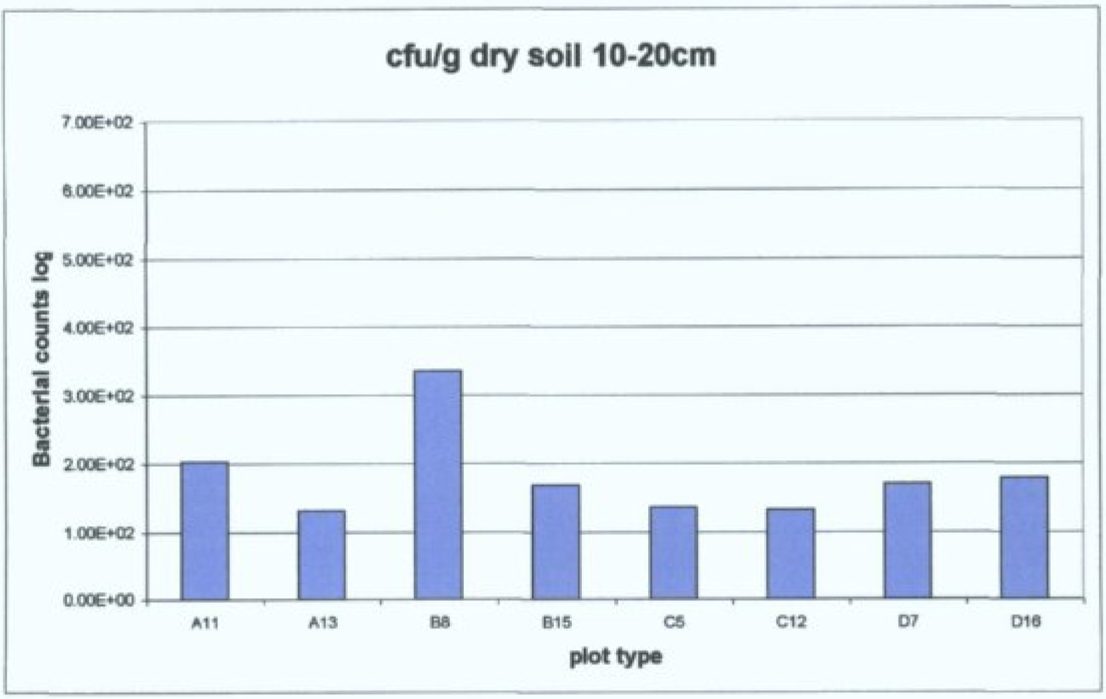


Sample set no.6 - 16/05/2002

**Microbial Counts** At 22.c 10-20cm Sampling depth

| Sample I.D | Dilution | cfu | cfu | Ave cfu | cfu/original ml(per 1g wet soil) | cfu/g dry soil | Std | std/ml (org) | std/g dry soil |
|---|---|---|---|---|---|---|---|---|---|
| A11 | 0.0001 | 186 | 154 | 170 | 1.70E+02 | 2.04E+02 | 22.63 | 2.26E+05 | 2.71E+05 |
| A13 | 0.000001 | 109 | 114 | 111.5 | 1.11E+02 | 1.31E+02 | 3.54 | 3.54E+06 | 4.16E+06 |
| | | | | | | | | | |
| B8 | 0.000001 | 284 | 269 | 276.5 | 2.76E+02 | 3.35E+02 | 10.61 | 1.06E+07 | 1.29E+07 |
| B15 | 0.0000001 | 145 | 134 | 139.5 | 1.39E+02 | 1.68E+02 | 7.78 | 7.78E+07 | 9.36E+07 |
| | | | | | | | | | |
| C5 | 0.00001 | 115 | 110 | 112.5 | 1.12E+02 | 1.36E+02 | 3.54 | 3.54E+05 | 4.28E+05 |
| C12 | 0.00001 | 104 | 117 | 110.5 | 1.10E+02 | 1.32E+02 | 9.19 | 9.19E+05 | 1.10E+06 |
| | | | | | | | | | |
| D7 | 0.0001 | 113 | 165 | 139 | 1.39E+02 | 1.70E+02 | 36.77 | 3.68E+05 | 4.49E+05 |
| D16 | 0.0001 | 154 | 143 | 148.5 | 1.48E+02 | 1.78E+02 | 7.78 | 7.78E+04 | 9.34E+04 |

| Sample I.D | cfu/g dry soil | std | % RSDev |
|---|---|---|---|
| A11 | 2.04E+02 | 22.63 | 11 |
| A13 | 1.31E+02 | 3.54 | 3 |
| B8 | 3.35E+02 | 10.61 | 3 |
| B15 | 1.68E+02 | 7.78 | 5 |
| C5 | 1.36E+02 | 3.54 | 3 |
| C12 | 1.32E+02 | 9.19 | 7 |
| D7 | 1.70E+02 | 36.77 | 22 |
| D16 | 1.78E+02 | 7.78 | 4 |

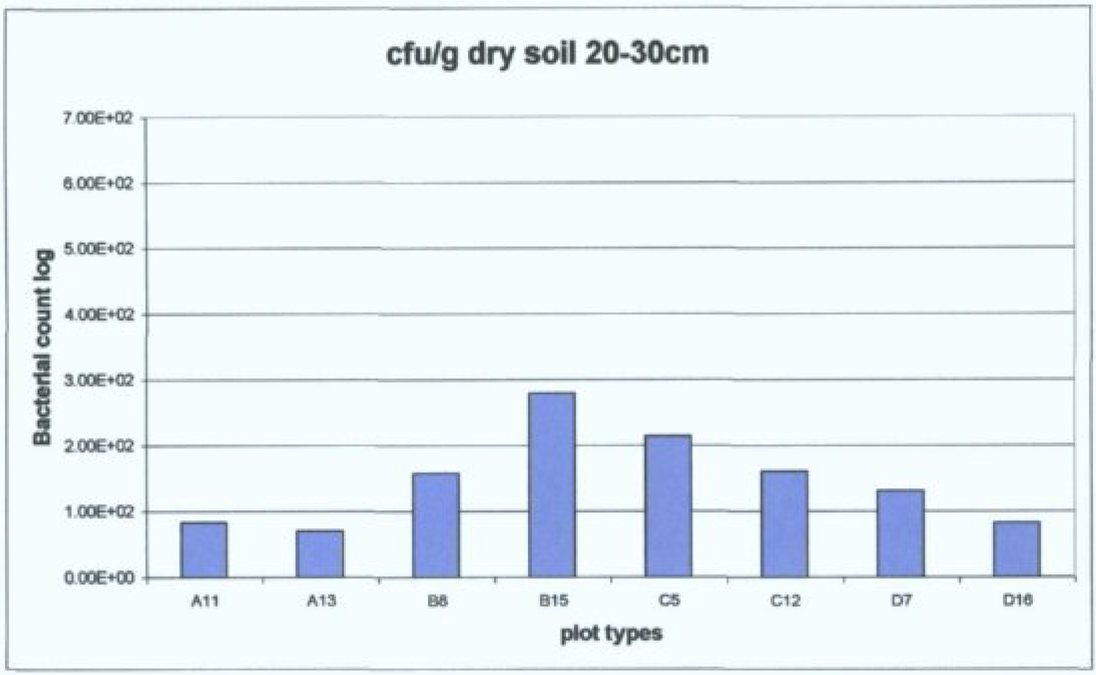


Sample set no.6 - 16/05/2002

**Microbial Counts** At 22.c 20-30cm Sampling depth

| Sample I.D | Dilution | cfu | cfu | Ave cfu | cfu/original ml(per 1g wet soil) | cfu/g dry soil | Std | std/ml (org) | std/g dry soil |
|---|---|---|---|---|---|---|---|---|---|
| A11 | 0.00000001 | 79 | 64 | 71.5 | 7.15E+01 | 8.27E+01 | 10.61 | 1.06E+09 | 1.23E+09 |
| A13 | 0.00000001 | 61 | 58 | 59.5 | 5.95E+01 | 7.07E+01 | 2.12 | 2.12E+08 | 2.52E+08 |
| | | | | | | | | | |
| B8 | 0.0001 | 128 | 132 | 130 | 1.30E+02 | 1.57E+02 | 2.83 | 2.83E+04 | 3.42E+04 |
| B15 | 0.00001 | 232 | 240 | 236 | 2.36E+02 | 2.79E+02 | 5.66 | 5.66E+05 | 6.68E+05 |
| | | | | | | | | | |
| C5 | 0.0001 | 188 | 170 | 179 | 1.79E+02 | 2.14E+02 | 12.73 | 1.27E+05 | 1.52E+05 |
| C12 | 0.0001 | 131 | 139 | 135 | 1.35E+02 | 1.60E+02 | 5.66 | 5.66E+04 | 6.70E+04 |
| | | | | | | | | | |
| D7 | 0.0001 | 106 | 112 | 109 | 1.09E+02 | 1.30E+02 | 4.24 | 4.24E+04 | 5.08E+04 |
| D16 | 0.0001 | 76 | 63 | 69.5 | 6.95E+01 | 8.27E+01 | 9.19 | 9.19E+04 | 1.09E+05 |

| Sample I.D | cfu/g dry soil | std | % RSDev |
|---|---|---|---|
| A11 | 8.27E+01 | 1.06E+01 | 13 |
| A13 | 7.07E+01 | 2.12E+00 | 3 |
| B8 | 1.57E+02 | 2.83E+00 | 2 |
| B15 | 2.79E+02 | 5.66E+00 | 2 |
| C5 | 2.14E+02 | 1.27E+01 | 6 |
| C12 | 1.60E+02 | 5.66E+00 | 4 |
| D7 | 1.30E+02 | 4.24E+00 | 3 |
| D16 | 8.27E+01 | 9.19E+00 | 11 |



Sample set no.6 - 16/05/2002

**Samples incubated at 32'c**

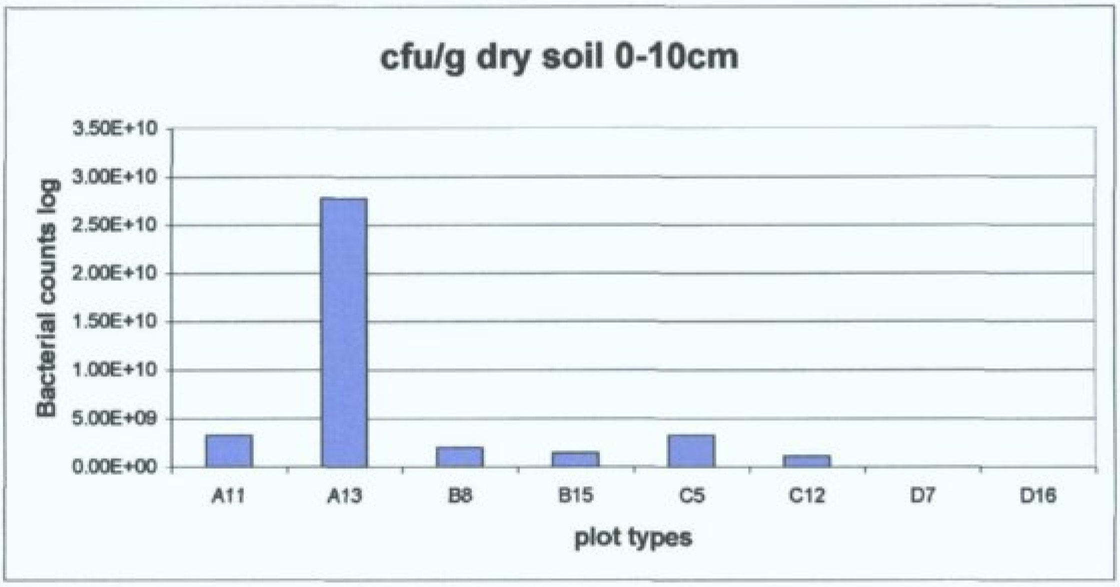
Microbial counts @ 32'c 0-10cm sampling depth

**Microbial Weight** **0-10cm**

| Sample I.D | Wet Weight | Dry Weight |
|---|---|---|
| A11 | 10.0594 | 8.408 |
| A13 | 10.0611 | 8.21 |
| | | |
| B8 | 10.0011 | 8.26 |
| B15 | 10.0078 | 8.3 |
| | | |
| C5 | 10.201 | 8.392 |
| C12 | 10.1003 | 8.269 |
| | | |
| D7 | 10.0056 | 8.332 |
| D16 | 10.0101 | 8.143 |

| **Sample I.D** | **Dilution** | **cfu** | **cfu/original ml(per1g wet soil)** | **cfu/g dry soil** |
|---|---|---|---|---|
| A11 | 0.0000001 | 272 | 2.72E+09 | 3.24E+09 |
| A13 | 0.00000001 | 228 | 2.28E+10 | 2.78E+10 |
| | | | | |
| B8 | 0.0000001 | 164 | 1.64E+09 | 1.98E+09 |
| B15 | 0.0000001 | 120 | 1.20E+09 | 1.45E+09 |
| | | | | |
| C5 | 0.0000001 | 272 | 2.72E+09 | 3.24E+09 |
| C12 | 0.0000001 | 96 | 9.60E+08 | 1.16E+09 |
| | | | | |
| D7 | 0.0001 | 203 | 2.03E+06 | 2.44E+06 |
| D16 | 0.0001 | 54 | 5.40E+05 | 6.63E+05 |

| Sample I.D | cfu/g dry soil |
|---|---|
| A11 | 3.24E+09 |
| A13 | 2.78E+10 |
| B8 | 1.98E+09 |
| B15 | 1.45E+09 |
| C5 | 3.24E+09 |
| C12 | 1.16E+09 |
| D7 | 2.44E+06 |
| D16 | 6.63E+05 |



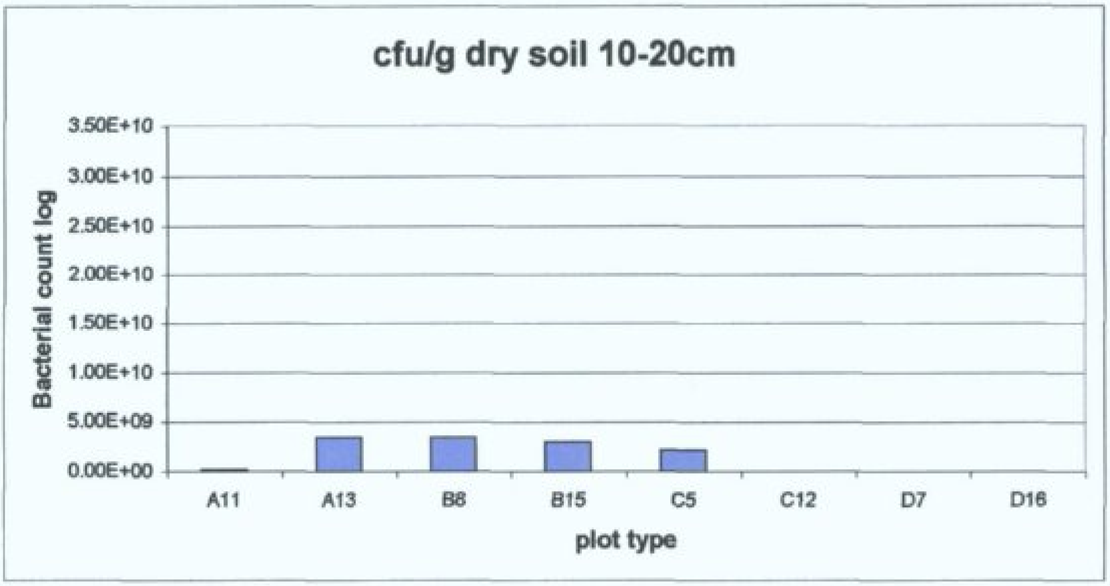
Sample set no.6 - 16/05/2002

**Microbial Weight** **10-20cm**

| Sample I.D | Wet Weight | Dry Weight |
|---|---|---|
| A11 | 10.0122 | 8.3522 |
| A13 | 10.0089 | 8.5059 |
| B8 | 10.0055 | 8.2415 |
| B15 | 10.0106 | 8.2906 |
| C5 | 10.014 | 8.257 |
| C12 | 10.0013 | 8.3633 |
| D7 | 10.0001 | 8.1921 |
| D16 | 10.0094 | 8.3244 |

| Sample I.D | Dilution | cfu | cfu/original ml(per1g wet soil) | cfu/g dry soil |
|---|---|---|---|---|
| A11 | 0.000001 | 142 | 1.42E+08 | 1.70E+08 |
| A13 | 0.0000001 | 292 | 2.92E+09 | 3.43E+09 |
| B8 | 0.0000001 | 284 | 2.84E+09 | 3.45E+09 |
| B15 | 0.0000001 | 249 | 2.49E+09 | 3.00E+09 |
| C5 | 0.0000001 | 179 | 1.79E+09 | 2.17E+09 |
| C12 | 0.0001 | 238 | 2.38E+06 | 2.85E+06 |
| D7 | 0.0001 | 81 | 8.10E+05 | 9.89E+05 |
| D16 | 0.0001 | 126 | 1.26E+06 | 1.51E+06 |

| Sample I.D | cfu/g dry soil |
|---|---|
| A11 | 1.70E+08 |
| A13 | 3.43E+09 |
| B8 | 3.45E+09 |
| B15 | 3.00E+09 |
| C5 | 2.17E+09 |
| C12 | 2.85E+06 |
| D7 | 9.89E+05 |
| D16 | 1.51E+06 |



Sample set no.6 - 16/05/2002

**Microbial Weight** **20-30cm**

| Sample I.D | Wet Weight | Dry Weight |
|---|---|---|
| A11 | 10.0084 | 8.6484 |
| A13 | 10.0009 | 8.4149 |
| B8 | 10.0061 | 8.2821 |
| B15 | 10.0003 | 8.4643 |
| C5 | 10.0021 | 8.3821 |
| C12 | 10.0014 | 8.4424 |
| D7 | 10.0023 | 8.3573 |
| D16 | 10.0004 | 8.4074 |

| Sample I.D | Dilution | cfu | cfu/original ml(per1g wet soil) | cfu/g dry soil |
|---|---|---|---|---|
| A11 | 0.000001 | 271 | 2.71E+08 | 3.13E+08 |
| A13 | 0.0000001 | 187 | 1.87E+09 | 2.22E+09 |
| B8 | 0.0000001 | 200 | 2.00E+09 | 2.41E+09 |
| B15 | 0.0000001 | 244 | 2.44E+09 | 2.88E+09 |
| C5 | 0.000001 | 107 | 1.07E+08 | 1.28E+08 |
| C12 | 0.00001 | 180 | 1.80E+07 | 2.13E+07 |
| D7 | 0.0001 | 68 | 6.80E+05 | 8.14E+05 |
| D16 | 0.0001 | 96 | 9.60E+05 | 1.14E+06 |

| Sample I.D | cfu/g dry soil |
|---|---|
| A11 | 3.13E+08 |
| A13 | 2.22E+09 |
| B8 | 2.41E+09 |
| B15 | 2.88E+09 |
| C5 | 1.28E+08 |
| C12 | 2.13E+07 |
| D7 | 8.14E+05 |
| D16 | 1.14E+06 |